Determination of Optimum Fixed and Adjustable Tilt Angles for Solar Collectors by Using Typical Meteorological Year data for Turkey

Yohannes Berhane Gebremedhen*‡

*Department of Agricultural Machinery Ankara University, Turkey

(yohannesq@yahoo.com)

‡ Corresponding Author; Yohannes Berhane Gebremedhen, yohannesq@yahoo.com

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Abstract: In this paper the possible optimum fixed and adjustable tilt angles for solar collectors are determined by using Typical Meteorology Year data set for nine main provinces of Turkey. The tilt angle types considered in this paper are monthly adjustment, seasonal adjustment (four times a year), semi annual adjustments (twice a year), optimum fixed tilt angle and an angle equals to the latitude of the area. As a result of this paper it has been observed that up to 6.9 % more solar radiation can be collected by using a monthly adjustment of collectors in comparison with tilt angles equals with the latitude of the area. The optimum angles have been found to range from a minimum of 2° for June up to a maximum of 57° for December for monthly adjustment, the seasonal adjustment angles found to be between 9° and 48°, the semi annual angles are from 18° to 28° and the fixed angles for the provinces are found to be between 13 to 18 degrees less than the latitude of the areas.

Key words: Solar radiation, Tilt angle, Typical Meteorological Year, Optimum, latitude,

1. Introduction

In this paper, fixed and adjustable optimum tilt angles with their corresponding energy to be collected for solar collectors for nine main provinces of Turkey have been determined.

The twenty-first century is forming into the perfect energy storm. Rising energy prices, diminishing energy availability and security, and growing environmental concerns are quickly changing the global energy panorama. Finding sufficient supplies of clean and sustainable energy for the future is the global society's most daunting challenge for the twenty-first century [8]. As a result, solar energy becomes one of the most important renewable energy sources that have been gaining increased attention in recent years. Solar energy is plentiful; it has the greatest availability compared to other energy sources. The amount of energy supplied to the earth in one day by the sun is sufficient to power the total energy needs of the earth for one year [2]. But the two main problems of solar energy are its intermittent nature and low efficiency of solar collecting panels. Solar tracking is one of the systems being used to maximize the amount of radiation falling on solar collectors. Reference [6] has suggested that tracking systems are expensive and are not easily applicable always. Application of optimum tilt angle is one alternative to improve the solar collector performances if solar tracking is not appropriate. Incident solar radiation falling on a solar collector can be maximized by using an optimum tilt angle [3]. As given in [5] for a 15° change in a tilt angle of a solar collector from the optimum tilt angle, there will be a reduction of an incident radiation by around 5 %. The fixed, monthly adjustable and seasonal adjustable optimum tilt angles of solar collectors are different for different locations [6, 9]. Reference [1] has determined a formula for optimum inclined of flat plate collector as a function of latitude and local climate data. Reference [6] has suggested that the annual based optimum tilt is approximately equals to latitude of the location. Optimum tilt angles ranges from latitude up to latitude plus 20 for collectors operating with sufficient high solar fraction [4]. Reference [5] has given two different angles for summer and winter that, for summer the optimum tilt angle should be 10 to 15 degrees less than the latitude and for winter tilt angles should be 10 to 15 degrees more than the latitude. In winter the optimum tilt angle is latitude plus 15 and in summer latitude minus 15 [3].

It has been identified in reference [3] that the tilt angle based on the latitude of the area is not accurate for all places that proper analysis has to be done prior to installation of stationary solar collectors; if not there will be system oversizing and high cost specially in PV solar power plants.

In this paper the possible optimum angles of tilt for solar collectors are determined by using hourly beam and diffuse radiation data from Typical Meteorological Year data set (TMY). TMY data is designed for use in simulation software that computes the outputs of a solar energy system. The TMY is derived from hourly time series covering all range of meteorological data. [7].

To determine the tilt angles, a Matlab Graphical User Interface program has been developed. In addition to the optimum tilt angle the corresponding monthly and annual total solar radiations to be collected on a meter square of collector area was determined.

Table 1. Provinces of Turkey considered with latitude and longitude in degrees

Provinces	Latitude	Longitude
Ankara	39.95	32.88
Antalya	36.88	30.70
Çannakale	40.13	26.40
Hakkari	37.57	43.70
Istanbul	40.97	28.82
Izmir	38.50	30.45
Konya	38.97	32.55
Muğla	37.20	28.35
Trabzon	41.00	39.72

The first step in quantifying solar radiation is to calculate the different angles of the sun earth and collector relationships. The solar angle relationship and radiation calculation formulas given in [5] have been used throughout this paper. The latitude angle of the areas in TMY data are given in degrees and minutes as a result it must be changed in to degrees as shown in equation 1; where Φ_1 and Φ_2 are degree and minute parts of the latitude angle given in TMY data set.

$$\Phi = \Phi_1 + \frac{\Phi_2}{60} \quad (1)$$

Where Φ is the latitude in degrees

The equation of time, E, and the standard meridian, L_{std}, are calculated as in equations 2 to 4 below.

$$E=229.2 \times (0.000075 + 0.001868 \times \cos(B) - 0.032077 \times \sin(B) - 0.014615 \times \cos(2 \times B) -0.04089 \times \sin(2 \times B) \quad (2)$$

$$\text{Where } B = \frac{360}{365}(n -1), \text{ n is the day of the year} \quad (3)$$

$$L_{std} = (\text{Time zone of the area}) \times 15 \quad (4)$$

The hours of the day given in the TMY data are the local times but the solar angles must be calculated using the solar hours. As a result the solar hours must be calculated as follows; where L_{loca} is the local longitude of the area.

$$\text{Solar time} = ((1/60) \times (4 \times (L_{std} - L_{loca}) + E) + \text{Standard time}) \quad (5)$$

Now, the angle of declination (б) and the hour angles (w) can be calculated as shown in equations 6 and 7 respectively.

$$б = (57.3) \times \; 0{,}006918 - 0{,}399912 \times \cos(B)) + (0{,}070257 \times \sin(B)) - (0.006758 \times \cos(2 \times B)) + (0.000907 \times \sin(2 \times B)) - (0.002697 \times \cos(3 \times B)) + (0.00148 \times \sin(3 \times B))) \quad (6)$$

$$w = (\text{Solar time} - 12) \times 15 \quad (7)$$

Taking ß = 1 to 90 with an increase of unity, the angle of incidence (∅) has been calculated as shown in equation 8 below.

$$\emptyset = \cos{-1}(\sin\delta \sin(\Phi - \beta) + \cos\delta \cos(\Phi - \beta) \cos w) \quad (8)$$

Finally having all the angles determined, the total radiation, I falling on a stationery tilted solar collector can be calculated as:

$$I = I_b \times (\cos(\theta)) + \; I_d \times (1 + \cos(\beta))/2 \quad (9)$$

Where, I_b and I_d are beam and diffused radiation of the sun.

Following the determination of the radiation amount falling on the collector, the tilt angles that yield maximum radiation have been selected. The single optimum tilt angle was selected based on the the maximum total annual radiation. The semi annual adjustable collector tilt angles are also selected for maximum radiation for each half of the year. Like wise the seasonal optimum tilt angles that maximizes the total radiation that can be collected for each season of the year has been selected. Finally the optimum angles that maximize the monthly radiation amount are selected for monthly adjustable angles.

The general flow char of the the written Matlab program for the computation of the fixed and adjustable tilt angles is given in Figure 1 below.

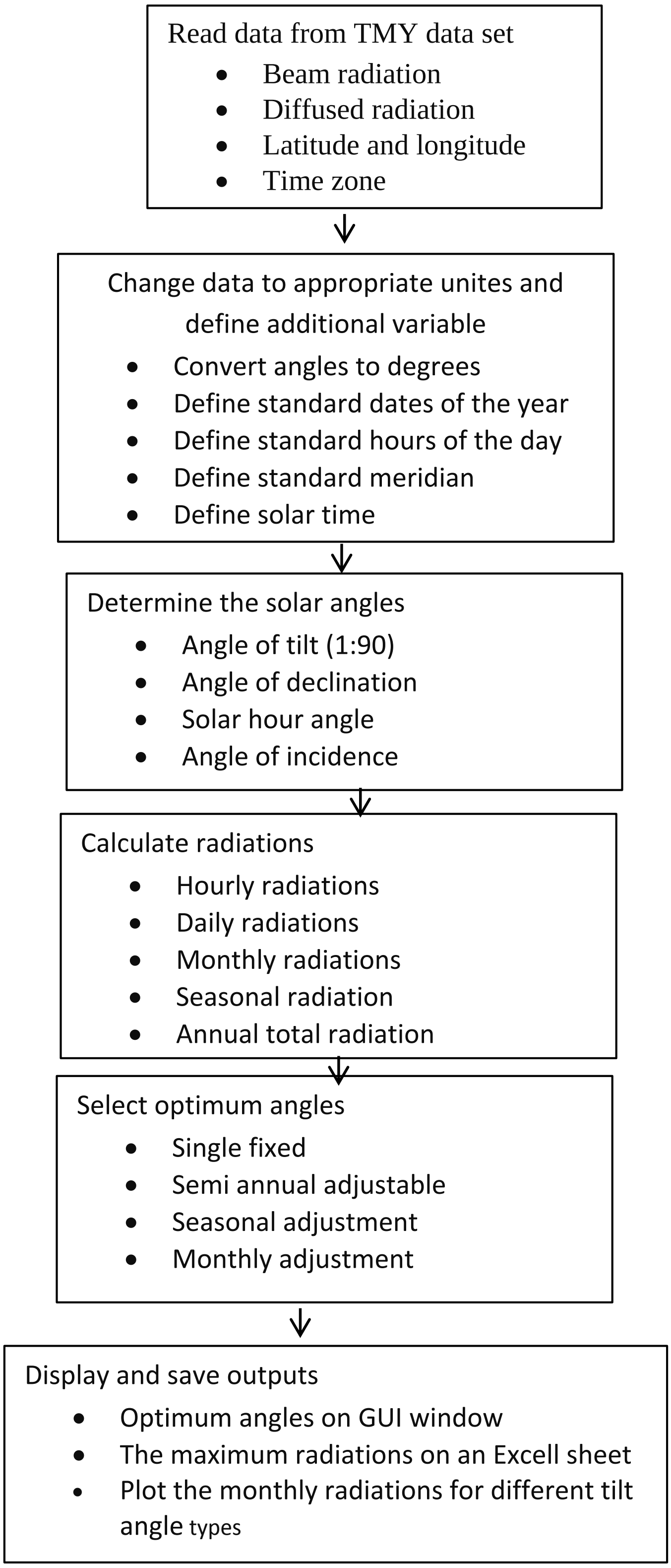

Figure 1. Flow char of the the Matlab program for optimum tilt angle determination

2. Result and Discussion

The optimum tilt angles determined for monthly, seasonal, semi annual adjustments and optimum fixed angles of each area is given in Table 2 below.

Table 2. Optimum Monthly, Seasonal, Semi annual adjustment and fixed angles (degrees)

	Ankara	Antalya	Çannakale	Hakkarı	Istanbul	Izmir	Konya	Muğla	Trabzon
January	53	52	51	51	51	48	51	52	55
February	43	42	43	43	43	46	46	45	44
March	32	31	31	25	25	30	31	32	32
April	21	19	19	18	18	17	19	18	17
May	10	8	11	8	8	11	9	8	8
June	5	2	6	3	3	6	4	2	5
July	8	4	8	6	6	9	7	6	7
August	18	15	17	15	15	18	17	15	15
September	31	28	30	28	28	30	29	28	26
October	44	40	42	40	40	42	42	42	40
November	52	51	51	53	53	50	54	51	51
December	51	55	53	54	54	52	56	52	57
Season - 1	41	40	40	39	39	39	41	41	43
Season - 2	11	9	11	9	11	9	10	9	9
Season - 3	18	15	17	16	18	15	17	16	15
Season - 4	48	47	47	47	47	46	49	47	48
1st- half	21	20	20	18	20	19	21	20	22
2nd - half	28	27	27	26	27	26	28	26	28
Single fixed	24	24	24	22	23	23	25	23	25

The corresponding amount of energy to be collected for the different methods of tilt angles, for each month of the year per meter square of solar collector surface area for Antalya for example is as shown in Figure 2 below.

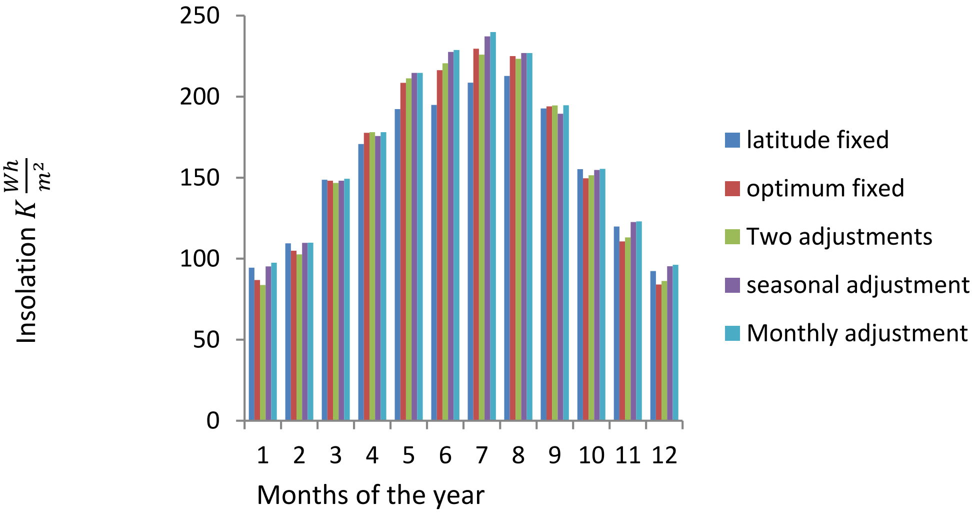

Figure 2. Monthly isolation, (kWh/m^2) for the different collector tilt angles (Antalya)

The total amount of energy per annum that falls on a meter square area of solar collector for the different types of collector tilt angles is given in Table 3 below. As one can expect, the maximum energy can be obtained by monthly adjustment of the tilt angle plus the minimum is for fixed latitude angles.

It can be seen from Table 3, among the areas of Turkey considered in this paper, a maximum of 6.9 % increase in energy can be obtained by monthly adjustments of optimum tilt angles of a solar collector in and around Istanbul when we compared it with an angle of tilt equals to the latitude of the area. Further 3.8 % more energy can be achieved by using an optimum tilt angle of 23° in place of the latitude angle. 4 % more energy by adjusting the tilt angles twice a year and 6.3 more energy by implementing seasonal tilt angle adjustments can be collected in Istanbul.

Table 3. Annual solar energy, (kWh/m^2) for different collector tilt angles

	latitude fixed	optimum fixed	Semi-annual adjustment	Seasonal adjustment	Monthly adjustment
Ankara	1888.6	1875.1	1829.1	1826.3	1773.1
Antalya	2014.5	1997.3	1938.0	1935.5	1892.3
Çannakale	1839.6	1828.2	1786.3	1784.1	1726.9
Hakkarı	1845.5	1830.1	1781.5	1778.0	1728.1
İstanbul	1777.4	1767.7	1729.8	1726.9	1663.2
Izmir	1781.5	1768.9	1723.4	1721.1	1674.0
Konya	1977.1	1962.1	1904.9	1901.6	1854.6
Muğla	1981.8	1967.4	1909.6	1907.5	1862.9
Trabzon	1472.9	1464.0	1420.8	1419.4	1378.5

The optimum tilt angles range from near horizontal (minimum of 2° for Antalya and Muğla) during the hot season up to a maximum angle of greater than 50° for all of the places, (55° for Antalya and 57° for Trabzon for example).

Again, a minimum of 9° for the months of April to June and a maximum of 47° for the months of October to December are the optimum angles for seasonal adjustments for Antalya. A 20° and 27° are also the angles for each half of the year for two adjustments per year. The fixed angles for the provinces are found to be between 13 and 18 degrees less than the latitude of the areas.

3. Conclusion

Installation of solar collectors with optimum fixed tilt angles has a significant advantage in energy gain for turkey. More Significant energy gain can also be harvested by making timely adjustments of angles of tilt. The more number of the adjustments per year the better are the energy benefits.

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