20th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2016, Mediterranean Sea Cruising, 24th September - 1st October, 2016

IMPORTANCE OF TILT ANGLE ON FLAT-PLATE SOLAR THERMAL COLLECTOR SYSTEMS FOR ANTALYA DISTRICTS

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ABSTRACT
Solar is an important energy source for the environment and energy production. One of the most important parameters that affect the performance of a solar collector is its tilt angle with the horizontal. The variation of tilt angle affects the amount of solar radiation reaching the collector surface. In this study, the optimum tilt angle for the south-facing single axis solar collector has been determined in order to maximize the system performance. The results show that the optimum tilt angle changed between 1° (June) and 65° (December) throughout year in districts of Antalya, Turkey.
Keywords: Solar energy, Antalya districts, Tilt angle

1. INTRODUCTION
Solar energy is used for variety of heating systems such as domestic hot water systems and industrial applications. The use of solar energy for domestic hot water and steam generation in industry is economical and environmentally friendly [1]. By utilizing maximum solar energy through the optimum tilt, we are able to harness the energy needed without polluting our environment. The studies on the new and renewable energy sources have gained speed and are encouraged due to the fact that energy resources used today run out rapidly and cause environmental pollution [2]. Tiris et al. [3] calculated the correlations of the monthly average daily global, diffuse and beam radiations with hours of bright sunshine in Gebze, Turkey. Bakirci [4] developed the correlations for estimation of daily global solar radiation with hours of bright sunshine in Turkey. Zuhairy and Sayigh [5] carried out simulation and modeling of solar radiation in Saudi Arabia. Ulgen and Hepbasli [6] investigated the diffuse fraction of daily and monthly global radiation for Izmir, Turkey. Vişa, Ion, et al presents the modeling of the sun-ray unit vector and of a solar panel normal unit vector in the reference system of an observer from Earth [7].
The performance of a solar collector is highly influenced by its orientation and its angle of tilt with the horizon. This is due to the fact that both the orientation and tilt angle change the solar radiation reaching the surface of the collector. In this study, the optimum tilt angle for flat plate solar collector has been determined in order to maximize the system performance in districts of Antalya, Turkey.

2. THEORETICAL ANALYSIS
The monthly average values of solar radiation incident on surfaces of various orientations are required for solar energy applications. The monthly averages of the daily solar radiation incident upon a horizontal surface are available for many locations. However, radiation data on tilted surfaces are

generally not available. A simple method to estimate the average daily radiation for each calendar month on surfaces facing directly towards the equator has been developed by Liu and Jordan [8].
The earth's axis is tilted approximately 23.45° with respect to the earth's orbit around the sun. As the earth moves around the sun, the axis is fixed if viewed from space. The declination of the sun is the angle between a plane perpendicular to a line between the earth and the sun and the earth's axis. An approximate formula for the declination of the sun is given as follows [9],

$$\delta = 23.45 \sin\left[(284+n)\frac{360}{365}\right] \qquad \ldots\ldots (1)$$

where n is the number of the day of year starting from the first of January (n=1 on January 1st and n=365 on December 31st , February 29th is ignored).
Sunrise and sunset occur when the sun is at the horizon and hence the cosine of the zenith angle is zero. Setting the cosine of the zenith angle to zero in the relation, we get the following equation,

$$\omega = \cos^{-1}(-\tan\phi\tan\delta) \qquad \ldots\ldots (2)$$

The monthly average daily radiation on a horizontal surface (H), the fraction of the mean daily extraterrestrial radiation (H0), the monthly average daily diffuse radiation (HD),

$$H_0 = \frac{24}{\pi} G_{sc}(1+0.033\cos(\frac{360n}{365})(\cos\phi\cos\delta\sin\omega + \frac{\pi\omega}{180}\sin\phi\sin\delta) \qquad \ldots\ldots (3)$$

where G_{sc} is the solar constant (1367 W/m^2), is the latitude of the Antalya.
Solar radiation incident outside the earth's atmosphere is called extraterrestrial radiation. On average the extraterrestrial irradiance is 1367 W/m^2. The monthly average daily solar radiation on tilted surface (HT), may be expressed as follow (Liu and Jordan, 1960) [8],

$$H_T = (H - H_D)R_b + \frac{H_D}{2}(1+\cos\beta) + \frac{H\rho}{2}(1-\cos\beta) \qquad \ldots\ldots (4)$$

where ρ is ground reflectance (≈0.2).

3. METHODOLOGY

The equations which calculate total solar radiation falling on tilted surface for optimum tilt angle the monthly and the annually are solved with a computer code which is written in Visual Studio 2012 and should be modular to allow users to update component modules easily as new findings become available. The calculations begin with measured hourly global and diffuse radiation received on a horizontal surface. These quantities are then transposed onto an inclined plane by a mathematical procedure. The optimum tilt angle was computed by searching for the values for which the total radiation on the collector surface is a maximum for a particular day or a specific period. In this regard, the calculations were made for a south facing solar collector for 365 days. The tilt angle is changed from 0° to 90°. The solar reflectivity (ρ) was assumed to be 0.2. The βopt obtained for a specific period allows us to collect the maximum solar energy for Antalya, Turkey.

4. RESULT AND DISCUSSION

The main aim of this study is to determine and analyze the optimum tilt angle for solar collectors in districts of Antalya, which is located in the southern part of Turkey and is the seventh biggest city in the country by population which is a main touristic attraction point by the south coast facing the Mediterranean.
Turkey lies in a sunny belt between 36° and 42°N latitudes and is geographically well situated with respect to solar energy potential. Turkey's yearly average total sunshine duration is 2640 h and the yearly average solar radiation is 1311 kWh/m^2 yr (3.6kWh/m^2 day) [11].
Table 1 show optimum tilt angles and Table 2 show calculated solar radiation on tilted surface for optimum tilt angles. The optimum angle of tilt of a flat-plate collector in January is 63° and the total monthly solar irradiation falling on the collector surface at this tilt is 529.11 MJ/m^2-month. The optimum tilt angle in July is 1° and the total monthly solar radiation at this angle is 701.05 MJ/m^2-month. The optimum tilt angle increases during the winter months and reaches a maximum of 65° in December which collects 517.75 MJ/m^2-month of solar energy.

Table 1. Monthly and annually optimum tilt angles

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly	63	54	39	21	5	1	1	15	33	50	61	65
Annually	33											

Table 2. Solar radiations on tilted surface for optimum tilt angles (MJ)

Months	**January**	**February**	**March**	**April**	**May**	**June**
Monthly	529,11	503,55	589,77	614,37	687,87	694,99
Annually	467,77	474,94	587,05	603,91	633,07	610,15
	July	**August**	**September**	**October**	**November**	**December**
Monthly	701,05	647,92	577,99	562,17	516,12	517,75
Annually	629,37	623,85	577,99	542,56	464,22	447,27
	Total					
Monthly	**7142,66**					
Annually	**6662,16**					

Fig 1 shows the average annually total radiation on a south facing surface on optimum tilt angle. The yearly average tilt was calculated by finding the average value of the tilt angles for all months of the year. The yearly-average optimum tilt angle was found to be 33° and the yearly collected solar energy was 6662.16 MJ/m^2-year for a south facing solar collector which nearly corresponding to the latitude of Antalya (36.89°).

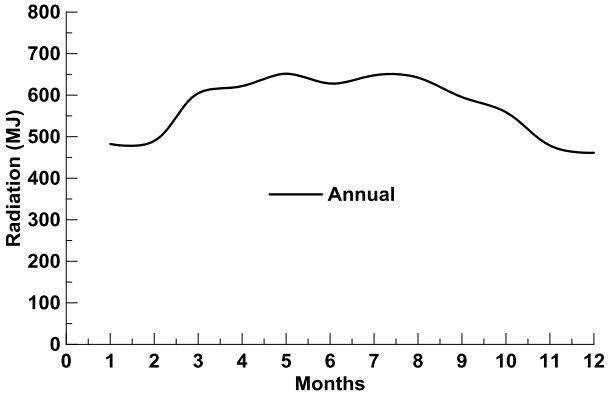

Fig 1. Annually average solar radiation availability of tilted surfaces.

Geographical data of some Antalya Districts are given in Table 3 and difference of optimum tilt angle between Antalya. Maximum and minimum altitudes are Kaş (125 m) and Finike (7) district, respectively. Among districts difference is small and it is negligible.

Table 3. Geographical data of some Antalya Districts

Districts	Altitude (m)	Latitude	Longitude
Kaş	125	36,1962421	29,6357506
Gazipaşa	20	36,268362	32,309776
Finike	7	36,2901844	30,1384521
Kumluca	29	36,3656005	30,2805447
Alanya	18	36,5456758	32,0056746
Kemer	10	36,5970148	30,5630274
Manavgat	9	36,7830179	31,4423215

5. CONCLUSION

The optimum tilt angle is different for each month of the year. The collected solar energy will be greater if we choose the optimum tilt angle for each month. Also it has been found that the optimum tilt angle in June and July becomes 1°. The optimum tilt angle then increases during the winter months and reaches a maximum of 65° in December. The results show that the average optimum tilt angle for the summer months is 4° and for the winter months 61°. Finally, the yearly-average optimum tilt angle found to be 33° and the yearly collected solar energy was 6662.16 MJ/m^2-year for a south facing solar collector which nearly corresponding to the latitude of Antalya (36.89°). This is in agreement with the results of many other researchers. Among districts difference is small and it is negligible.

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