Estimating and statistically analyzing the global solar radiation potential over big cities in Turkey

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Abstract

This study develops empirical models in order to estimate the monthly average daily global solar radiation on a horizontal surface (H). The seven big cities considered in the model have 33.4% of Turkey's population and are as follows: Izmir in the Aegean Sea, Samsun in the Black Sea, Ankara in the Central Anatolia, Van in the East Anatolia, Istanbul in the Marmara, Antalya in the Mediterranen Sea, and Urfa in the Southeast Anatolia Region of Turkey. The developed models were analyzed using the seven statistical analyzing methods such as the mean percentage error (MPE), mean absulate percentage error (MAPE), sum of squares of relative error (SSRE), relative standard error (RSE), mean bias error (MBE), root mean square error (RMSE) and correlation coefficient (R). It may be concluded that the present models estimate the values of H, reasonably well for the cities studied and possibly elsewhere with similar climatic conditions.

Keywords: Global Solar Radiation; Solar Energy System; Empirical Model; Statistical Analysis Methods; Turkey.

NOMENCLATURE

a,b,c,d	coefficients in empirical relationships (-)
H	monthly average daily global solar radiation (MJ/m^{2}day)
H_o	monthly average daily extraterrestrial solar radiation (MJ/m^{2}day)
MBE	mean bias error (MJ/m^2)
MPE	mean percentage error (%)
MAPE	mean absolute percentage error (%)

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R	correlation coefficient (%)
$RMSE$	root mean square error (MJ/m^2)
RSE	relative standard error (per cent)
S	day length (h)
S_o	bright sunshine duration (h)
$SSRE$	sum of squares of relative errors (per cent)

1. INTRODUCTION

Turkey's geographic location has several advantages for extensive use of most of the renewable energy sources, as shown in Fig. 1. It is on the humid and warm climatic belt, which includes most of Europe, the near east and western Asia. A typical Mediterranean climate is predominant at most of its coastal areas, whereas the climate at the interior part between the mountains that are a part of the Alpine Himalayan mountain belt is dry with typical steppe vegetation. This is mainly because the country is surrounded by seas at three sides: the Black sea at the north, the Marmara sea and Aegean sea to the west and the Mediterranean sea to the south. Although solar energy is the most important renewable energy source, it has not yet become widely commercial, even in nations with high solar potential such as Turkey. In the early 1960s, solar energy was realized as an alternative energy in Turkey, while the mid-1970s, solar thermal utilization technologies began gaining high attention of universities, the government and the industry and have been developed at an increasing speed. Residential and industrial consumption of solar energy in Turkey started in 1986 and 1988, respectively. Solar energy use accounted for 129 kilo tons of oil equivalent (ktoe) in 2000 and is projected to be 431 ktoe and 828 ktoe in 2010 and 2020, respectively. There are limited applications, and most of them are inefficient, both in terms of energy use and economical benefits. The economical feasibility of a solar energy system is mainly determined by its initial cost and long term efficiency. The cost of the conventional energy replaced by solar means is, of course, another important parameter. Therefore, in the use of solar energy systems, careful consideration is vital to determine the system capacity for optimum useful energy collection at the installation site. Clean, domestic and renewable energy is commonly accepted as the key for future life, not only for Turkey but also for the world. All nations, regardless of their degree of development, are trying to develop and apply technologies that will enable them to use renewable energy sources in the most efficient ways. The mainly renewable energy resource is the solar energy utilized in solar water heaters, crop driers, stoves, ovens, wood drying and photovoltaic. Because Turkey lies in a sunny belt in the northern hemisphere between latitudes 36-42^o N and longitudes 26-45^o E, it receives aboundant solar energy potential. The yearly average total solar radiation varies from a low of 1,120 kWh/m^2 per year in the Black Sea Region with 1,971 hours of annual sunshine duration to a high of 1,460 kWh/m^2 per year in the Southeast Anatolia Region with 2,993 hours of annual sunshine duration. The annual average total insolation duration is 2,640 hours (7.2 hours/day) and average annual solar radiation is 1,311 kWh/m^2-year (3.6 kWh/m^2-day) in Turkey. Main solar energy utilization in Turkey is the flat plate collectors in the domestic hot water systems. These systems are mostly used in the

Aegean and Mediterranean regions. In recent years, the public interest in different solar enegy applications are in the areas such as solar water heating, solar drying, building cooling and heating in Turkey (Ediger and Kentel, 1999; EIE; Kaygusuz, 1999; Kaygusuz and Sari, 2003; Sozen et al.,2005; SSI; Tiris et al.,1996; Ulgen and Hepbasli, 2002.a).

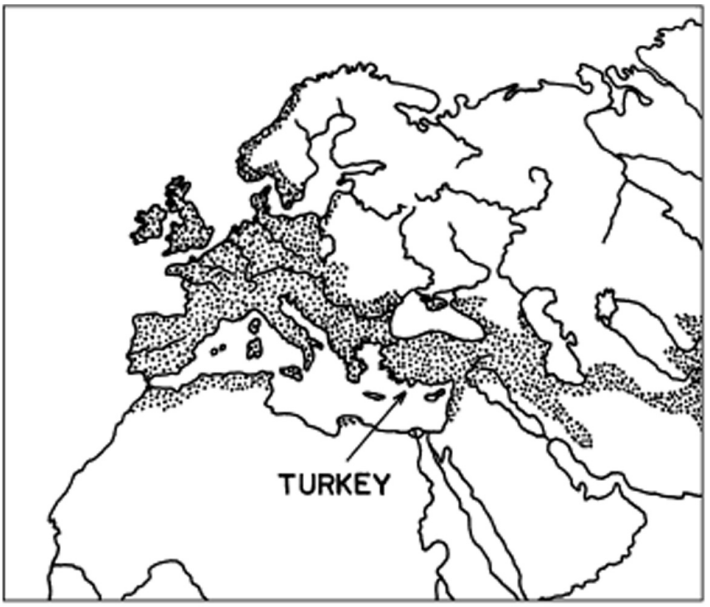


Figure 1. Geographic location of Turkey. The stippled area depicts the humid and warm climatic belt extending between Europe and western Asia [Sources:Ediger & Kentel, 1999].

Knowledge of the solar radiation enables us to derive information about the performance of solar energy systems (Chakradhar and Veziroglu 2004.a; Chakradhar and Veziroglu 2004.b). In other words, a reasonably accurate knowledge of solar energy potential is required for solar engineers, architects, agriculturists, hydrologists and meteorologists dealing with solar energy. It is common practice to estimate its value from other measurement parameters. For this reason, various parameters have been tested in the past several empirical correlations in order to estimate the solar radiation around the world. The studies conducted on the evaluation of solar radiation measurements in Turkey have been given in more detail elsewhere. The cities having the highest populations and the highest levels of economic development were selected in the each geographical region of Turkey in this study. Empirical models for estimating the monthly average daily global solar radiation on a horizontal surface (H) were developed and the measured data with the calculated values from the empirical models for each provinces were compared using statistical analysis methods. The big cities studied are illustrated in Fig. 2, while information of geographical parameters, population and measurement period are given in Table 1.

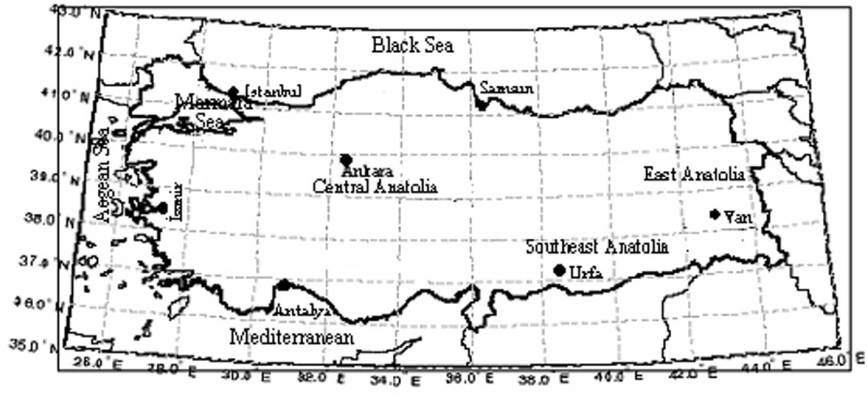


Figure 2. The seven big cities in geographical regions of Turkey.

Table 1. The information of population, geographical paramaters and measurement periods of the seven big cities in regions of Turkey.

City	Region	Total Population*	Latitude (N)	Longitude (°E)	Elevation (m)	Measurement Period
Izmir	Aegean Sea	3,387,908	38.40	27.09	25	1990-1996
Samsun	Black Sea Region	1,203,681	41.28	36.20	44	1990-1996
Ankara	Central Anatolia	4,007,860	39.95	32.52	885	1990-1996
Van	East Anatolia	877,524	38.47	43.20	1725	1990-1996
Istanbul	Marmara	10,033,478	41.10	28.58	114	1990-1996
Antalya	Mediterranean	1,726,205	36.25	30.42	42	1990-1996
Urfa	Southeast Anatolia	1,436,956	37.13	38.46	547	1990-1996

*According to the population census of Turkey made on 22 October 2000 [Sources:SSI]

2. SOLAR RADIATION MODELS DEVELOPED

The data of the monthly average daily global solar radiation and sunshine duration measured by Turkish State Meteorological Service (DMI) in the period from January 1990 to December 1996 were used. The maximum possible sunshine duration-day length and the extraterrestrial solar radiation for these cities were calculated from the mathematical relations given in the literature (Amoto et al.,1988; Aras et al., 2006; Chen et al., 1994; Helwa et al., 2002; Michalsky,1992; Ogelman et al., 1984; Ogulata and Ogulata, 2002; Sahin et al., 2001; Samuel 1991; Saylan et al., 2002; Ulgen and Hepbasli, 2002.b). The measured data of the monthly average daily global solar

radiation and the calculated values of the monthly average daily extraterrestrial solar radiation are given in Table 2. The measured data of the monthly average daily sunshine duration and the calculated values of the maximum possible monthly average daily sunshine duration-day length are also presented in Table 3.

Various empirical models have been developed to estimate the global solar radiation. The most commonly used one is the modified Angstrom linear regression equation given by [Ulgen and Hepbasli, 2002.a]

$$H = H_o(a + b\frac{S}{S_o}) \tag{1}$$

where H is the monthly average daily global solar radiation (MJ/m^2), H_o is the monthly average daily extraterrestrial radiation (MJ/m^2), S is the monthly average daily measured sunshine duration (h) and S_o is the monthly average daily maximum possible sunshine duration (h). This formula has been used in practical applications for many years to estimate the daily, monthly and annual global solar radiation amount. In the course of time, the nonlinear polynomial relation models derived from Angstrom linear regression equation were suggested to increase the accuracy of models at extreme points. The present linear, quadratic and cubic polynomial models relating $\frac{H}{H_o}$ to $\frac{S}{S_o}$ were developed as fitted to the experimental data. These models for the seven big cities in the regions of Turkey are given as follows:

Linear model : $H = H_o(a + b\frac{S}{S_o})$

Quadratic model
$$H = H_o(a + b\frac{S}{S_o} + c\left(\frac{S}{S_o}\right)^2) \tag{2}$$

and cubic model
$$H = H_o(a + b\frac{S}{S_o} + c\left(\frac{S}{S_o}\right)^2 + d\left(\frac{S}{S_o}\right)^3) \tag{3}$$

where a, b, c, and d are calculated model parameters given in Table 4 for seven big cities.

Table 2. The monthly average daily measured global solar radiation and calculated extraterrestrial solar radiation values (MJ/m^2day).

Months	Izmir		Samsun		Ankara		Van		Istanbul		Antalya		Urfa	
	Cities													
	H	H_o	H	H_o	H	H_o	H	H_o	H	H_o	H	H_o	H	H_o
January	8.3	16.2	5.8	14.4	6.1	15.5	8.7	16.2	5.5	14.5	10.1	17.5	10.3	17.0
February	10.8	21.5	7.9	19.8	9.1	20.8	11.3	21.4	7.4	19.9	13.1	22.7	13.4	22.2
March	15.7	28.2	10.9	26.9	13.4	27.6	15.3	28.1	11.9	26.9	16.6	29.1	18.4	28.7
April	19.2	35.0	14.8	34.3	17.5	34.7	19.8	35.0	16.3	34.3	22.3	35.6	23.3	35.4
May	23.0	39.8	17.9	39.6	22.1	39.7	23.3	39.8	20.4	39.6	25.8	39.9	27.1	39.9
June	26.3	41.7	21.8	41.7	25.3	41.7	26.0	41.7	23.9	41.7	28.6	41.6	29.6	41.6
July	26.1	40.7	22.3	40.6	25.6	40.6	26.1	40.7	23.8	40.6	28.1	40.7	29.0	40.7
August	24.0	36.8	20.8	36.3	23.6	36.6	23.8	36.8	21.7	36.3	25.9	37.1	26.5	37.0
September	19.2	30.6	15.3	29.5	18.9	30.1	19.5	30.6	16.9	29.6	21.5	31.4	21.9	31.1
October	13.8	23.4	10.5	21.8	12.7	22.7	14.0	23.3	10.5	21.9	15.6	24.5	16.4	24.0
November	9.5	17.4	6.9	15.7	7.5	16.7	9.7	17.4	6.4	15.8	9.5	18.7	11.7	18.2
December	8.2	14.8	5.8	13.0	5.1	14.0	7.6	14.7	5.1	13.1	8.8	16.1	9.6	15.5

Table 3. The monthly average daily measured sunshine duration and maximum possible sunshine duration-day length values (h).

	Izmir		Samsun		Ankara		Van		Istanbul		Antalya		Urfa	
Months	*Cities*													
	S	S_o	S	S_o	S	S_o	S	S_o	S	S_o	S	S_o	S	S_o
January	4.4	9.6	3.1	9.4	2.6	9.5	5.1	9.6	2.6	9.4	5.7	9.8	4.2	9.8
February	5.1	10.6	3.5	10.4	4.0	10.5	5.6	10.6	2.9	10.5	6.4	10.7	4.8	10.7
March	6.9	11.7	3.9	11.7	5.4	11.7	6.5	11.7	4.6	11.7	7.2	11.8	6.4	11.8
April	7.4	13.0	5.0	13.1	6.4	13.1	7.8	13.0	5.9	13.1	8.4	12.9	7.8	13.0
May	9.0	14.1	6.0	14.3	8.5	14.2	9.2	14.1	7.6	14.3	9.8	13.9	9.5	14.0
June	11.8	14.6	8.2	14.9	10.4	14.8	11.6	14.6	9.7	14.9	11.9	14.4	11.9	14.5
July	12.2	14.4	8.7	14.7	11.0	14.5	12.4	14.4	10.1	14.6	11.8	14.2	12.4	14.3
August	11.5	13.5	8.8	13.6	10.7	13.5	11.9	13.5	9.6	13.6	11.6	13.3	11.4	13.4
September	9.8	12.2	6.7	12.3	9.3	12.2	10.5	12.2	8.1	12.3	10.0	12.2	9.7	12.2
October	7.4	11.0	5.2	10.9	6.8	10.9	8.1	11.0	5.0	10.9	7.9	11.1	7.8	11.0
November	5.3	9.9	3.9	9.7	4.0	9.8	6.0	9.9	3.1	9.7	5.3	10.1	5.6	10.0
December	4.2	9.4	3.0	9.1	2.4	9.3	4.6	9.4	2.2	9.1	4.9	9.6	4.1	9.5

Table 4. Calculated model parameters.

City	*Altitude (°N)*	*Longitude (°E)*	*Region*	Equation *Type*	Coefficients in empirical relationships			
					a	b	c	d
Izmir	38.40	27.09	Aegean Sea	Linear	0.3767	0.3147		
				Quadratic	0.4738	0.0027	0.2377	
				Cubic	1.1875	-3.5145	5.8602	-2.9152
Samsun	41.28	36.20	Black Sea Region	Linear	0.2396	0.5138		
				Quadratic	0.31	0.1975	0.3356	
				Cubic	0.6011	-1.7276	4.449	-2.8479
Ankara	39.95	32.52	Central Anatolia	Linear	0.2465	0.5073		
				Quadratic	0.2197	0.6219	-0.1078	
				Cubic	0.2117	0.6757	-0.2192	0.0716
Van	38.47	43.20	East Anatolia	Linear	0.3643	0.323		
				Quadratic	0.2519	0.6607	-0.2434	
				Cubic	-0.0308	1.9501	-2.1644	0.9347
Istanbul	41.10	28.58	Marmara	Linear	0.2506	0.4909		
				Quadratic	0.2514	0.4872	0.0039	
				Cubic	0.4257	-0.7881	2.894	-2.0465
Antalya	36.25	30.42	Mediterranean Sea	Linear	0.2826	0.4928		
				Quadratic	-0.0181	1.3876	-0.6456	
				Cubic	0.8285	-2.4612	5.0894	-2.8009
Urfa	37.13	38.46	Southeast Anatolia	Linear	0.501	0.2541		
				Quadratic	0.4394	0.4571	-0.1572	
				Cubic	0.6579	-0.36331	1.5951	-0.9096

3. RESULTS AND DISCUSSION

In this study, the monthly average measured daily global solar radiation values over the seven big cities of Turkey (Izmir in the Aegean Sea, Samsun in the Black Sea, Ankara in the Central Anatolia, Van in the East Anatolia, Istanbul in the Marmara, Antalya in the Mediterranen and Urfa in the Southeast Anatolia Regions), covering 33.4% of Turkey's population were analyzed to develop the new empirical models in order to estimate the monthly average daily global solar radiation on a horizontal surface. The results of statistical analyzing methods indicated that the present developed models were more suitable in order to estimate the monthly average daily global solar radiation over the seven big cities in the different regions of Turkey. The results obtained from statistical analysis show that the agreement between the measured and estimated values of monthly average daily global solar radiation is reasonably good. A number of statistical analysis methods have been used to evaluate the accuracy of the models of solar radiation estimations. Using the seven statistical analyzing methods mentioned above, the estimated values of the monthly average daily global solar radiation for the seven big cities were compared with the measured

data, as tabulated in Table 5. The following results may be obtained from this table indicating the results of the statistical analysis methods.

Izmir: The best results for *MPE, SSRE, RSE, MBE, RMSE* and *R* were obtained from the cubic polynomial model, while the best result for *MAPE* was computed from the quadratic model.

Samsun: The best result for *MPE* was obtained from the linear polynomial model, while the best results for *MAPE, SSRE, RSE, MBE, RMSE* and *R* were computed from the cubic polynomial model.

Ankara: The best results for *MPE, MAPE, SSRE* and *RSE* were obtained from the cubic polynomial model, while those for *MAPE, MBE, RMSE* and *R* were computed from the quadratic polynomial model.

Van: The best results for *MPE, MAPE, SSRE, RSE, MBE, RMS* and *R* were obtained from the cubic polynomial model.

Istanbul: The best results for *MPE, MAPE, SSRE and RSE* were obtained from the cubic polynomial model, while the best result for *MBE* was computed from the quadratic polynomial model.

Antalya: The best results for *MPE, MAPE, SSRE, RSE, RMSE, MBE* and *R* were obtained from the cubic polynomial model.

Urfa: The best results for *MPE and MBE* were obtained from the quadratic polynomial model, while those for *MAPE, SSRE, RSE, RMSE, R* were computed from the cubic polynomial model.

It may be concluded that the present models estimate the values of H, reasonably well for the cities studied and possibly elsewhere with similar climatic conditions.

4. CONCLUSIONS

Global solar-radiation is composed of two components: direct and diffuse radiations. In many applications of solar energy, the most important parameters are often the mean global solar radiation and its components. Unfortunately, measurements of this radiation are available only for a few places. Hence, it has been necessary to estimate the magnitude of solar radiation by theoretical models. Especially, the amount, direction and variation of radiation are very important for heating and cooling systems for the necessary calculations of heat gain from solar energy. The solar energy potential is also necessary to estimate maximum solar energy loads on walls, windows and roofs. Solar radiation provides a basis for design calculations, solar heat gain, solar flux and cooling design temperature profiles, provided that weather data are used to generate design parameters for a city.

Renewable energy is accepted as a key source for the future, not only for Turkey, but also for the world. This is primarily due to the fact that renewable energy resources have some advantages when compared to fossil fuels. At the present time, with the existing technology, it is impossible to supply the total demand of any country from renewable resources. However, environmental concerns and limited energy sources make renewable energy technology a good candidate for fossil fuels. They are, in fact, complementary to each other and can be used effectively alone or in combinations of two or more renewable energy sources (e.g., wind and biomass). Thus, all renewable options should be pursued in tandem .

Table 5. The results of the MBE, MAPE, SSRE, RSE, MBE, RMSE and R^2 of the present models developed for the seven big cities of Turkey

City	*Altitude* (*°N*)	*Longitude* (*°E*)	*Region*	*Equation Type*	Statistical analyzing methods						
					MPE	*MAPE*	*SSRE*	*RSE*	*MBE*	*RMSE*	*R2*
Izmir	38.40	27.09	Aegean Sea	Linear	0.0753613	1.4669218	0.0006424	0.0073169	0.0235803	0.2531437	0.9992723
				Quadratic	0.0559046	1.5293405	0.0006080	0.0071181	0.0128583	0.2509606	0.9992806
				Cubic	0.0511027	1.5935839	0.0005472	0.0067528	0.0073417	0.2486140	0.9992923
Samsun	41.28	36.20	Black Sea Region	Linear	0.0659474	1.7348215	0.0007606	0.0079616	0.0157554	0.1880286	0.9995177
				Quadratic	0.0842526	1.6795293	0.0007288	0.0077931	0.0136173	0.1878247	0.9995172
				Cubic	0.0717179	1.5655888	0.0007133	0.0077100	0.0105839	0.1812824	0.9995491
Ankara	39.95	32.52	Central Anatolia	Linear	0.0393172	1.1496516	0.0002359	0.0044338	-0.0236809	0.1572872	0.9997811
				Quadratic	0.0312680	1.0020240	0.0001920	0.0039999	-0.0165680	0.1177922	0.9998850
				Cubic	0.0214039	1.0071430	0.0001914	0.0039932	-0.0182731	0.1190325	0.9998841
Van	38.47	43.20	East Anatolia	Linear	0.0201052	0.7504810	0.0000845	0.0026531	-0.0250640	0.1665751	0.9997339
				Quadratic	0.0040893	0.6031200	0.0000528	0.0020978	-0.0194934	0.1152116	0.9998869
				Cubic	0.0016027	0.5709834	0.0000484	0.0020084	-0.0182644	0.1095388	0.9999013
Istanbul	41.10	28.58	Marmara	Linear	0.0417679	1.3476375	0.0004284	0.0059750	-0.0016316	0.1472819	0.9997796
				Quadratic	0.0483428	1.3505083	0.0004281	0.0059730	-0.0008960	0.1479561	0.9997772
				Cubic	0.0325346	1.2727852	0.0003121	0.0050994	0.0016742	0.1486127	0.9997706
Antalya	36.25	30.42	Mediterranean Sea	Linear	0.0779777	1.8264890	0.0007031	0.0076547	-0.0244674	0.4202899	0.9982992
				Quadratic	-0.7153351	1.9860724	0.0006126	0.0071451	-0.1670563	0.3759953	0.9990886
				Cubic	0.0534949	1.6479326	0.0005358	0.0066823	-0.0098118	0.3069865	0.9991007
Urfa	37.13	38.46	Southeast Anatolia	Linear	0.0031453	0.6392888	0.0000683	0.0023850	-0.0044380	0.1604624	0.9997472
				Quadratic	0.0028353	0.5187391	0.0000500	0.0020421	-0.0007152	0.1068642	0.9998889
				Cubic	0.0068744	0.4605846	0.0000430	0.0018921	-0.0020092	0.0913037	0.9999206

The best values for each city are indicated with the italic numbers.

REFERENCES

Amoto, U., Cuomo, V., Fontana, F., Serio, C., and Silverstrini, P. (1988).Behavior of hourly solar irradiance in the Italian climate. Solar Energy, Vol. 40(1), pp.65-79.

Aras H., Balli O., Hepbasli A. (2006).Estimating the horizontal diffuse solar radiation over the Central Anatolia Region of Turkey. Energy Conversion and Management, Vol. 47, pp.2240-2249.

Chakradhar L, Veziroglu TN. (2004.a).A universal relationship for estimating daily clear sky insolation. Energy Conversion and Management, Vol. 45, pp.2313-2333.

Chakradhar L, Veziroglu TN. (2004.b). A universal relationship for estimating clear sky insolation . Energy Conversion and Management, Vol. 45, pp.27-52.

Chen, A.A., Forrest, W., Chin, P.N., McLean, P., and Grey, C. (1994).Solar radiation in Jamaica. Solar Energy, Vol.53(5), pp.455-460.

Ediger V.S., Kentel E. (1999).Renewable energy potential as an alternative to fossil fuels in Turkey, Energy Conversion and Management, Vol.40, pp. 743-755.

EIE, The Turkish State Electrical Power Resources Survey and Development Administration. (2005). www.eie.gov.tr.

Helwa, N.H., Baghdad, A.B.G., El Shafee, A.M.R., and El Shenawy, E.T. (2002). Computations of the solar energy captured by different solar tracking systems. Energy Sources, Vol.22, pp.35-44.

Kaygusuz, K. (1999). The comparison of measured and calculated solar radiation in Trabzon, Turkey. Energy Sources, Vol.21, pp.347-353.

Kaygusuz K. and Sarı A. (2003). Renewable energy potential and utilization in Turkey, Energy Conversion and Management, Vol.44, pp. 459-478.

Michalsky, J.J.(1992).Comparison of a national weather service foster sunshine recorder and the world meteorological organization standard for sunshine duration. Solar Energy, Vol.48, pp.133-141.

Ogelman H, Ecevit A, Tasdemiroglu E. (1984).A new method for estimating solar radiation from bright sunshine data. Solar Energy, Vol.33(6), pp.619-625.

Ogulata, R. T. and Ogulata S. N. (2002).Solar radiation on Adana, Turkey. Applied Energy, Vol.71, pp.351-358

Sahin A.D, Kadioglu M, Sen Z.(2001).Monthly clearness index values of Turkey by harmonic analysis approach. Energy Conversion and Management, Vol.42, pp.933-940.

Samuel TDMA.(1991).Estimation of global radiation for Sri Lanka. Solar Energy, Vol.47(5), pp.333-337.

Saylan L , Sen O, Toros H and Arisoy A.(2002).Solar energy potential for heating and cooling systems in big cities of Turkey. Energy Conversion and Management, Vol.43, pp.1829-1837.

Sozen, A., Arcaklioglu, E., Ozalp, M., and Kanit, E.G. (2005). Solar energy potential in Turkey. Applied Energy, Vol.80(4), pp.367-381.

SSI , Turkish State Statistical Institute [DIE] (2005) www.die.gov.tr.

Tiris, M., Tiris, C., and Ture, I.E.(1996). Correlations of monthly average daily global, diffuse and beam radiations with hours of bright sunshine in Gebze, Turkey. Energy Conver. Mgmt., Vol.37, pp.1417-1421.

Ulgen, K., and Hepbasli, A.(2002.a).Comparison of solar radiation correlation for Izmir, Turkey. Int. J. Energy Res., Vol.26 pp.413-430.

Ulgen, K.; Hepbasli, A.(2002.b). Estimation of Solar Radiation Parameters for Izmir, Turkey, International Journal of Energy Research, Vol.26(9), pp. 807-823.

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