Optimization of Tilt Angle for Solar Collectors: A Case Study for Bursa, Turkey

N. Arslanoglu

***Abstract*—**This paper deals with the optimum tilt angle for the solar collector in order to collect the maximum solar radiation. The optimum angle for tilted surfaces varying from 0° to 90° in steps of 1° was computed. In present study, a theoretical model is used to predict the global solar radiation on a tilted surface and to obtain the optimum tilt angle for a solar collector in Bursa, Turkey. Global solar energy radiation on the solar collector surface with an optimum tilt angle is calculated for specific periods. It is determined that the optimum slope angle varies between 0° (June) and 59° (December) throughout the year. In winter (December, January, and February) the tilt should be 55°, in spring (March, April, and May) 19.6°, in summer (June, July, and August) 5.6°, and in autumn (September, October, and November) 44.3°. The yearly average of this value was obtained to be 31.1° and this would be the optimum fixed slope throughout the year.

***Keywords*—**Optimum tilt angle, global solar radiation, tilted surface.

I. Introduction

THE performance of a solar collector is highly affected by its orientation and its angle of tilt with the horizontal. This is because both of these parameters vary the amount of solar radiation arriving the surface of the collector. In literature, some authors have found the optimum tilt angle as $\beta_{opt} = \varphi \pm 15°$ in the northern hemisphere [1]-[3]. However, Duffie and Beckman [4], recommended this value as (φ ±15◦) ± 15◦. They show "rules of thumb" to perform maximum annual energy availability, a surface tilt equal to latitude is the ideal and the surface should face the equator. It means a solar collector in southern hemisphere should face to the North with slope equal to its latitude to get maximum solar energy radiation.

Different suggestions have been made for the ideal slope angle depending on the latitude in literature [5], [6]. Chiou and El-Naggar [7], have performed the optimum slope angle in winter season as about ≈ 30◦ (βopt = φ + 10°). Elsayed [8] obtained the ideal slope angle and the surface azimuth angle for absorber plate containing using one and/or two glass covers. Yakup and Malik [9] calculated the ideal slope angle for Brunei Darussalam

Ulgen [10] obtained the ideal slope angle for a solar collector and the global solar energy radiation on a tilted surface in Izmir, Turkey. Benghanem [11] developed a methodology to obtain the ideal slope angle (βopt) for Madinah, Saudi Arabia. Gunerhan et al. [12] obtained the ideal orientation for solar collectors in Izmir is due south. They recommended that solar collector should be mounted at the monthly average slope angle and the slope adjusted once a month.

The aim of present paper is to obtain the optimum slope angle for a solar collector and the global solar energy radiation on a tilted surface in Bursa, Turkey. Global solar radiation on the solar collector with an optimum tilt angle is calculated for monthly, seasonal, and yearly.

Nurullah Arslanoglu is with the University of Uludag, Bursa, Turkey (phone: +90-224-2941994; e-mail: nurullaharslanoglu@ gmail.com).

II. Theoretical Analysis

The monthly average daily extraterrestrial radiation on a horizontal surface (Ho) can be calculated from [13]:

$$H_o = \frac{24\times3600G_{sc}}{\pi}\left[1 + 0.033\cos\left(\frac{360D}{365}\right)\right] \times \left[cos\varphi cos\delta sin w_s + \frac{2\pi w_s}{360} sin\varphi sin\delta\right] \quad (1)$$

where G_{sc} is the solar constant (1367 W/m^2), φ is the latitude of the site, δ is the solar declination, w_s is the mean sunrise hour angle for the given month and D is the number of days of the year, starting from first of January. The solar declination (δ) and the mean sunrise hour angle (w_s) can be computed by (2) and (3), respectively [13]:

$$\delta = 23.45 sin\left[\frac{360(D+284)}{365}\right] \quad (2)$$

$$w_s = \cos^{-1}[-\tan(\delta)\tan(\varphi)] \quad (3)$$

Global radiation collected on the plane of the tilted solar collector is the summation of direct, diffuse and ground-reflected radiations on the tilted collector as [13]

$$H_T = H\left(1 - \frac{H_d}{H}\right)R_b + H_d\left(\frac{1+cos\beta}{2}\right) + H\rho\left(\frac{1-cos\beta}{2}\right) \quad (4)$$

H is the monthly average daily solar radiation on a horizontal surface, β the tilt of the surface from horizontal, and ρ (=0.2) the ground reflectance. H_d is the monthly average daily diffuse radiation and is defined by Page [14]

$$\frac{H_d}{H} = 1 - 1.13K_T \quad (5)$$

where $K_T \left(= \frac{H}{H_0}\right)$ is the monthly average daily clearness index

Liu and Jordan [15] have recommended that R_b can be predicted by assuming that it has the value which would be determined if there were no atmosphere. For surfaces facing directly towards the equator, the equation for R_b is defined as below and it is used in this paper.

International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:10, No:5, 2016

$$R_b = \frac{cos(\phi-\beta)cos\delta sin w_s' + \left(\frac{\pi}{180}\right) w_s' \sin(\phi-\beta)\sin\delta}{cos\phi cos\delta sin w_s + \left(\frac{\pi}{180}\right) w_s \sin\phi \sin\delta} \quad (6)$$

where w_s' is the sunset hour angle for the tilted surface expressed by [13]

$$w_s' = min\begin{bmatrix} cos^{-1}(-tan\phi tan\delta \\ cos^{-1}(-\tan(\phi-\beta)tan\delta \end{bmatrix} \quad (7)$$

III. Results and Discussions

For Bursa station, the monthly average daily global radiation values on a horizontal surface used in this paper were obtained from Turkish State Meteorological Service in the periods between 1967 and 2015. Using (1)-(7), global solar radiation arriving on tilted surface was calculated for different slope angles (0° to 90°) for each month of the year for Bursa. The monthly-average daily solar radiation values for extraterrestrial, global, and diffuse solar radiation on a horizontal surface for Bursa, Turkey are shown in Table I and Fig. 1.

TABLE I
Monthly-Average Daily Solar Radiation Values of H_O, H, H_D for Bursa, Turkey

Months	H_0 (MJ/m^{2}day)	H (MJ/m^{2}day)	H_D (MJ/m^{2}day)
Jan	15.142	5.522	3.246
Feb.	20.433	7.47	4.385
Mar.	27.391	10.773	5.985
Apr.	34.582	14.229	7.613
May.	39.689	18.037	8.774
June	41.767	20.409	9.139
July	40.671	20.484	8.826
Aug.	36.534	18.246	7.948
Sep.	29.931	14.597	6.552
Oct.	22.460	9.665	4.965
Nov.	16.370	6.414	3.574
Dec.	13.677	4.723	2.880

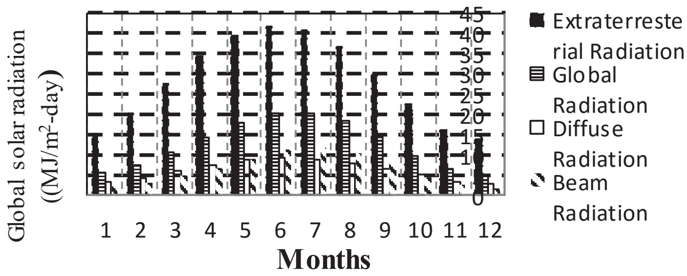
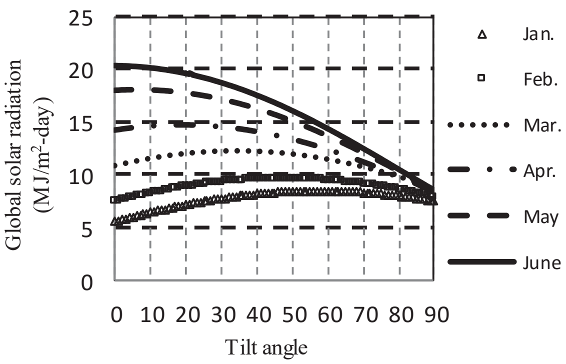
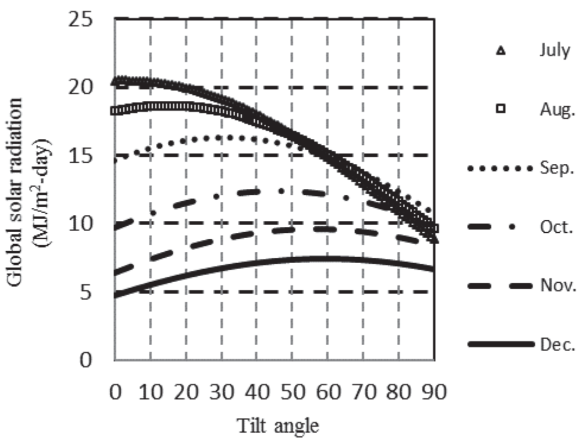


Fig. 1 Monthly-average daily extraterrestrial, global, beam and diffuse solar radiation on horizontal surfaces in Bursa, Turkey

Fig. 2 shows the monthly average daily global solar energy for different tilt angles. It is clear from the figures that a unique ideal slope angle exists for each month of the year for which the solar energy radiation is at a peak for the given month.



(a) January- June



(b) July-December

Fig. 2 Daily global solar radiation (H_T) on tilted surface for different slope changing from 0° to 90°

Table II shows that the optimum tilt angle varies between 0◦ (June) and 59◦ (December) throughout the year.

TABLE II
OPTIMUM TILT ANGLE (B_{OPT}) AND GLOBAL SOLAR RADIATION ON A TILTED SURFACE (H_{OPT}) FOR EACH MONTH OF THE YEAR IN BURSA, TURKEY

Months	β_{opt} (o)	H_{opt} (MJ/m^{2}day)	Months	β_{opt} (o)	H_{opt} (MJ/m^{2}day)
Jan	58	8.44	July	2	20.49
Feb.	48	9.66	Aug.	15	18.65
Mar.	34	12.19	Sep.	31	16.27
Apr.	19	14.72	Oct.	46	12.39
May.	6	18.09	Nov.	56	9.63
June	0	20.40	Dec.	59	7.44

TABLE III
SEASONAL AND YEARLY AVERAGE OPTIMUM TILT ANGLE AND MONTHLY-AVERAGE DAILY SOLAR RADIATION ON A TILTED SOUTH-FACING SURFACE IN BURSA

Months	Seasons	Seasonal average		Yearly average	
		β_{opt} (o)	H_{opt} (MJ/m^{2}day)	β_{opt} (o)	H_{opt} (MJ/m^{2}day)
Dec.			7.42		6.77
Jan	Winter	55	8.43		7.77
Feb.			9.60		9.38
“Mar.			11.92		12.18
Apr.	Spring	19.6	14.72		14.51
May.			17.81	31.1	17.11
June			20.33		18.67
July	Summer	5.6	20.47		19.04
Aug.			18.49		18.18
Sep.			15.97		16.27
Oct.	Autumn	44.3	12.38		12.09
Nov.			9.47		8.94

Table III and Fig. 3 show the tilt angle for each month, the seasonal average, and the yearly average. The seasonal average was computed by finding the average value of the slope angle for each season and the implementation of this requires the collector slope to be varied four times a year. In spring the slope should be 19.6^o, in summer 5.6^o, in autumn 44.3 ^{o} and in winter 55^o. The yearly average tilt was computed by finding the average value of the slope angles for every months of the year. The yearly average tilt was determined to be 31.1^o and this result indicates an ideal fixed tilt throughout the year.

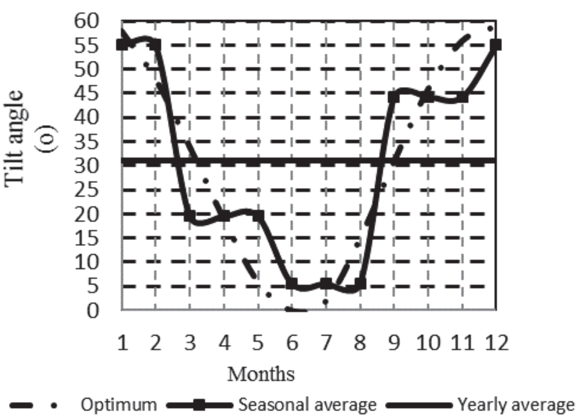


Fig. 3 Optimum, seasonal average, and yearly average tilt angles for each month of the year

Fig. 4 shows the global solar radiation received when the tilt angle is optimum, and when the seasonal and yearly average angles are used.

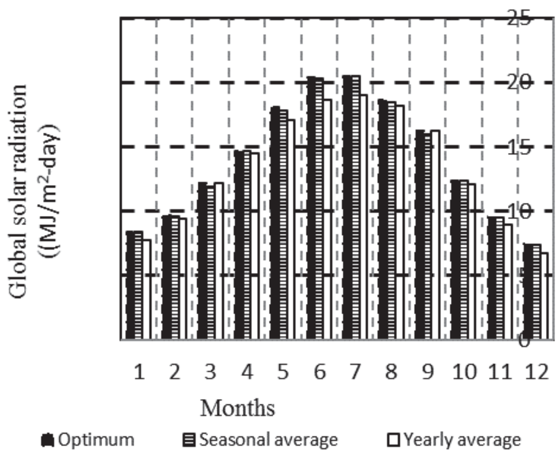


Fig. 4 Total solar energy radiation for optimum, seasonal, and yearly slope angles in Bursa

IV. CONCLUSION

According to the above results, the following conclusions can be drawn:

- The optimum tilt angle in June reaches to a minimum of 0 ^{o} and the monthly-average daily global radiation at this slope is 20.40 MJ/m^2 day.
- The ideal slope angles increased during the winter season and reached a maximum in December.
- The results perform that the average optimum slope angle for the summer season is 5.6° and for the winter season 55°.
- The yearly-average optimum tilt angle determined to be 31.1° for a south-facing solar collector.
- When the monthly ideal tilt angle was used, the yearly received solar energy was 5051.1 MJ/m^2- year.
- When the seasonal average tilt angle was used, the yearly received solar radiation was 5010.3 MJ/m^2- year.
- When the yearly average tilt angle was used, the yearly received solar radiation was 4827.3 MJ/m^2- year.
- It is clear that the amount of received solar radiation for Bursa was generally in order of optimum, seasonally and yearly average.

ACKNOWLEDGMENT

The author thanks the Turkish State Meteorological Service for providing the solar radiation, the bright sunshine and air temperature data.

REFERENCES

[1] H, Heywood, “Operational experience with solar water heating,” *J. Inst. Heat Vent Energy, 1971, Vol. 39, pp.63-69*
[2] P.J, Lunde, P. J. 1980. *Solar Thermal Engineering*. New York: Wiley.
[3] H. P, Garg, 1982. *Treatise on Solar Energy: Volume 1: Fundamentals of Solar Energy*. New York: Wiley.

[4] J. A, Duffie, and W. A. Beckman, 1991. *Solar Engineering of Thermal Processes*. New York: Wiley.
[5] J, Kern, and L, Harris, "On the optimum tilt of a solar collector." *Solar Energy,* 1975, Vol. 17, pp. 97–102.
[6] M, Iqbal, "Optimum collector slope for residential heating in adverse climates," *Solar Energy,* 1979, pp. 22:77.
[7] J. P, Chiou, and M. M, El-Naggar, "Optimum slope for solar insolation on flat surface tilted toward the equator in heating season," *Solar Energy,* 1986, Vol. 36, pp. 471–478.
[8] M.M, Elsayed, "Optimum orientation of absorber plates," *Solar Energy,* 1989, Vol. 42, pp. 89–102.
[9] M.A bin H.M, Yakup, and A.Q, Malik, "Optimum tilt angle and orientation for solar collector in Brunei Darussalam," *Renewable Energy, 2001, Vol.* 24, pp. 223–234.
[10] K, Ulgen. "Optimum Tilt Angle for Solar Collectors," *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 2006, Vol.28, pp. 1171-1180.
[11] M. Benghanem," Optimization of tilt angle for solar panel: Case study for Madinah, Saudi Arabia," *Applied Energy*, 2011, Vol. 88, pp. 1427-1433.
[12] H, Gunerhan and A, Hepbasli, "Determination of the Optimum Tilt Angle of Solar Collectors for Building Applications." *Building and Environment.* 2007, Vol. 42, pp.779 – 783.
[13] A, Yigit, I, Atmaca, 2010 Solar Energy (Güneş Enerjisi).: Alfa-Aktüel Yayınları; (in Turkish). Bursa, Turkey.
[14] J.K, Page, "The estimation of monthly mean values of daily total short-wave radiation on vertical and inclined surfaces from sunshine records for latitudes40_N–40_S," In: Proceedings of UN conference on new sources of energy, vol. 4, August 21–31, Rome, Italy, United Nations, Paper No. 598; 1961. p. 378–90.
[15] B.Y.H, Liu, R.C. Jordan, "The relationship and characteristics distribution of direct diffuse and total radiation," *Solar Energy*, 1960; Vol. 4, pp.1–19.