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MEASUREMENT OF SOLAR RADIATION IN ANKARA, TURKEY

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Abstract: The solar energy potential of Ankara, Turkey, (39.89°N, 32.78°E) has been investigated using the measurements of global and beam radiation over the period May 2008 to May 2009. Surface air temperature was also measured and variation in clearness index evaluated over this period. Global and beam radiations have been analyzed using hourly, daily and monthly averages obtained from 1-minute averages of recorded data. Results show that annual average daily global and beam radiations were 17.04 and 15.72 MJ/m^2/day, respectively, for this period. The results are compared with the data available for several other cities in Turkey. The study shows that Ankara has a large solar potential. The consistency of these data with that from the State Meteorological Service (SMS) weather station in Ankara was analyzed. Significant differences between these 2 stations were found and are attributed to measurement error at the SMS station. New radiation-measurement stations should be established to create a better national radiation database for Turkey.
Keywords: Global radiation, Beam radiation, Surface air temperature, Clearness index.

TÜRKİYE'NİN ANKARA İLİNDE YAPILAN GÜNEŞ IŞINIMI ÖLÇÜMLERİ

Özet: Türkiye'nin Ankara ili (39.89°K, 32.78°D) güneş enerjisi potansiyeli, Mayıs 2008'den Mayıs 2009'a kadar yapılan toplam ve direkt güneş ışınımı ölçümleri kullanılarak araştırılmıştır. Aynı ölçüm süresinde, hava sıcaklığı da kaydedilmiş ve açıklık indeksinin değişimi incelenmiştir. Toplam ve direkt güneş ışınımları, dakikalık ortalama olarak toplanan ve kaydedilen veriler kullanılarak saatlik, günlük ve aylık ortalamalar bazında analiz edilmiştir. Sonuçlar, bahsedilen ölçüm aralığında yıllık ortalama günlük toplam ve direkt güneş ışınımı değerlerinin sırasıyla 17.04 ve 15.72 MJ/m^2/gün olduğunu göstermiştir. Sonuçlar Türkiye'nin diğer bölgelerinden seçilen bazı illerin mevcut verileri ile de karşılaştırılmıştır. Bu çalışma göstermiştir ki Ankara oldukça iyi bir güneş potansiyeline sahiptir. Ayrıca, çalışmada yapılan ölçümlerle Devlet Meteoroloji İstasyonunun yaptığı ölçümler karşılaştırılmış ve sonuçlar yorumlanmıştır. İki istasyon verileri arasında kayda değer farklılıklar çıkmış ve bunun olası sebepleri açıklanmıştır. Bu durum göstermiştir ki verilerin güvenilirliği açısından Türkiye'de daha yaygın bir güneş ışınımı ölçüm ağı oluşturulmalıdır.
Anahtar Kelimeler: Toplam güneş ışınımı, Direkt güneş ışınımı, Hava sıcaklığı, Açıklık indeksi.

INTRODUCTION

Solar radiation data is essential to determine the solar potential of a region for solar energy applications such as heating, cooling, electricity production and industrial purposes. Most of the studies to determine the solar energy potential of a certain location have concentrated on the estimation of global radiation on a horizontal surface using measured data (Al-Mohamad, 2004; Al-Sanea et al., 2004; Ampratwum and Dorvlo, 1999; Badescu, 1999; Chen et al., 2007). Some of the estimation methods rely on conventional regression techniques (Sabziparvar and Shetaee, 2007; Lingamgunta and Veziroglu, 2004; Aksakal and Rehman, 1999; Supit and Kappel, 1998) and others have utilized modeling approaches such as artificial neural networks and wavelet-networks (Dorvlo et al., 2002; Mellit et al., 2006; Wan et al., 2008; Azadeh et al., 2009; Zervas et al., 2008; Mubiru and Banda, 2008). There are also several studies based on satellite data (Janjai et al., 2009). Available solar gain must also be known to decide the feasibility of solar energy in industry because the needs for electricity and heating/cooling processes are dominant in industrial applications (Kalogirou, 2003). Measured data alone are used to evaluate solar potential of some Arabian states (Islam et al., 2009; Sahin et al., 1999).

The utilization of solar energy in Turkey has not reached its desired level although it is a country with a large solar potential. Turkey lies in the solar belt (L:36-42°N) and has an annual sunshine duration of approximately 2610 hours on average (Sözen et al., 2004). Currently solar energy usage is primarily limited to heating and cooling applications in the southern part of the country. The usage of solar technologies is expected to increase after February 5, 2009, when the Turkish government signed the Kyoto Protocol and committed to reduce its greenhouse gas emissions after 2012.

Several studies on solar radiation in Turkey have been performed. Bulut and Büyükalaca (2007) suggested a simple model for simulating daily global radiation. Oğulata and Oğulata (2002) estimated monthly-mean global radiation and hourly global, diffuse and direct radiation for Adana, a city on the southeastern edge of Turkey's Mediterranean coast. Empirical correlations were developed to estimate monthly average daily global radiation for Turkey as a whole by Bakirci (2009) and for Elaziğ, a city in central-eastern Turkey, by Toğrul and Onat (1999). A number of models in the literature for estimating global radiation were compared for Konya by Menges et al. (2006) and for Antalya by Ertekin and Yaldiz (2000). A simple calculation method was developed to estimate the instantaneous global radiation on a horizontal surface in Erzurum by Bakırcı (2009). A new model was proposed by Yıldız (2011) to estimate hourly global clear sky radiation in İzmir as a function of zenith angle and results were compared with ASHRAE model and other correlations in the literature. On the other hand, Sözen and Arcaklioğlu (2005) determined the solar energy potential in Turkey using artificial neural-networks while Şenkal and Kuleli (2009) made a similar model using satellite data. Models developed by both regression analysis and artificial neural-network were used to estimate the monthly average global radiation for Zolguldak (Deniz and Atik, 2007). Measured data were used in all studies. However, only a few investigations have been made about the actual solar potential using long-term data (Bulut and Büyükalaca, 2007; Kaygusuz and Ayhan, 1999). Beam radiation was rarely investigated. Additionally, the accuracy of the radiation measurements was never investigated. The present study assesses the solar potential in Ankara, Turkey, using measured data and evaluates the consistency of data obtained from two measuring stations in Ankara.

MEASUREMENTS AND MISSING DATA

Measurement of solar radiation is very important to predict the performance, and therefore applicability, of solar energy systems (Myers, 2005). However, there can be errors related to solar radiation measurement, mainly due to equipment technical failure and operation-related problems (Moradi, 2009). Beam and diffuse radiation measurements are required for obtaining more accurate data and the number of stations needs to be increased in order to establish a large network of reliable solar radiation data. A measurement station was established in April 2008 on the roof of the A-Building of the Department of Mechanical Engineering in Middle East Technical University (METU), Ankara, Turkey (Latitude: 39.89°N, Longitude: 32.78°E). The solar radiation measurement has been made based on real-time high-resolution measurements in this study.

Two pyranometers and a pyrheliometer are used to measure global horizontal radiation, global radiation on a tilted surface and beam radiation, respectively. Eppley Lab Black and White type pyranometers are used. The pyranometers were calibrated by the EPLAB Company and are accurate within ±1.0 % for intensities up to 1400 W/m^2. The pyrheliometer is linear to within ±0.5 % for intensities up to 1400 W/m^2 and the calibration of this instrument is traceable to standard self-calibrating cavity pyrheliometers. Surface air temperature was measured using a T-type thermocouple. A Datataker-DT85 data acquisition device is used to monitor and record the radiation and temperature measurements. The software program (DeLogger) supplied by the Datataker company is used for downloading and monitoring the measured data on a computer. Data were collected every second and archived as 1 minute, 15 minute and 1 hour averages. The pyranometers and the pyrheliometer were cleaned once every two days.

Measurements started on May 1, 2008 and continued until April 30, 2009 to achieve one full year of data. Some data are missing due to technical problems during measurements. The missing data, accounting for 5% of the whole database, were replaced with estimated values based on data filling methods. The data filling methods used in this study are taken from the manual of the National Solar Radiation Database (NSRDB) produced by the U.S. National Renewable Energy Laboratory (NREL) (2007). Different methods were employed for different gap lengths. The long-term filling method (periods from 2 days to one year) requires the use of past data over the same period from the station itself. Alternately, the Linacre method uses measurements from an adjacent station. For this research the Linacre method is used since there are no historical data from the present station. In this method, it is assumed that there exists a constant relationship between two neighboring stations (Linacre, 1992). The nearby station without missing data was of the State Meteorological Service (SMS) in Ankara (39.97°N, 32.86°E) and 14-year radiation and temperature data were taken from there. A regression analysis was used to find the most accurate correlation between the two stations. The model is as follows:

$$I_e = C_0 + \sum_{i=1}^{n} C_i V_i \tag{1}$$

where I_e is estimated global radiation, C_0 is a constant, C_i is the coefficient of the i^{th} variable, V_i is the value of i^{th} variable, and n denotes number of variables. Variables of global radiation (G_s), clearness index (k_s) and surface air temperature (T_s) from the other station were correlated individually and in combinations. The multivariate regression equation that contains all three variables gave the highest correlation coefficient (R^2) of 0.9615 with a root mean square error (RMSE) of 61.7 W/m^2. The model was applied to all missing radiation data without considering gap length. Missing temperature data were also estimated by the same methodology.

RESULTS AND DISCUSSION

Complete data were processed for the period May 1, 2008 to April 30, 2009. Fig. 1 represents the variation of daily average and daily maximum global radiation over this one year period. Daily average global radiation was calculated as the average of 24 hours. As expected, both average and maximum global radiations are higher in summer months and lower in winter months. A maximum global radiation value was obtained as 1056 W/m^2 on May 31, 2008 between the hours 12-13. Daily average global radiation varied between 16 and 383 W/m^2. The minimum value was obtained on March 2, 2009 and the maximum value on May 31, 2008. Fig. 1 also shows that the global radiation has large daily fluctuations over the year, especially during the winter season. These fluctuations are likely caused by the instability in clear sky conditions since the weather was often cloudy except during the summer season. However, the summer season clearly has a high solar potential.

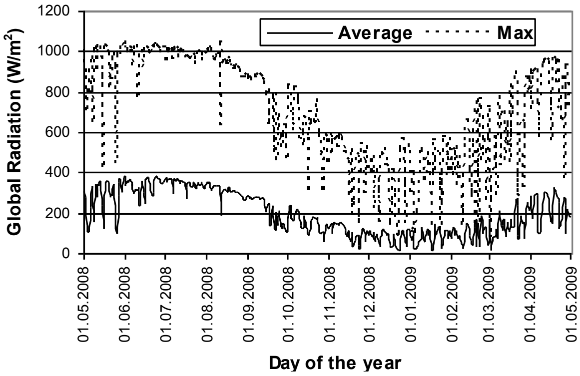

Fig. 1. Daily maximum and daily average global radiation throughout the year.

Fig. 2 shows the monthly average and maximum global radiations for this one year. The maximum monthly average radiation is for July 2008 with the value of 348 W/m^2. On the other hand, the months December 2008 and January 2009 have the lowest monthly average global radiations with values 77 and 81 W/m^2, respectively. One can see from Fig. 2 that the maximum global radiation is almost proportional to average radiation. In other words, lower monthly average values occur when maximum radiation values are lower and vice versa.

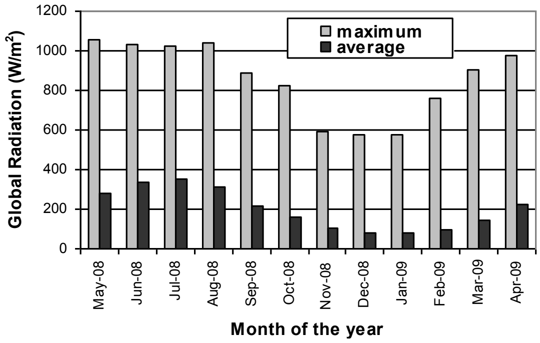

Fig. 2. Monthly maximum and monthly average global radiation.

A comparison of monthly average daily global radiation of Ankara with several other large cities in Turkey is shown in Table 1. Table 1 includes Ankara data from both the present study and SMS for one year starting from of May 1, 2008. The table also includes calculated mean values for long periods when data are available from the Turkish SMS archive since 1995. There were missing data due to the same problems as mentioned above. Among the cities selected from different regions in Turkey, Ankara's solar potential is at an intermediate level for a complete year. For long period averages of over a decade, Ankara has higher solar radiation values than the northern cities İstanbul and Trabzon, and has lower values than the southern cities Antalya and Van. Ankara's annual average global radiation was 17.04 MJ/m^2/day. The METU global radiation data is significantly higher than the historical 14-year average data for Ankara. Furthermore, the differences between the METU and the SMS stations are significant. The measurement devices and procedure for the METU station were checked. For quality control, two other pyranometers were placed near the existing pyranometer and it was seen that the deviation between the devices was less than ±2%. The data logger and software

Table 1. Monthly and annual average daily total solar radiation for Ankara and other large cities in Turkey.

Stations	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Annual
Monthly and annual average global radiation in MJ/m^2/day													
Ankara, METU May 08-Apr. 09	24,13	29,05	30,11	26,65	18,33	13,64	9,01	6,61	7,01	8,23	12,46	19,25	17,04
Ankara, SMS May 08-Feb. 09	22,41	26,88	27,92	24,72	16,78	12,53	7,99	5,63	6,12	7,42	11,35	17,73	15.62
Ankara 14-year average	21,86	24,25	24,91	21,92	17,62	12,13	7,64	5,45	6,28	9,61	13,57	17,30	15,26
Antalya 14-year average	22,65	24,95	24,47	22,00	18,97	13,86	9,38	6,99	8,13	11,29	15,66	18,93	16,44
İstanbul 14-year average	21,38	23,60	23,36	19,69	15,64	10,14	6,24	4,34	5,13	7,99	11,85	16,17	13,79
İzmir 12-year average	23,92	26,72	26,24	23,54	19,23	14,03	9,31	6,61	7,88	10,87	15,34	18,94	16,88
Trabzon 14-year average	17,22	18,67	17,22	14,43	12,53	8,76	6,47	4,90	5,61	8,09	10,73	13,62	11,49
Van 13-year average	25,42	29,06	27,79	25,25	21,48	15,14	11,04	8,83	10,29	14,05	17,96	20,68	18,86

program were also checked and a voltmeter was used to confirm the accuracy of the data acquisition system. The radiation measurements at the SMS were also investigated. The METU pyranometers used in this study were placed next to the SMS's pyranometer at the location of the SMS. Data were collected for several hours. Results showed that the METU pyranometer used to measure global radiation gave readings 4.4% higher than the SMS pyranometer. It was concluded that there are two major factors that cause the significant difference in radiation measurements. First, the SMS is located in the center of Ankara while METU is located in a large open and slightly elevated area outside the city center. When the Ankara city center is viewed from METU on many days, a brown cloud is visible due to particulate pollution. Therefore the higher radiation measurements at METU are likely due to at least partially to differences in clearness index related with local pollution. Second, the SMS's pyranometer has a higher uncertainty than the pyranometer used in the METU station. Hence the data from the METU measurements are assumed to be more accurate than that from the SMS.

The variation of beam radiation throughout the year is shown in Fig. 3. Daily average beam radiation varied between 0 and 495 W/m^2. The maximum beam radiation value obtained was 1010 W/m^2 on May 17, 2008 between the hours 11-12. Relative to the global radiation data, the effect of cloudy days is seen more clearly. Fluctuations are more frequent and steeper. Fig. 4 shows the monthly average and maximum beam radiation. Monthly maximum beam radiation values undergo a small change and did not decrease more than 15% from the annual maximum value for any month. The maximum monthly average beam radiation is 402 W/m^2 for July 2008 and the minimum is 24 W/m^2 for February 2009. Unlike maximum beam radiation values, monthly average values showed variations similar to that for global radiation.

Monthly average daily beam radiation of Ankara is compared with several other large cities in Turkey in Table 2. 5-year averages are only listed since the SMS only started to collect reliable beam radiation data after 2004. Data for three large cities were taken from the archive of the SMS. Significant difference are seen between the METU and SMS stations due to similar reasons as mentioned above in the comparison of global radiation. The difference by percentage in beam radiation is greater than that of global radiation since beam radiation is more dependent on the location and sensitive to particulate pollution. Table 2 shows that for the period considered for the present work, Ankara received significantly higher beam solar radiation than the 5-year average. In general, Ankara has the highest monthly values of the cities considered.

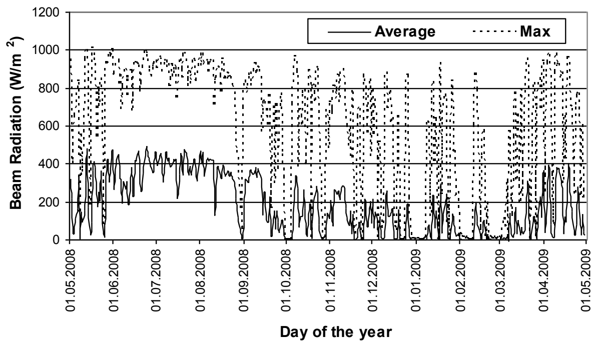

Fig. 3. Daily maximum and daily average beam radiation throughout the year.

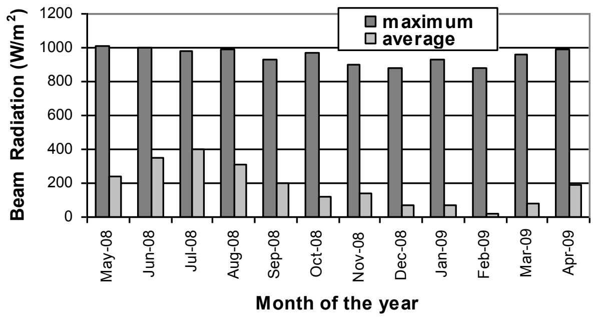

Fig. 4. Monthly maximum and monthly average beam radiation.

The variation of surface air temperature for Ankara is represented in Fig. 5. The daily average, maximum and minimum temperatures have been plotted during the measurement period. The plot shows that the maximum surface air temperature of 36.2 ^{o}C occurred on July 23, 2008 and the minimum value of -14.6 ^{o}C occurred on January 2, 2009. The maximum and minimum daily average temperatures were 28.9 ^{o}C and -8.8 ^{o}C on July 24, 2008 and January 2, 2009, respectively. The average temperature for the complete year was 11.4 ^{o}C.

Table 2. Monthly and annual average beam radiation for Ankara and other large cities in Turkey.

Stations	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Annual
Monthly and annual average beam radiation in MJ/m^2/day													
Ankara, METU May 08-Apr. 09	20,45	29,82	34,73	26,99	17,52	9,98	12,13	6,33	5,77	2,09	6,85	16,02	15,72
Ankara, SMS May 08-Feb. 09	15,38	25,41	29,36	25,37	15,58	12,99	9,38	5,03	5,01	4,13	6,65	13,72	14,00
Ankara 5-year average	15,56	15,75	23,64	20,20	16,31	9,80	6,55	5,18	3,92	5,44	8,17	11,60	11,84
Antalya 5-year average	12,78	12,72	13,56	10,29	12,55	11,39	9,33	9,38	8,69	8,08	10,46	11,05	10,86
İstanbul 5-year average	14,57	13,50	18,91	12,07	11,59	7,00	4,66	4,95	4,52	5,20	9,25	12,12	9,86

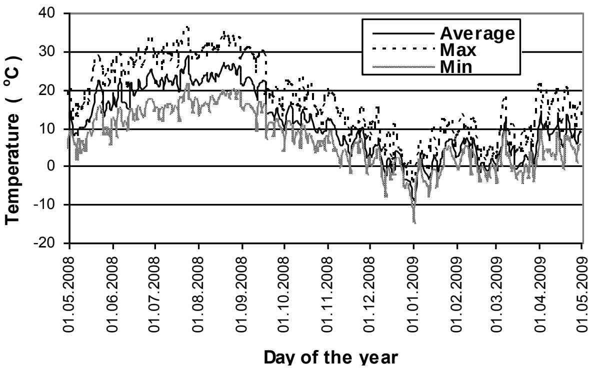

Fig. 5. Daily average, maximum and minimum temperatures during the one-year period.

Fig. 6 shows the monthly average, maximum and minimum temperatures for the measured data. The highest monthly average temperature was 24.4 ^{o}C in August and the minimum average temperature was 0.8 ^{o}C in December. It can be observed from Fig. 2 and Fig. 6 that surface air temperature usually increases with increasing global radiation. Temperatures measured are also compared with temperatures from the SMS and for several other cities in Table 3. Ankara has colder climatic conditions than most Turkish cities based on the annual average temperature. The reason for this is the very low temperatures in the winter season in spite of the high temperatures in the summer season. It can also be concluded that Ankara has a higher solar potential than some hotter cities when global radiation and temperatures are compared in Tables 1 and 3. This potential provides Ankara with competitive advantages for investment in solar applications.

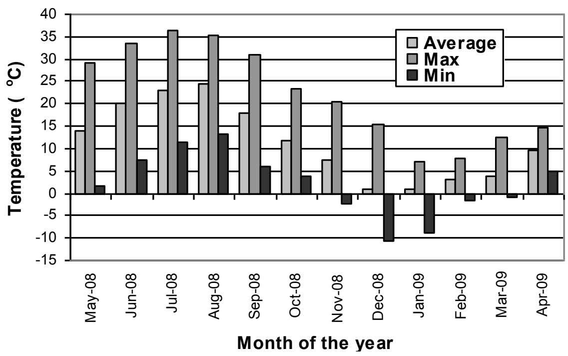

Fig. 6. Monthly average, maximum and minimum temperatures during the measurement period.

The variation of daily clearness index for the METU station throughout one year is shown in Fig. 7. The daily clearness index is defined as the ratio of daily total solar radiation (H) to daily total extraterrestrial radiation for the corresponding day (H_0) (Duffie and Beckman, 1991). The daily clearness index varied between 0.06 and 0.81. The minimum value was observed on March 2 and the maximum value on March 20. Large fluctuations can be seen from the figure like for global radiation. The fluctuations can be explained by clouds, especially in the winter. Consistent clear sky conditions were generally limited to summer days. Monthly clearness index values are presented in Fig. 8. The values 0.74 in July 2008 and 0.41 in February 2009 indicate the maximum and minimum monthly clearness indexes. Annual average clearness index was calculated as 0.58. The monthly and annual clearness indexes for several other cities in Turkey are tabulated and compared with Ankara stations in Table 4. It can be seen that the clearness index of Ankara during the summer months of 2008 is higher than that of the long-term averages of the other cities as is the case of global radiation. Furthermore, a significant increase in clear sky conditions for Ankara in the last year is shown when compared with the 14-year average of the city. Another important point is the difference between the two stations in Ankara. This significant difference results from large uncertainties in radiation measurements at the SMS station as mentioned above. The same difference as global radiation can be seen for clearness index because clearness index is a function of global radiation.

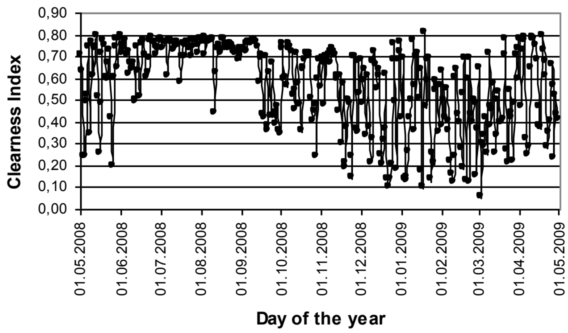

Fig. 7. Variation of daily average clearness index throughout the year.

Table 3. Monthly and annual average surface air temperatures for Ankara and other large cities in Turkey (^{o}C).

Stations	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Annual
Ankara, METU May 2008-Apr. 2009	13,9	20,1	22,9	24,4	17,9	11,6	7,4	0,8	1,0	2,9	3,8	9,6	11,4
Ankara, SMS May 2008-Feb. 2009	15,5	22,0	24,9	26,7	20,0	13,3	8,8	2,1	2,3	4,4	5,1	11,6	13,1
Ankara 11-year average	16,5	20,7	24,1	24,3	19,1	13,4	6,8	2,1	0,5	2,1	7,1	11,4	12,4
Antalya 14-year average	21,3	26,2	29,2	28,8	25,2	20,7	15,5	11,8	10,2	10,9	13,2	16,2	19,1
İstanbul 14-year average	17,2	22,0	24,7	24,6	20,5	15,9	11,6	8,1	6,2	6,4	8,3	12,3	14,8
İzmir 14-year average	21,3	26,3	28,7	28,2	23,7	19,1	14,1	10,6	9,1	9,6	12,1	15,9	18,2
Trabzon 14-year average	16,1	20,6	23,9	24,4	20,8	16,8	12,6	9,2	7,4	7,2	8,9	11,9	15,0
Van 14-year average	13,5	18,8	22,7	23,0	18,1	12,0	5,3	0,0	-2,3	-1,5	2,8	8,1	10,1

Table 4. Monthly and annual average clearness indexes for Ankara and other large cities in Turkey.

Stations	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Annual
Ankara, METU May 2008-Apr. 2009	0,60	0,70	0,74	0,74	0,62	0,61	0,55	0,48	0,46	0,41	0,45	0,56	0,58
Ankara, SMS May 2008-Feb. 2009	0,55	0,64	0,68	0,66	0,55	0,54	0,46	0,43	0,40	0,37	0,41	0,51	0,52
Ankara 14-year average	0,54	0,58	0,61	0,59	0,59	0,52	0,45	0,46	0,40	0,45	0,48	0,48	0,51
Antalya 14-year average	0,53	0,57	0,58	0,57	0,60	0,54	0,47	0,41	0,44	0,49	0,51	0,50	0,52
İstanbul 14-year average	0,53	0,57	0,57	0,53	0,52	0,43	0,37	0,53	0,36	0,38	0,43	0,45	0,47
İzmir 12-year average	0,59	0,64	0,64	0,62	0,63	0,58	0,50	0,40	0,45	0,49	0,53	0,52	0,55
Trabzon 14-year average	0,39	0,44	0,42	0,38	0,42	0,38	0,39	0,50	0,37	0,38	0,39	0,38	0,40
Van 13-year average	0,63	0,69	0,68	0,67	0,69	0,63	0,63	0,63	0,64	0,65	0,63	0,57	0,64

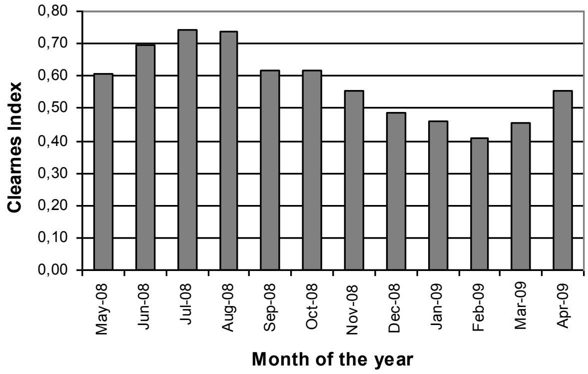

Fig. 8. Monthly average clearness index variation.

Clearness index and the amounts of global radiation support the fact that Ankara may make investments for solar applications especially for the summer season. The application may be electricity generation as well as cooling of dwellings or power plants.

CONCLUSIONS

Global radiation, beam radiation and surface air temperature measurements were made for a complete year during May 2008-May 2009 in the capital of Turkey, Ankara. The missing data, accounting for 5% of the whole database, were estimated by data filling methods. Correlation coefficient R^2=0.9615 and root mean square error *RMSE*=61.7 W/m^2 were obtained for the data filling estimation model. The maximum recorded global radiation was 1056 W/m^2 in May. The maximum daily and monthly average recorded global radiations were 383 and 348 W/m^2 in May and July, respectively. Annual average daily solar gain was 17.04 MJ/m^2/day. The maximum recorded beam radiation was 1010 W/m^2 in May. The maximum recorded surface air temperature was 36.2 ^{o}C on July 23, 2008 and the maximum daily average temperature was 28.9 ^{o}C on July 24, 2008. The daily clearness index varied between 0.06 and 0.81. The maximum and minimum monthly clearness indexes were 0.74 in July and 0.41 in February, respectively. Annual average clearness index was calculated as 0.58. Results were also compared with data of SMS in Ankara. The comparison of these two stations shows that an expanded and improved monitoring network is needed for accurately mapping the solar potential of Ankara. Hence, the solar potential of the city could be used more effectively.

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