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Analysis of Ankara's Exposure to Solar Radiation: Evaluation of Distributional Parameters Using Long-Term Hourly Measured Global Solar Radiation Data

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Abstract

Turkey is becoming more dependent on imported primary energy to meet its increasing energy demand. The ratio of indigenous primary energy production to primary energy consumption is decreasing noticeably. Therefore, it is of great importance for Turkey to make use of its indigenous energy resources more effectively, including its solar energy potential. Solar energy is one of the most abundant energy resources in the country and should be utilized at the maximum level possible. The global solar radiation incident on a horizontal surface and daily sunshine hours are measured in Turkey by many recording stations of the Turkish State Meteorological Service (DME). According to these measurements, the yearly average daily solar radiation was 3.6 kWh/m^2, with a yearly total radiation period of over 2640 h. However, in recent years it has widely been acknowledged that the actual solar energy potential of Turkey is more than was previously thought.

In the present article, the solar radiation data on Ankara (lat 39.95 °N, long 32.88°E; elevation: 891 m) are analyzed based on 6 years of global solar radiation data measured on a horizontal surface by the DME. The distributional solar radiation parameters are derived from the available data and analyzed. The available solar radiation data on a horizontal surface are converted to that of various tilt angles and the yearly and monthly optimum tilt angles are determined.

Key words: Renewable energy, Solar radiation, Optimal tilt angle, Clearness index.

Introduction

The ratio of indigenous primary energy production to primary energy consumption of Turkey has been declining in recent years. This declination will continue unless major measures are taken. Considering the production objectives and demand forecasts, it will be necessary to import a total of nearly 100 Mtoe of primary energy in 2010. In the long term, Turkey's primary energy consumption is expected to reach over 160 Mtoe by 2010 and exceed 300 Mtoe by 2020. As of early 2004, Turkey has an electric power generating capacity of around 32,000 MW, with an additional 13,000 MW currently being constructed.

Located between latitudes 36 °N and 42 °N, and longitudes 26 °E and 45 °E, Turkey receives an abundance of sunshine and therefore has significant solar energy potential. Regional solar energy potentials are presented in Table 1, on an annual basis, derived as the average of years of data measured by the State Meteorological Service of Turkey (DME). As seen from the table, Southeast Anatolia and the Mediterranean regions receive relatively more solar energy than Turkey's other regions, thus offering ideal locations for large-scale installation of solar energy systems. The most uniformly distributed renewable energy throughout the country is solar energy, which currently is mainly used for roof-top hot water heating. The thermal energy production/consumption from roof-top solar water heating in Turkey is summarized in Table 2 for the years 1990 to 2001. Installed photovoltaic power is insignificant in Turkey, with a total capacity of about 0.5 MWe. Therefore, the photovoltaic contribution to electricity generation is negligible. Most of the photovoltaic systems are for experimental purposes set up by universities and research institutions.

A literature survey: Research studies on solar energy in Turkey

Most of the research on solar radiation has concentrated on the estimation of daily global solar radiation based on the duration of sunshine, determining the best model and its coefficients for different locations. Ertekin and Yaldız (2000) used solar radiation data from Antalya (lat 36.88 °N, long 30.70 °E; altitude: 51 m) to test the applicability of 26 different models available for computing the monthly average daily global radiation on a horizontal surface. The models were compared on the basis of statistical error tests, using the mean percentage error (MPE), root mean square error (RMSE), and the mean bias error (MBE). They concluded that the third degree polynomial model (known as the Samuel model) was the most accurate.

Toğrul et al. (2000) investigated the feasibility of clear sky radiation for predicting the average global solar radiation for 6 cities in Turkey: Antalya, İzmir, Ankara, Yenihisar (Aydın), Yumurtalık (Adana), and Elazığ. Various regression analyses were carried out using the ratios of sunshine duration to day length ($\bar{n}/\bar{N}$) and sunshine duration to sunshine duration that takes into account the natural horizon of the site ($\bar{n}/\bar{N}_{nh}$) (on a monthly average daily basis). They concluded that the equations developed by using $\bar{n}/\bar{N}$ and $\bar{n}/\bar{N}_{nh}$ have approximately the same results. In addition, they concluded that the use of the RMSE and MBE in isolation were not adequate indicators of model performance.

Toğrul and Onat (2000) examined the variation of global solar radiation reaching Elazığ (lat 39.67 °N, long 39.22 °E; altitude: 991 m) at hourly and monthly average daily periods based on daily global solar radiation for a 1-year period. Taking the measured values as a reference, the statistical performance of the 3 equations used in estimating the monthly average global solar radiation was investigated. Additionally, it was shown that bright sunshine hours and day length, and its standard deviation could be used to estimate the monthly average daily solar radiation/extraterrestrial radiation by applying the maximum likelihood quadratic fit method to the data taken from DME in Elazığ between 1983 and 1994.

Table 1. Annual average solar energy potential of Turkey by region*.

	Solar radiation (kWh/m^2)	Sunshine duration (hour)
Marmara	1168	2409
Southeast Anatolia	1460	2993
Aegean	1304	2738
Mediterranean	1390	2956
Black Sea	1120	1971
Central Anatolia	1314	2628
East Anatolia	1365	2664
Average	**1303**	**2623**

*Source (Ultanır, 1998)

Table 2. The thermal energy production/consumption of roof-top solar water heating in Turkey from 1990 to 2001*.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Solar heat (x1000 Tep)	28	41	60	88	129	143	159	179	210	236	262	287

*Source (ETKB, 2005)

Şahin and Şen (1998) proposed a simple substitution method for the dynamic estimation of Angstrom coefficients, which play a significant role in the relationship between global radiation and sunshine duration. The methodology was applied to 28 radiation measurement stations across Turkey, and Angstrom equation parameters' regional variations were obtained for the entire country.

Şen and Şahin (2000) presented a solar irradiance polygon (SIP) concept for evaluating, both qualitatively and quantitatively, the within-year variations in solar energy variables. Using the global radiation and sunshine duration measurements from 29 stations scattered throughout Turkey, monthly, seasonal, and annual parameters of the classical Angstrom equation were calculated on the basis of SIPs. They stated that, "Classical approaches include mostly linear and, to a lesser extent, non-linear relationships between these variables." The parameters in these relationships were determined invariably by the least squares technique, leading to regression lines or curves as models. None of these models provided within-year variations in the parameters and they were all very rigid in the application, yielding to a single solar global irradiation estimate for a given sunshine duration value. They concluded that the SIPs provided more detailed information than the classical regression analyses that are commonly employed in engineering solar system design, planning, and management.

Other than the research on the Angstrom formula, the following articles concentrated on different aspects of solar energy in Turkey. Üner and İleri (2000) developed typical hourly weather data by using actual recordings from 23 selected provinces that were representative of demographic and climatic conditions in Turkey. By using these typical meteorological years, heating and cooling degree-days, dry-bulb temperature bins, and winter and summer design dry-bulb temperatures were further calculated.

Kaygusuz and Ayhan (1999) presented an analysis of measured solar radiation data in Trabzon in the form of hourly-average daily and percentage frequency distribution. Diurnal distribution of total and diffuse solar radiation on a horizontal surface was analyzed on a monthly basis, as well as the diurnal distribution of clearness index. The variation of the monthly average hourly and daily clearness indices were plotted against the fraction of diffuse radiation. They concluded that the maximum value of the monthly-average daily global radiation was 21.6 MJ/m^2 and was recorded in June, and the minimum value of the monthly-average daily global radiation was 4.6 MJ/m^2, which was recorded in December. The monthly average daily clearness indexes varied from 0.29 in March to 0.47 in June.

Distribution of days with various clearness indexes

The monthly clearness index values $\bar{K}_T$, calculated for Ankara from both the available measured and the theoretically calculated extraterrestrial solar radiation data, are presented in Table 3. The monthly clearness index values varied between 0.35 and 0.64, while the yearly average values ranged from 0.50 to 0.53 between the years 1995 and 2000.

The cumulative distribution curves are obtained by plotting the fraction of the days that are less clear than K_T (fractional time) versus K_T for locations with a particular value of $\bar{K}_T$. Liu and Jordan (1960) found that the cumulative distribution curves are nearly identical for locations having the same values of $\bar{K}_T$, although the locations varied widely in latitude. Moving on from this idea, they developed a set of generalized distribution curves of K_T versus fractional time, which are functions of $\bar{K}_T$. Recent studies showed that for these distributions there might be some seasonal dependence in certain locations (Duffie and Beckman, 1991). Moreover, the same approach has been applied to different climates throughout the world for which alternative curves have been proposed. It has also been observed that when the hourly and daily curves for a location are plotted, the curves are very similar (Duffie and Beckman, 1991). Therefore, the distribution curves of daily occurrences of K_T can also be applied to the hourly clearness index k_T.

In the present article, the distribution of clear and cloudy days was studied by plotting the available K_T data in the form of cumulative distribution. The cumulative distribution curves were arranged in the bins of 0.35-0.39, 0.40-0.44, 0.45-0.49, 0.50-0.54, 0.55-0.59, and 0.60-0.65 of the monthly clearness indexes. These cumulative distribution curves for Ankara were then compared to those of the generalized distribution curves of Liu and Jordan (1960). Bendt et al. (1981) developed the following equations to represent the Liu and Jordan (1960) distributions:

Table 3. Extraterrestrial and measured monthly total solar radiation values and clearness indexes.

	Total solar radiation (kWh/m^2)							Clearness index					
	Extraterrestrial	1995	1996	1997	1998	1999	2000	1995	1996	1997	1998	1999	2000
January	131.38	52.23	48.31	63.52	58.67	49.28	55.59	0.40	0.37	0.48	0.45	0.38	0.42
February	157.99	85.39	64.13	85.05	84.71	62.84	78.33	0.54	0.39	0.54	0.54	0.40	0.48
March	236.77	110.59	92.80	121.66	109.72	113.07	137.69	0.47	0.39	0.51	0.46	0.48	0.58
April	288.49	142.37	139.67	118.98	142.02	158.39	129.51	0.49	0.48	0.41	0.49	0.55	0.45
May	341.91	195.63	189.25	187.29	160.08	199.18	187.35	0.57	0.55	0.55	0.47	0.58	0.55
June	346.67	195.74	219.96	195.56	197.09	177.50	189.56	0.56	0.63	0.56	0.57	0.51	0.55
July	348.85	194.56	218.75	209.51	224.01	208.22	221.05	0.56	0.63	0.60	0.64	0.60	0.64
August	312.15	186.43	192.46	173.02	200.51	176.15	189.28	0.60	0.62	0.55	0.64	0.56	0.61
September	247.21	147.90	141.06	158.63	142.12	148.17	151.39	0.60	0.58	0.64	0.57	0.60	0.62
October	190.60	111.68	99.93	95.34	110.94	97.12	106.16	0.59	0.53	0.50	0.58	0.51	0.56
November	135.47	56.26	67.31	62.14	62.18	68.38	70.12	0.42	0.50	0.46	0.46	0.50	0.52
December	117.03	40.78	41.97	45.23	40.77	50.98	50.27	0.35	0.36	0.39	0.35	0.44	0.43
Average	**237.88**	**126.63**	**126.30**	**126.33**	**127.74**	**125.77**	**130.52**	**0.51**	**0.50**	**0.52**	**0.52**	**0.51**	**0.53**
Total	**2854.52**	**1519.55**	**1515.60**	**1515.93**	**1532.83**	**1509.28**	**1566.29**						

$$f(K_T) = \frac{\exp(\gamma K_{T,\min}) - \exp(\gamma K_T)}{\exp(\gamma K_{T,\min}) - \exp(\gamma K_{T,\max})} \tag{1}$$

where γ is determined from the following equation:

$$\bar{\bar{K}}_T = \frac{(K_{T,\min} - 1/\gamma)\exp(\gamma K_{T,\min}) - (K_{T,\max} - 1/\gamma)(\exp(\gamma K_{T,\max})}{\exp(\gamma K_{T,\min}) - \exp(\gamma K_{T,\max})} \tag{2}$$

or alternatively, the following curve fit can be used to obtain γ,

$$\gamma = -1.498 + \frac{1.184\xi - 27.182\exp(-1.5\xi)}{K_{T,\max} - K_{T,\min}} \tag{3}$$

where

$$\xi = \frac{K_{T,\max} - K_{T,\min}}{K_{T,\max} - \bar{\bar{K}}_T} \tag{4}$$

A $K_{T,min}$ value of 0.05 is usually used, and $K_{T,max}$ can be estimated from,

$$K_{T,\max} = 0.6313 + 0.267\bar{\bar{K}}_T - 11.9(\bar{\bar{K}}_T - 0.75)^8 \tag{5}$$

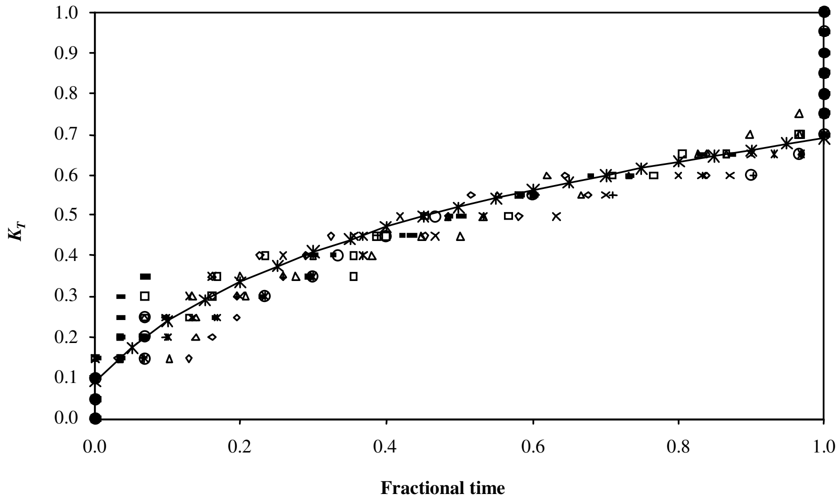

Figure 1. Distribution of days with various values of K_T as a function of $\bar{\bar{K}}_T$ for $0.45 \leq \bar{\bar{K}}_T < 0.49$.

An example of the distribution of days with various values of K_T as a function of $\bar{\bar{K}}_T$ derived from Ankara data is presented in Figure 1 for $0.45 \leq \bar{\bar{K}}_T < 0.49$. The continuous line is derived from the equations developed from the generalized distribution curves of Liu and Jordan (1960) by Bendt et al. (1981). Even though the continues line seems to be a good fit for the Ankara data, further analysis by the author of this article showed that the coefficients of the equations of Bendt et al. (1981) can be modified to significantly improve the fit of the curve to the Ankara data. However, this is not addressed in detail in the present article, as this is beyond its scope.

Determination of optimal tilt angle for Ankara

Solar energy systems are usually installed at an angle from the horizontal surface to increase the solar energy angle of incidence on the surface of the collectors. The aim of the present study is to determine the monthly optimal tilt angles for Ankara, based on measured radiation data, and to compare it to theoretically obtained optimal tilt angles. The solar radiation on a horizontal surface is converted to different tilt angles so that the optimal tilt angle can be determined. As the available hourly data for Ankara were measured on a horizontal surface as global radiation, it first needs to be split into its beam and diffuse components. The beam and diffuse components are not only essential for calculating the total solar radiation on tilted surfaces, but also the ratio of diffuse to total radiation has an important effect on the performance of solar energy systems.

Adopting the isotropic diffuse model, the solar radiation on a on tilted surface surface can be calculated on an hourly basis based on the following well-known equations (Duffie and Beckman, 1991),

$$I_T = I_b R_b + I_d \left(\frac{1 + \cos\beta}{2} \right) + I\rho_g \left(\frac{1 - \cos\beta}{2} \right) \tag{6}$$

The ratio of global radiation on a tilted plane to that on a horizontal plane is denoted by R,

$$R = \frac{I_T}{I} = \frac{I_b}{I} R_b + \frac{I_d}{I} \left(\frac{1 + \cos\beta}{2} \right) + \rho_g \left(\frac{1 - \cos\beta}{2} \right) \tag{7}$$

where I is the hourly total radiation on a horizontal plane, I_b is the hourly beam radiation, I_T is the hourly radiation on tilted plane, I_d is the hourly diffuse radiation, β is the angle of tilt, and ρ_g is the ground reflectance factor. R_b, the geometric factor, is the ratio of beam radiation on the tilted surface to that on a horizontal surface at any given time. For surfaces facing directly towards the equator in the Northern Hemisphere, R_b is given by the following equation,

$$R_b = \frac{\cos(\phi - \beta)\cos\delta\cos\omega + \sin(\phi - \beta)\sin\delta}{\cos\phi\cos\delta\cos\omega + \sin\phi\sin\delta} \tag{8}$$

where ϕ is the latitude in degrees, δ is the solar declination, and ω is the hour angle.

The ratio of tilted to horizontal solar radiation on a monthly basis for 6 years of Ankara data is shown in Figure 2. The tilt angle, in this case, is equal to the latitude of Ankara. The monthly ratio of tilted to horizontal radiation shows little variation from April to September. In the remaining months, the ratio varies relatively more from year to year. In May, June, and July the ratio is below the unity, meaning that a horizontal surface receives more solar radiation than a surface tilted 40°. In the remaining 9 months, the surface tilted 40° receives more solar radiation than the horizontal surface.

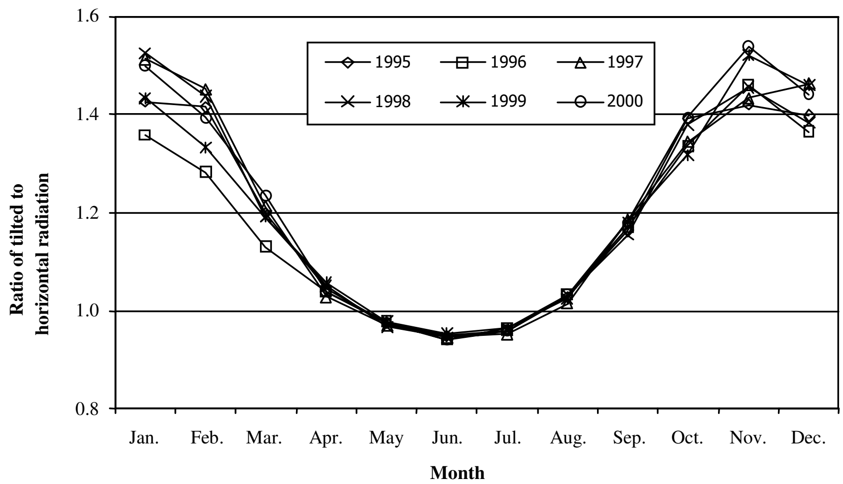

Figure 2. The ratio of tilted to horizontal solar radiation on a monthly basis for various years (the angle of the tilted surface is equal to the latitude of Ankara).

Detailed analysis was carried out based on the Ankara data of the calendar year 2000 to study the effect of tilt angle on the total solar radiation incident on a surface. The yearly average daily solar radiation at different tilt angles is presented in Figure 3. If the solar radiation curve seen in Figure 3 is represented by a function of $f(x)$, the x satisfying the following equation is the optimal tilt angle,

$$\frac{\partial f(x)}{\partial x} = 0 \quad (9)$$

The optimal tilt angle is 39.40°, which is very close to the latitude of Ankara, as was expected. The monthly average daily solar radiation at different tilt angles for the year 2000 is shown in Figure 4. When the monthly curves are represented by functions and solved as described above, the monthly optimal tilt angles can be determined. The optimal tilt angles determined in this way can be seen in Figure 5. The monthly optimal tilt angle can be determined theoretically for the beam radiation for a plane rotated about a horizontal east-west axis with a single daily adjustment, so that the beam radiation is normal to the surface at noon each day (Duffie and Beckman, 1991),

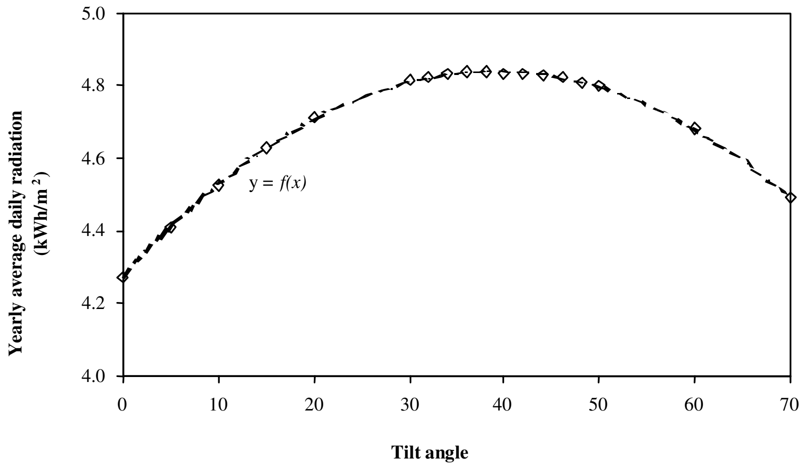

Figure 3. Yearly average daily solar radiation at different tilt angles.

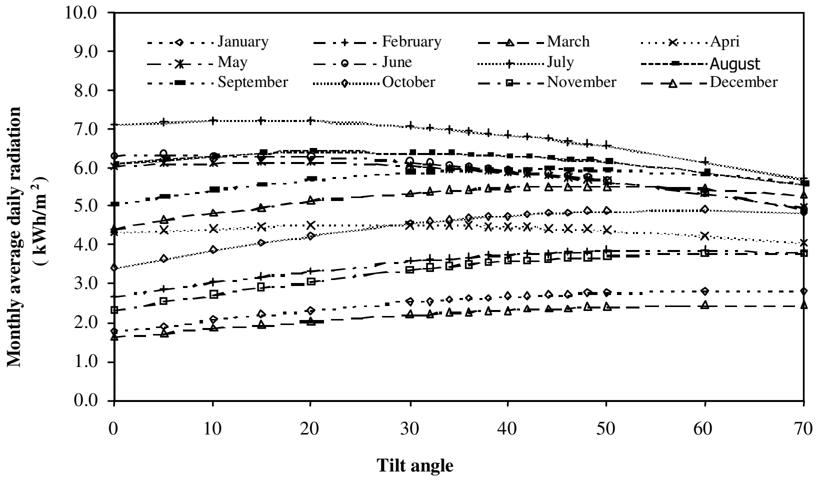

Figure 4. Monthly average daily solar radiation at different tilt angles.

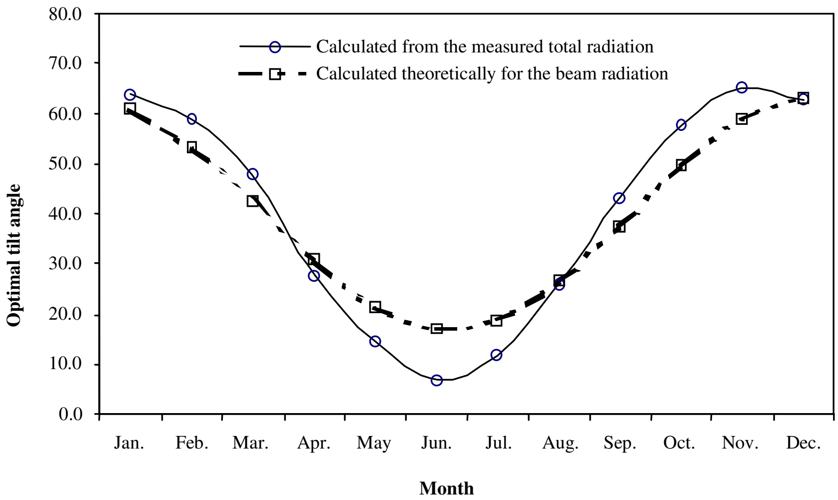

Figure 5. Monthly optimal tilt angles found theoretically for the beam radiation and those derived from the measured total radiation.

$$\cos\theta = \sin^2\delta + \cos^2\delta\cos\omega \qquad (10)$$

The slope of this surface will be fixed for each day and will be,

$$\beta = |\phi - \delta| \qquad (11)$$

The monthly optimal tilt angles found theoretically for the mid-day of each month versus those derived from the measured data, using the method presented above, are given in Figure 5. As can be seen from the figure, theoretically calculated optimal tilt angles and those found from the measured data show a consistent relationship; the optimal tilt angles calculated from the measured data are lower than those found theoretically for May, June, and July, whereas they are nearly equal in April, August, and December. For the remainder of the months, the optimal tilt angles calculated from the measured data are larger than those found theoretically.

Other distributional parameters

The duration of theoretical day length together with the measured duration of sunshine hours on a monthly and yearly average daily basis for the available data from Ankara is presented in Table 4. The yearly average daily sunshine durations vary between 6.65 and 7.09. Overall, the monthly average daily measured sunshine duration is longest in July. The winter months of December and January have a relatively low duration of sunshine. However, it is noted that the monthly average daily sunshine duration varies significantly from year to year; for example, see November of 1995 and 1996, and March of 1996 and 2000 (Table 4).

The ratio of diffuse to total radiation on a monthly and yearly average basis is summarized in Table 5. Overall, the yearly average ratios vary between 0.45 and 0.50. However, it is noted that in 5 years out of 6, the ratio varies from 0.48 to 0.50. The ratio on a monthly basis shows the following trend; it is low from May to October, in some months as low as 0.33, as observed in June 1996, and it is higher in November, January, March, and April. The highest ratio of diffuse to total radiation is seen in December of 1996, measuring 0.69.

Finally, monthly persistence values for various years of Ankara data are provided in Figure 6. It has been shown that persistence has an important impact on the performance of solar energy systems. The persistence of solar radiation refers to the dependence of today's solar radiation on the solar radiation of preceding days. The persistence of daily solar radiation has been studied by various researchers (Brinkworth, 1977; Klein and Beckman, 1987). These authors concluded that the persistence of solar radiation on a daily basis could be adequately described by a first order auto-regressive process. The single parameter of this model is the correlation coefficient of the daily solar radiation on successive days defined by,

$$\phi = \frac{\sum_{t=1}^{n-1}\left(H_t - \bar{H}\right)\left(H_{t+1} - \bar{H}\right)}{\sum_{t=1}^{n-1}\left(H_t - \bar{H}\right)^2} \tag{12}$$

where H_t and H_{t+1} are the daily solar radiation per unit area on a surface for days t and $t+1$, and $\bar{H}$ is the average daily radiation during a period of n days.

The diurnal variation of the measured solar radiation, on a monthly average hourly basis for the calendar year 2000, is presented in Figure 7. The maximum monthly average hourly solar radiation is 845.46 Wh/m^2 in July, between the hours of 12 pm and 1 pm, whereas between the same hours in December, the minimum monthly average hourly solar radiation is 296.45 Wh/m^2.

Table 4. Average day length and duration of sunshine on a monthly basis.

	Day length (hour)	Sunshine duration (hour)					
		1995	1996	1997	1998	1999	2000
January	9.51	2.90	2.11	4.02	3.70	2.72	2.24
February	10.52	6.48	3.26	4.88	6.19	3.25	3.48
March	11.73	5.33	3.00	5.99	4.97	5.92	7.15
April	13.07	5.93	6.11	4.68	6.10	8.34	5.72
May	14.21	9.93	9.53	9.57	6.77	10.34	8.92
June	14.79	10.44	11.57	9.74	10.15	8.35	10.21
July	14.53	10.21	11.49	11.71	12.36	11.72	12.88
August	13.54	11.10	10.89	9.19	12.03	10.12	10.84
September	12.25	9.23	8.13	9.44	8.59	9.49	9.40
October	10.91	7.03	5.87	5.15	7.89	6.04	6.93
November	9.77	2.62	6.08	4.29	4.30	5.18	6.21
December	9.21	2.02	1.82	2.33	1.81	3.65	2.28
Average	**12.00**	**6.93**	**6.65**	**6.75**	**7.07**	**7.09**	**7.19**

Table 5. Ratio of diffuse to total solar radiation.

	Diffuse/total radiation					
	1995	1996	1997	1998	1999	2000
January	0.60	0.67	0.52	0.56	0.62	0.55
February	0.46	0.63	0.44	0.44	0.56	0.48
March	0.50	0.59	0.48	0.53	0.52	0.39
April	0.50	0.51	0.57	0.52	0.46	0.55
May	0.42	0.44	0.45	0.53	0.42	0.42
June	0.42	0.33	0.43	0.41	0.50	0.41
July	0.43	0.36	0.42	0.35	0.40	0.36
August	0.42	0.39	0.44	0.36	0.45	0.39
September	0.41	0.42	0.36	0.42	0.40	0.38
October	0.39	0.48	0.46	0.41	0.49	0.41
November	0.58	0.53	0.54	0.54	0.47	0.47
December	0.66	0.69	0.64	0.68	0.62	0.64
Average	**0.48**	**0.50**	**0.48**	**0.48**	**0.49**	**0.45**

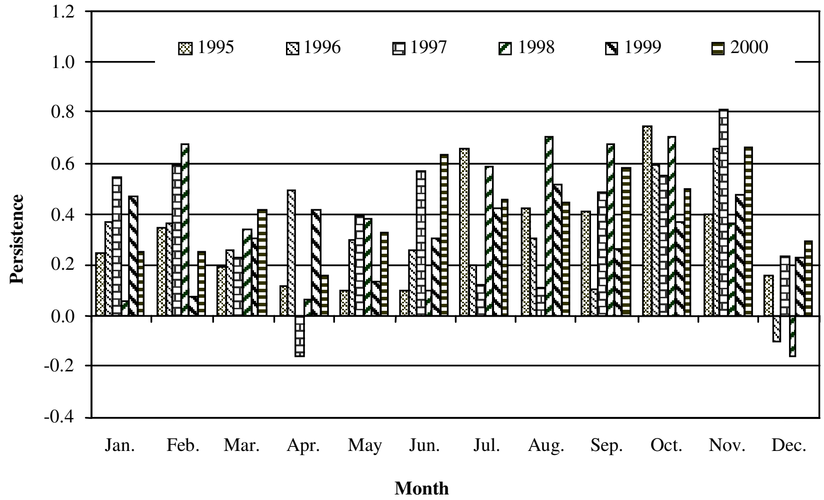

Figure 6. Monthly persistence values for various years.

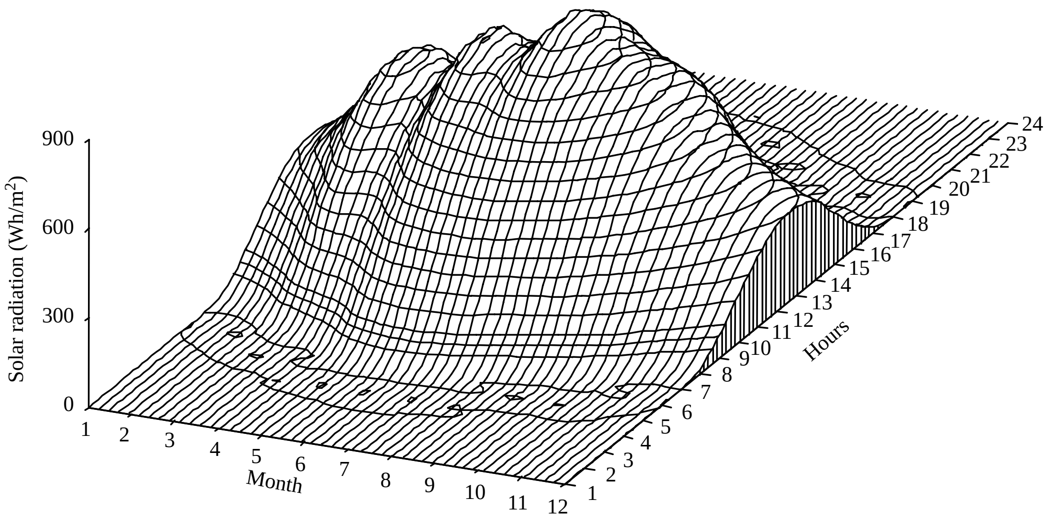

Figure 7. Diurnal variation of solar radiation for the calendar year 2000, on a monthly average basis.

Conclusions

The analysis of the energy situation in Turkey indicates that the ratio of indigenous primary energy production to primary energy consumption has been decreasing steadily during recent years. This declination is expected to continue. Furthermore, the demand for electricity is expected to grow significantly in the coming years due to the expectation of rapid economic growth. The use of renewable energy, in general, and solar energy in particular, has been negligible when compared to their economically exploitable potential. The solar radiation potential of Ankara was studied in the present article based on 6 years of hourly global solar radiation data. This will contribute to the exploration of the potential of solar energy in Turkey. The most important findings arising from this study are as follows:

Renewable energy use in the production of electric power is miniscule in comparison to the economically exploitable renewable energy potential in Turkey.

The yearly total solar radiation for Ankara varied from 1509.28 to 1566.29 kWh/m^2 for the years analyzed. When this is compared to the previously given value of 1314.0 kWh/m^2 for the region of Central Anatolia (Ankara is located in this region), it is noted that the solar energy potential for this region is about 17% greater than previously thought.

It was shown that even though the generalized distribution curves provide a reasonable fit for the Ankara data, the fit could be improved significantly by either developing a new set of equations or by modifying the parameters of the equations developed for the generalized distribution curves.

The yearly optimal tilt angle was 39.40° for the calendar year 2000. The monthly optimal tilt angles were further calculated from the measured data. The smallest optimal tilt angle was 6.7° in June, and the largest was 65.2° in November.

The yearly average ratio of diffuse to total radiation varied from 0.45 to 0.50, while the sunshine duration varied from 6.65 to 7.19 hours.

The monthly persistence was between − 0.16 and 0.81, showing no seasonal or yearly dependence.

The diurnal analysis of the measured solar radiation showed that the maximum monthly average hourly solar radiation recorded for the calendar year 2000 was 845.46 Wh/m^2 in July, between the hours of 12 pm and 1 pm, whereas the minimum monthly average hourly solar radiation was 296.45 Wh/m^2 in December.

Nomenclature

$f(K_T)$	fractional time
$\bar{H}$	daily average radiation during a period of n days (kWh/m^2)
H_t	daily solar radiation for days t (kWh/m^2)
H_{t+1}	daily solar radiation for days $t+1$ (kWh/m^2)
I	hourly total radiation on a horizontal surface (kWh/m^2)
I_b	hourly beam radiation (kWh/m^2)
I_d	hourly diffuse radiation (kWh/m^2)
I_T	hourly total radiation on a tilted surface (kWh/m^2)
k_T	hourly clearness index
K_T	daily clearness index
$\bar{K}_T$	monthly clearness index
n	number of the days of the year starting with the 1^{st} of January
R	geometric factor for the total radiation
R_b	geometric factor for the beam radiation
β	angle of tilt (degree)
ρ_g	ground reflectance factor
γ	a model parameter
ϕ	latitude (degrees)
δ	solar declination (degrees)
ω	hour angle (degrees)

Acronyms

DME	State Meteorological Service of Turkey
MBE	mean bias error
MPE	mean percentage error
Mtoe	million tons of equivalent petroleum
RMSE	root mean square error

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