ACTA TECHNICA CORVINIENSIS – Bulletin of Engineering
Tome VI (Year 2013) – FASCICULE 4 [October–December]
ISSN 2067–3809

[1.] Irina PETROVA PAVLOVA

SOLAR POTENTIAL AT AN OPTIMUM ANGLE OF PLANE INCLINATION FOR THE CITY OF VARNA

[1.] DEPARTMENT OF HEAT ENGINEERING TU-VARNA, 9010, №1 STUDENTSKA STR., BULGARIA

ABSTRACT: The ever growing interest in the utilization of solar energy as an accessible, renewable, environmentally-friendly and easily-manageable type of energy makes it a prospective branch of power engineering. The paper presents data about the potential solar energy which the city of Varna receives at an optimum angle of plane inclination. The results are obtained on the basis of a methodology developed for the purposes of calculating the solar energy received. The experimental values of the total solar radiation on a horizontal plane observed within a year at a certain geographic location, namely the Technical University of Varna, serve as an output.
KEYWORDS: solar radiation, solar panel optimum inclination

INTRODUCTION

The ever growing interest in the utilization of solar energy as an accessible, renewable, environmentally-friendly and easily-manageable type of energy makes it a prospective branch of power engineering.

The utilization of the maximum possible amount of total solar radiation reaching a certain surface depends on the azimuth angle and its inclination in relation to a horizontal plane. The empirical data about the solar radiation intensity reaching the horizontal surface under discussion within the year 2011 makes it possible to determine the solar potential at an optimum angle of an inclined surface. The empirical data concern the region of the Technical University of Varna with geographical coordinates 43°13.3858'N, 27°56.3065'E registered with a LI-COR 200 pyranometer mounted on an NRG Now System 34 m meteorological mast.

The maximum solar energy utilized at the inclined surface in the region under discussion is determined by the constituents obtained by means of the methodology developed in [1] in the following steps:

- Calculation of direct solar radiation on a horizontal and an inclined surface;

$$I_b = I - I_d, \quad (1)$$

$$I_{b,\beta} = R_b * I_b. \quad (2)$$

- Calculation of the solar radiation emitted on a horizontal and an inclined surface;

The diffuse solar radiation on a horizontal surface (I_d) is defined through the method of Reindl et al - 2 [2].

$$I_d = k_t * I, \quad (3)$$

$$I_{d,\beta} = R_d * I_d. \quad (4)$$

- Calculation of the reflecting solar radiation;

$$I_{ref} = I * R_r. \quad (5)$$

- Determination of the total solar radiation on an inclined surface.

$$I_\beta = I_{b,\beta} + I_{d,\beta} + I_r, \quad (6)$$

where:

I - the intensity of global radiation on a horizontal surface, W/m^2;

I_b - the intensity of direct solar radiation on a horizontal surface, W/m^2;

I_d - the intensity of diffuse radiation on a horizontal surface, W/m^2;

k_t - clearness index,

$$k_t = \frac{I}{I_{oH}};$$

I_{oH} - extraterrestrial radiation on a horizontal surface, W/m^2;

$I_{b,\beta}$ - the intensity of the beam radiation on an inclined surface, W/m^2;

R_b - ratio of the beam radiation on an inclined surface and the beam radiation on a horizontal surface,

$$R_b = \frac{cos(\theta)}{cos(\theta_z)},$$

θ - the incidence angle of the sun rays on the horisontal surface, deg;

θ_z - the zenith angle, deg;

$I_{d,\beta}$ - the intensity of diffuse radiation on an inclined surface, W/m^2;

I_r - the intensity of reflected radiation on a horizontal surface, W/m^2;

R_r - ratio of reflected radiation on an inclined surface and the reflected radiation on a horizontal surface,

$R_r = 0.5*(1-cos(\beta))*\rho$,

β - the inclination angle, deg;

ρ - the ground surface (albedo).

The calculations of the total solar radiation are carried out at a different angle of the surface varying from 10^o to 90^o within the period from 1st January to 31st December, 2011.

RESULTS - MONTHLY OPTIMUM ANGLE OF AN INCLINED SURFACE

Figure 1, as well as Table 1, illustrates the results of the monthly optimum angle on an inclined surface obtained in the city of Varna. The graphs are based on the total monthly value of the solar potential received. The table also shows the average daily value of the solar energy per month.

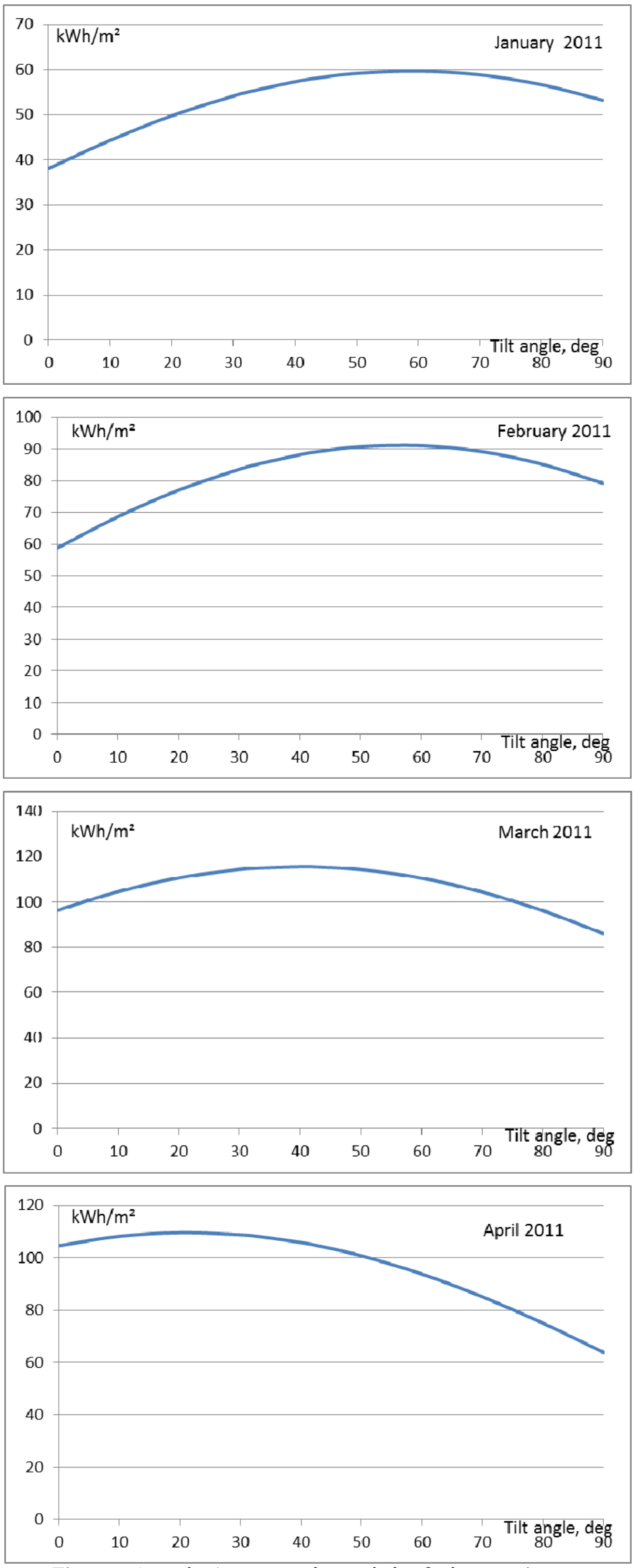

Figure 1.a-d. A general model of the optimum monthly angle on an inclined surface on the basis of the total monthly value of the solar radiation for 2011

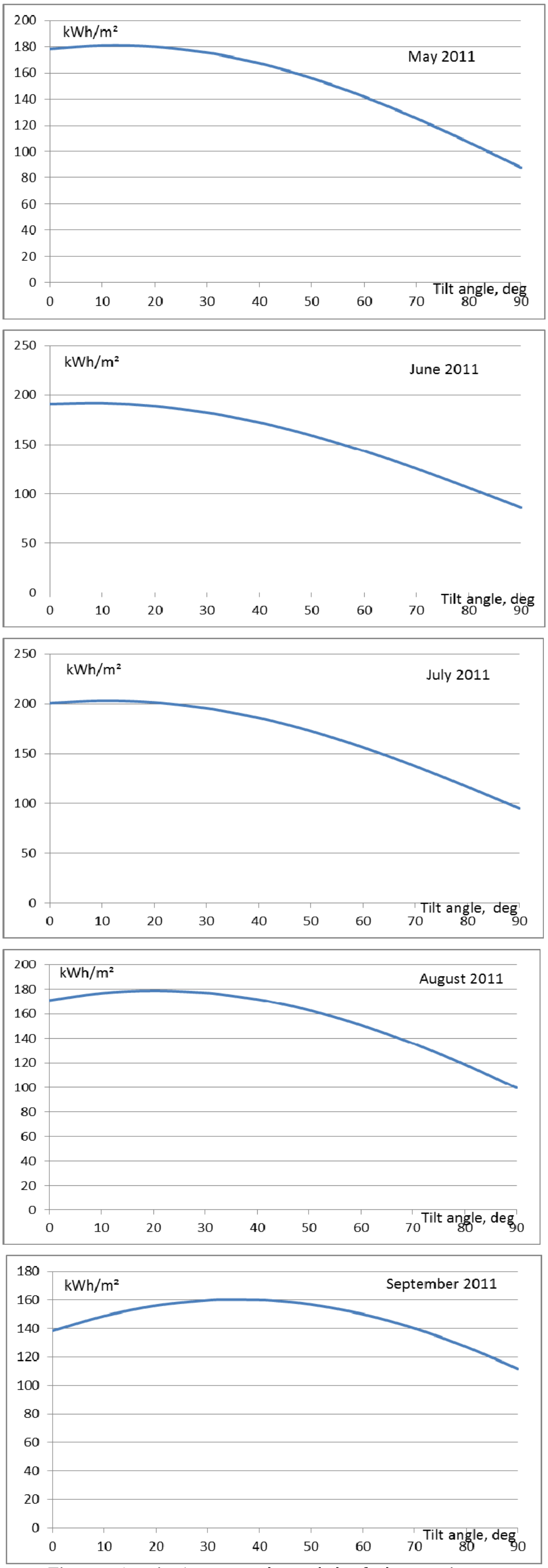

Figure 1.e-i. A general model of the optimum monthly angle on an inclined surface on the basis of the total monthly value of the solar radiation for 2011

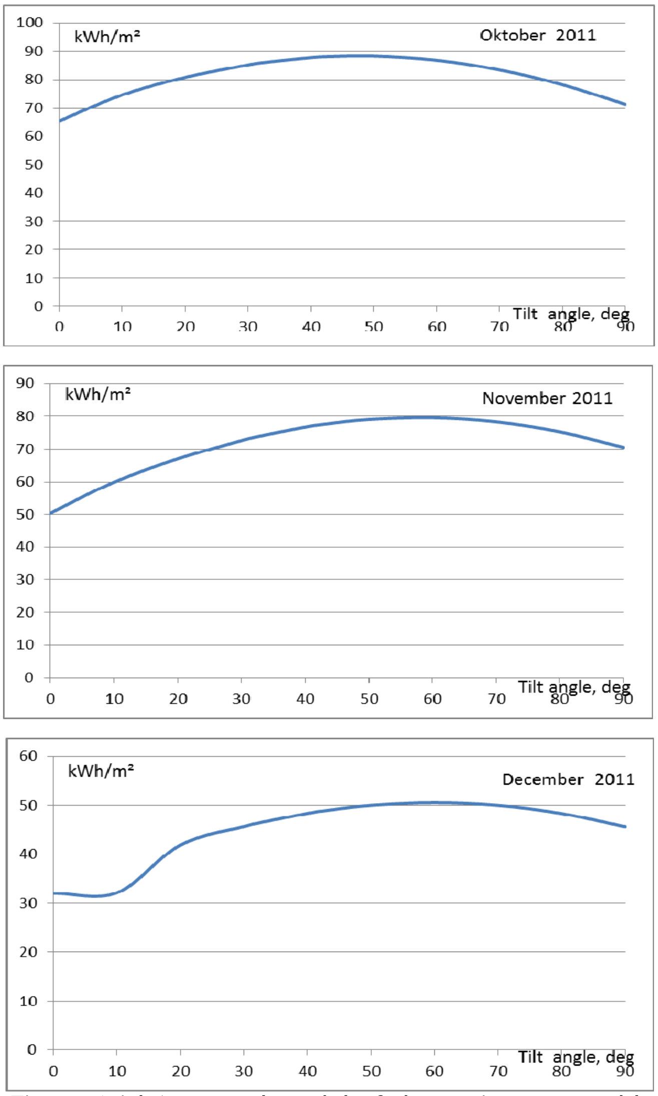

Figure 1.j-l A general model of the optimum monthly angle on an inclined surface on the basis of the total monthly value of the solar radiation for 2011

Table 1. Monthly optimum angle of the inclined surface of Varna

Month	Opt. angle	I_{max}, kWh/m^2	I_{srm}, kWh/(m^2.day)
1	2	3	4
I	60°	59.70	1. 9
II	60°	91. 02	3 .25
III	40° 43°	115.54 115. 41	3. 73 3. 72
IV	20°	109 .581	3 .78
V	10°	181. 08	5. 84
VI	10°	191. 60	6. 39
VII	10°	203. 03	6 .55
VIII	20°	178.78	5. 77
IX	33°	160. 20	5. 34
X	50°	88 .23	2.85
XI	60°	79. 54	2. 65
XII	60°	50 .58	1. 63

Figure 2 shows the changes in the optimum angle on an inclined surface by month. As can be seen, during winter months (January, February, November and December) the optimum angle is 60° and during the summer months (May, June, July) it is 10°.
All results obtained for the total solar radiation on an inclined surface for 2011 are shown in Table 2.

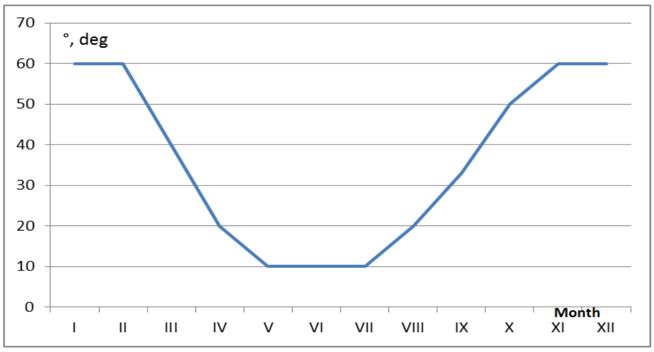

Figure 2. Variation of the optimum angle on an inclined surface by month

Table 2. Total monthly solar radiation on an inclined surface, kWh/m^2

Angle/ Month	0°	10°	20°	30°
I	38.05	44.34	49.77	54.14
II	58.79	68.66	77.00	83.58
III	96.38	104.59	110.63	114.31
IV	104.62	108.19	109.58	108.77
V	178.29	181.08	180.08	175.45
VI	190.70	191.60	188.70	182.14
VII	200.67	203.03	201.27	195.46
VIII	171.01	176.78	178.78	177.09
IX	138.35	148.76	155.97	159.76
X	65.52	74.65	80.79	85.19
XI	50.39	59.91	66.98	72.62
XII	32.04	32.13	41.91	45.62
I-XII	**1324.8**	**1393.7**	**1441.5**	**1454.1**
IV-IX	983.7	1009.4	1014.4	998.7
X-III	341.2	384.3	427.1	455.5

Angle/ Month	33°	40°	50°	60°
I	55.22	57.31	59.18	59.70
II	85.17	88.19	90.70	91.02
III	114.94	115.54	114.26	110.52
IV	108.10	105.79	100.74	93.76
V	173.36	167.31	155.99	141.86
VI	179.50	172.19	159.14	143.42
VII	192.91	185.82	172.61	156.31
VIII	175.82	171.75	162.90	150.84
IX	160.20	160.00	156.72	149.99
X	86.14	87.69	88.23	86.78
XI	74.00	76.67	79.00	79.54
XII	46.55	48.35	50.03	50.58
I-XII	**1451.9**	**1436.6**	**1389.5**	**1314.3**
IV-IX	989.9	962.9	908.1	836.2
X-III	462.0	473.8	481.4	478.2

Angle/ Month	70°	80°	90°
I	58.85	56.65	53.18
II	89.16	85.16	79.15
III	104.43	96.17	86.01
IV	85.10	75.03	63.88
V	125.36	107.10	87.82
VI	125.58	106.31	86.49
VII	137.48	116.79	95.16
VIII	135.95	118.73	99.77
IX	140.01	127.09	111.65
X	83.40	78.19	71.29
XI	78.29	75.25	70.55
XII	50.02	48.34	45.60
I-XII	**1213.6**	**1090.8**	**950.6**
IV-IX	749.5	651.0	544.8
X-III	464.1	439.8	405.8

OPTIMUM AMOUNT OF SOLAR ENERGY ON AN INCLINED SURFACE

The optimum amount of solar energy for the one-year period of study, as Figure 3 shows, is obtained at an optimum angle of an inclined surface of 30° having a value of 1454.12 kWh/m².

Table 2 shows that the values of the solar energy at 20° and 33° are similar – 1441.5 kWh/m² and 1451.9 kWh/m² respectively.

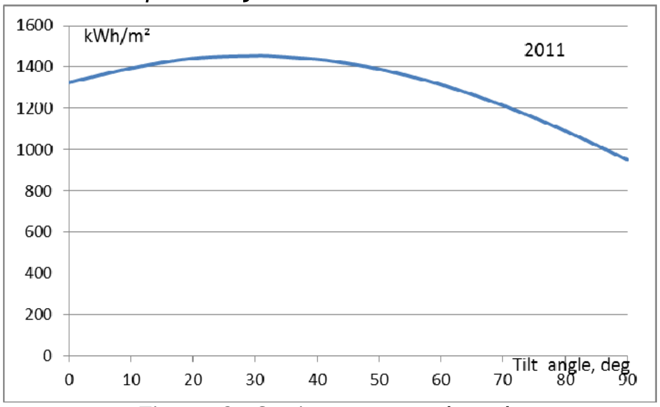

Figure 3. Optimum annual angle on an inclined surface

Figure 4 presents the line graph of the solar energy which the region under study receives during the summer and the winter months.

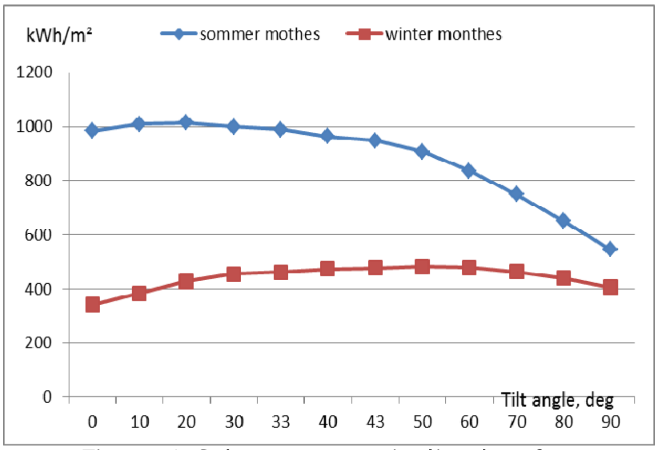

Figure 4. Solar energy on inclined surface in summer and winter

CONCLUSIONS

The results obtained are intended to be preliminary data for the purposes of a solar system design. The selection of the type of a certain solar system in advance will reduce the time necessary for its design and construction in the region studied.

The following conclusions can be made from the obtained results:

1. *The optimal annual angle of an inclined surface for the city of Varna as per experimental data (2011) is 30°.*
2. *The obtained data for the solar radiation of an inclined surface show that the city of Varna has a sufficient solar potential (1454.12 kWh/m²), which can be used for heating and energy production.*
3. *The results obtained serve as preliminary information and can be used by technologists, designers and architects when designing a solar system.*

The preliminary selection of the type of the respective solar system (heating or energy transformation/power conversioning), will decrease the time for its design and construction in the respective studied region.

REFERENCES

[1.] Pavlova, I. Dissertation (in Bulgarian) Павлова И. Дисертация на тема „Теоретична и експериментална оценка на слънчевия потенциал за град Варна", 2012 г., Технически университет – Варна.

[2.] Batlles F.J., M.A. Rubio , J. Tovar, F.J. Olmo, L. Alados-Arboledas; Empirical modeling of hourly direct irradiance by means of hourly global irradiance, Energy 25 (2000) 675-688.

[3.] Ahmad M. Jamil, G.N. Tiwari; Optimization of Tilt Angle for Solar Collector to Receive Maximum Radiation, Renewable Energy Journal, 2009, 2, 19-24.

[4.] Ulgen K., Optimum Tilt Angle for Solar Collectors, Energy Sources, Part A, 28:1171-1180, 2006, ISSN:1556-7036.

[5.] Radosavljević Jasmina, Amelija Đorđević; Defining of the intensity of solar radiation on horizontal and oblique surfaces on earth, UDC 551.521.1:504.06, Facta Universitatis Series: Working and Living Environmental ProtectionVol. 2, No 1, 2001, pp. 77 – 86.

[6.] Wlodarczyk D., H. Nowak, Statistical analysis of solar radiation models onto inclined planes for climatic conditions of Lower Silesia in Poland, ARCHIVES OF CIVIL AND MECHANICAL ENNNNNGINEERING Vol. IX, 2009.