OPTIMUM TILT ANGLE FOR SOUTH FACING FLAT SOLAR COLLECTORS IN DUHOK CITY

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Abstract

One of the important parameters that affect the performance of a solar collector is its' tilt angle with the horizon. This is because of the variation of tilt angle changes the amount of solar radiation reaching the collector surface. In this paper, the global irradiation observed in Duhok from 1990 to 2007 was used to estimate the optimal tilt angle for solar collectors. The observed data are resolved into diffusion, beam and albedo components. Total solar radiation on the solar collector surface with an optimum tilt angle is computed for specific periods. It is found that the optimum tilt angle changes between 0◦ (June) and 62° (December) throughout the year. In winter (December, January, and February) the tilt should be 58°, in spring (March, April, and May) 20, in summer (June, July, and August) 5°, and in autumn (September, October, and November) 46.3°. The yearly average of this value was found to be 32.33° and this would be the optimum fixed tilt throughout the year.

Keywords**:** *Solar radiation, Collector angle, Duhok city Kurdistan-Iraq*

Nomenclature

H_o: monthly average daily extraterrestrial radiation on a horizontal surface ($kW.h/m^2$ .day)
I: solar constant (W/m^2)
H: monthly average daily global radiation on a horizontal surface ($kW.h/m^2$ .day)
Hb: monthly average daily direct radiation on a horizontal surface ($kW.h/m^2$ .day)
Hd: monthly average daily diffuse radiation on a horizontal surface ($kW.h/m^2$ .day)
Ht(β): monthly average daily total radiation on a tilted surface ($kW.h/m^2$ .day)
Hb(β): monthly average daily direct radiation on a tilted surface ($kW.h/m^2$ .day)
Hd(β): monthly average daily diffuse radiation on a tilted surface ($kW.h/m^2$ .day)
Kt: the monthly-average clearness index
N: number of the day of year starting from the first January
Rb: the ratio of the average beam radiation on the tilted surface to that on a horizontal surface for each month
β: tilt of the surface from horizontal (°)
δ: solar declination angle (°)
Ø: latitude of site (°)
ρ: ground reflectance (≈ 0.2)
ωs: sunshine hour angle for the month (°)
ωss: sunset hour angle for the tilted surface (°)

Introduction

Solar radiation on tilted planes is very important to engineers designing plate collectors, photovoltaic systems and other solar energy collecting devices (Salem Nijmeh et al, 2000).Solar radiation data is usually measured in the form of global solar radiation on a horizontal surface at the latitude of interest. Flat-plat solar collectors are tilted so that they capture maximum radiation and the problem of calculating solar radiation on tilt surface is in determining the relative amount of beam and diffuse containing in measured global solar radiation on horizontal surface. Since the solar collectors are positioned at angle it is necessary to calculate the optimal angle which maximizes the amount of collected energy (D. Ibrahim, 1995). It is generally known that in the northern hemisphere the optimum collector orientation is south facing (e.i.$\gamma = 0$) and the optimum tilt depends upon the latitude, local climate and the solar declination (Koray, 2006). Researchers like Duffie and Beckman suggested that the tilt angle should be 10°–15° more than the latitude during winter and 10°–15° less than the latitude during summer (Duffie et al, 1991)

Hamdy K. Elminir concluded that the tilt angle for Helwan, Egypt is $(Ø\pm15)^o$ (Hamdy K. Elminir et al, 2005). Can Ertekin in a study on 158 cities in Turkey found that the optimum tilt angle to be $(Ø-8.14)^o$ in winter months and $(Ø-35.17)^o$ for summer months(Can Ertekin et al, 2008). Tian Pau Chang propose that the yearly optimum tilt angle is $(0.764Ø+2.14)^o$ for $(Ø \leq 65)^o$ and $(0.224Ø+33.65)^o$ otherwise (Tian Pau, 2008)

The objective of this study is to determine the optimum tilt angle for a fixed south facing solar collector and the total solar radiation on a tilted surface in Duhok, Kurdistan Region of Iraq. Total solar radiation on the solar collector surface with an optimum tilt angle is computed for specific periods (monthly, seasonal, and yearly).

Theoretical Analysis

Monthly average daily total solar radiation $H(\beta)$ on a tilted surface at angle (β), is normally estimated by individually considering the direct beam $Hb(\beta)$, diffuse $Hd(\beta)$ and reflected components $Hr(\beta)$ of the radiation on a tilted surface. Thus for a surface tilted at a slope angle from the horizontal, the incident total radiation is given by (Luque et al, 2003):

$$Ht(\beta) = Hb(\beta) + Hd(\beta) + Hr(\beta) \quad \ldots\ldots\ldots (1)$$

The daily beam solar radiation received on a horizontal surface may be expressed as (Luque et al, 2003):

$$Hb = (H - Hd) \quad \ldots\ldots\ldots.. (2)$$

And daily beam solar radiation on an inclined surface can be expressed as:

$$Hb(\beta) = (H - Hd)Rb \quad \ldots\ldots\ldots\ldots (3)$$

Where H and Hd are the monthly-average daily global and diffuse radiation on a horizontal surface respectively, and Rb is the ratio of the average beam radiation on the tilted surface to that on a horizontal surface for each month. Rb is a function of the transmittance of the atmosphere, which depends upon the atmospheric cloudiness, water vapor, and particulate concentration Liu and Jordan have suggested that Rb can be estimated to be the ratio of extraterrestrial radiation on the tilted surface to that on a horizontal surface for each month. For a surface facing directly towards the equator (Liu et al, 1960):

$$Rb = \frac{Cos(Ø-\beta)Cos\delta Sin\omega ss + \left(\frac{\pi}{180}\right)\omega sSin(Ø-\beta)Sin\delta}{CosØCos\delta Sin\omega s + \left(\frac{\pi}{180}\right)\omega sSinØSin\delta} \quad \ldots\ldots\ldots (4)$$

Where β is the tilt of the surface from horizontal, Ø is the latitude, ωs is the sunrise hour angle ,ωss is the sunset hour angle for the tilted surface and δ is the solar declination angle , ωs, ωss and δ can be fined by using the following equations (Liu et al, 1960. Gilbert M. Masters, 2004. Duffie et al 1991) :

$$\omega s = arcCos(-tan\delta tanØ) \quad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

$$\omega ss = \min\left[\omega s = (arcCos(-tanØtan\delta), arcCos(-\tan(Ø-\beta)tan\delta)\right] \quad \ldots\ldots. (6)$$

$$\delta = 23.45\ \mathrm{Sin}\left(\frac{360(N+284)}{365}\right) \qquad \text{.............. (7)}$$

Where N is the number of the day of the year starting from the first of January

In order to determine monthly average daily diffuse solar radiation on a horizontal surface the following correlation was used (Page, 1964):

$$Hd = (1 - 1.13Kt)H \qquad \text{....... (8)}$$

For an inclined surface the diffuse solar radiation is given by (Luque et al, 2003):

$$Hd(\beta) = \frac{Hd}{2}(1 + \mathrm{Cos}\beta) \qquad \text{......... (9)}$$

The monthly average clearness index (Kt) is the ratio of monthly average daily radiation on a horizontal surface (H) (kW.h m^{-2} d^{-1}) to monthly average daily extraterrestrial radiation on a horizontal surface (*Ho*) (kW.h m^{-2} d^{-1}).Kt and Ho can be calculated from the following equation (K.N Liou, 1992):

$$Kt = \frac{H}{Ho} \qquad \text{.............. (10)}$$

$$Ho = I \times \frac{24}{\pi} \times \left(1 + 0.003\mathrm{Cos}\left(\frac{360N}{365}\right)\right) \times \left(\frac{\pi}{180}\omega s \mathrm{Sin}\delta \mathrm{Sin}\varnothing + \mathrm{Cos}\delta \mathrm{Cos}\varnothing \mathrm{Sin}\omega s\right). \quad (11)$$

Where I is the solar constant (1367 W m^{-2})

The daily ground-reflected radiation may be written as (Luque et al, 2003):

$$Hr(\beta) = \frac{H\rho}{2}(1 - \mathrm{Cos}\beta) \qquad \text{.......... (12)}$$

ρ is the ground reflectance (≈ 0.2).

Substituting equations (3), (9) and (12) in equation (1) one can get:

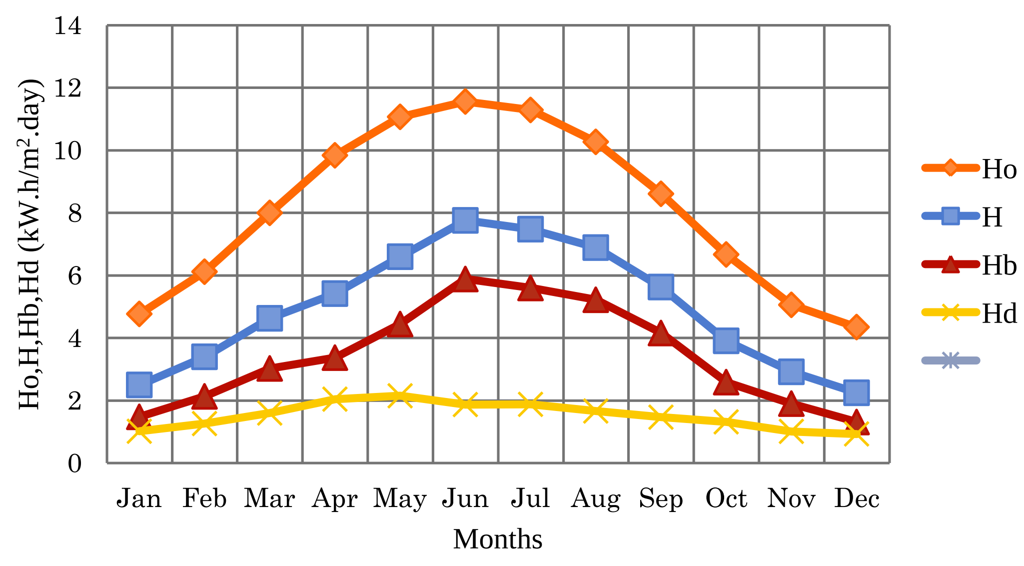
$$Ht(\beta) = (H - Hd)Rb + \frac{Hd}{2}(1 + \cos\beta) + \frac{H\rho}{2}(1 - \cos\beta) \qquad \text{........ (13)}$$

Results and Discussion

Since there is no ground base satation for measuring solar radiation data in Duhok city, the global solar radiation data was taken from the NASA surface meteorology and solar energy satellites (NASA, 1997) and the values of Ho, Kt, Hb and Hd were found by using equations (11),(10),(2) and (8) respectively and the results are shown in table (1) and plotted in figure (1).

Table (1): Monthly average of daily of (Ho, H, Hb, Hd and Kt).

Month	Ho(kW.h/m^2.day)	H(kW.h/m^2.day)	Hb(kW.h/m^2.day)	Hd(kW.h/m^2.day)	Kt
Jan	4.77	2.5	1.480608	1.019392	0.524109
Feb	6.12	3.4	2.134444	1.265556	0.555556
Mar	8	4.63	3.027962	1.602038	0.57875
Apr	9.84	5.42	3.373509	2.046491	0.550813
May	11.07	6.6	4.446504	2.153496	0.596206
Jun	11.56	7.76	5.886322	1.873678	0.67128
Jul	11.29	7.48	5.599996	1.880004	0.662533
Aug	10.27	6.89	5.223318	1.666682	0.670886
Sep	8.61	5.63	4.159988	1.470012	0.653891
Oct	6.67	3.91	2.590038	1.319962	0.586207
Nov	5.06	2.92	1.904117	1.015883	0.577075
Dec	4.35	2.25	1.315086	0.934914	0.517241

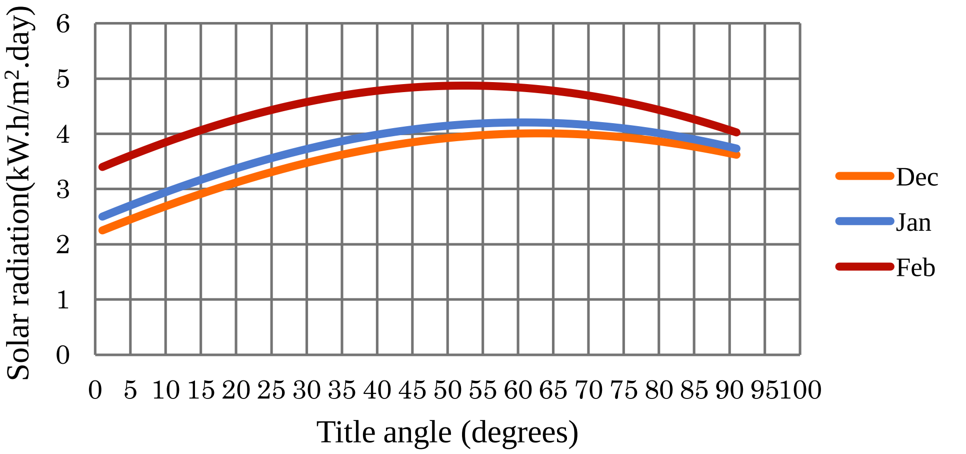


Fig(1): Monthly average of daily of Ho, H, Hb,Hd for Duhok city

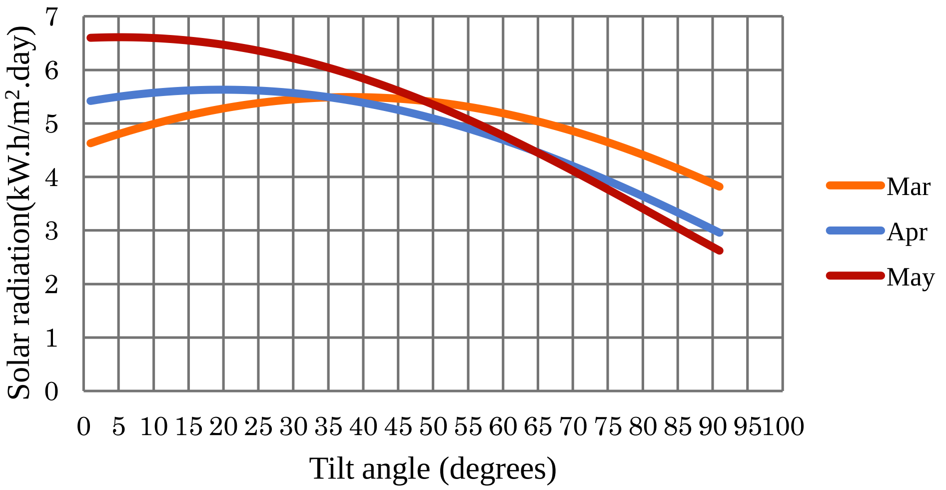
Equation (13) was used to calculate the monthly average daily total radiation on a south-facing surface. Figures (2), (3), (4) and (5) show the average daily total solar radiation on a south-facing surface when the angle of the tilt varied from 0° to 90° in steps of 1°. It can be seen that there is only one angle of tilt that offers maximum solar radiation interception to south facing inclined surface of a flat plate collector. Optimum tilt angle and the monthly-average daily total solar radiation on an optimum tilted surface are given in Table 2. It is found that the optimum tilt angle was changing between 0° (June) and 62° (December) throughout a year.

Table (2): Optimum tilt angle (β_{opt}) and monthly-average daily solar radiation on a tilted surface (H_{opt}) for each month of the year for a south-facing solar collector in Duhok.

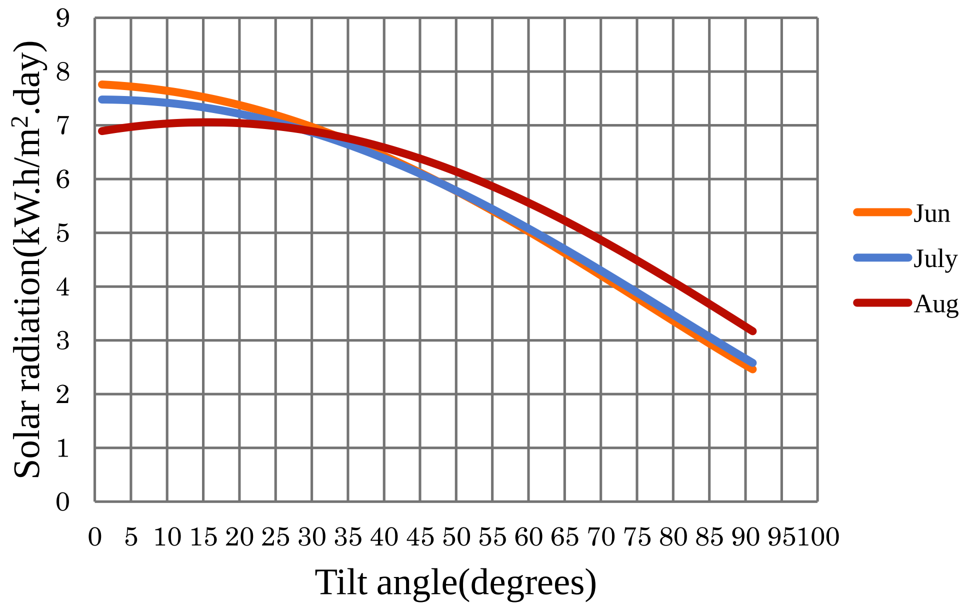
Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
β^{o}_{opt}	60	52	37	19	4	0	0	15	32	48	59	62
H_{opt}(Kw.h/m^2.day)	4.203	4.873	5.490	5.630	6.61	7.76	7.48	7.053	6.422	5.312	4.911	4.009



Fig(2): Monthly average of daily solar radiation on tilted surfaces (Winter months)



Fig(3): Monthly average of daily solar radiation on titlted surfaces (Spring months)



Fig(4): Monthly average of daily solar radiation on tilted surfaces (Summer months)

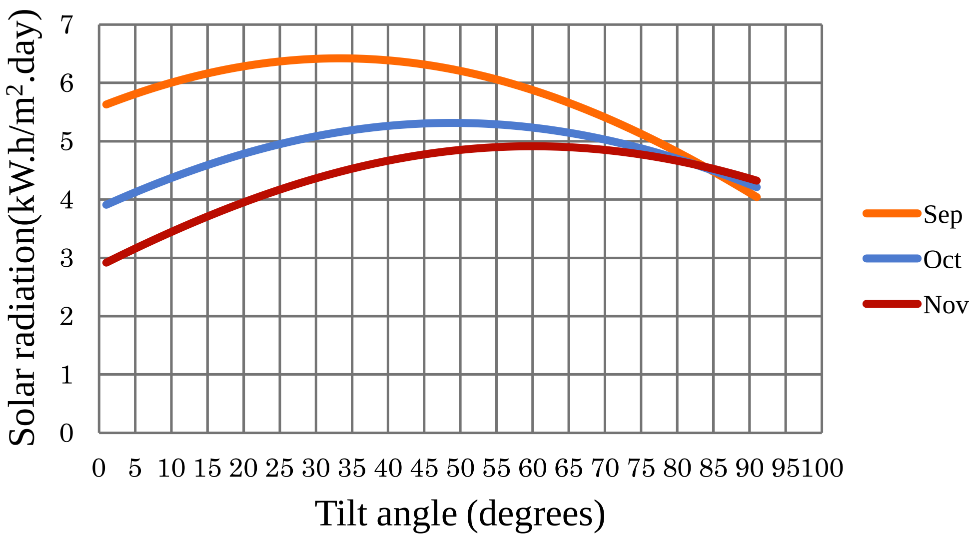


Fig (5): Monthly average of daily solar radiation on tilted surfaces (Automn months)

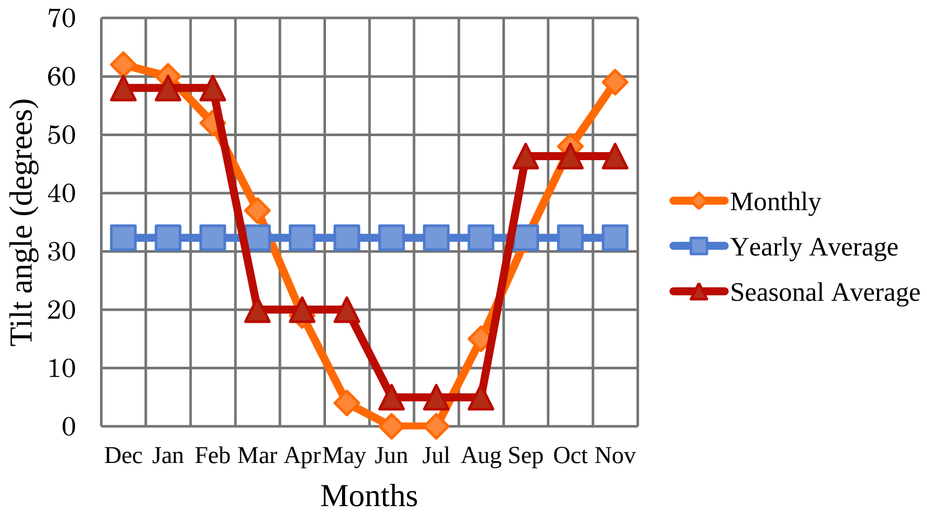
Table 3 and Figure (6) show the tilt angle for each month of the year when the solar collector is tilted at the optimum angle, which clearly showed the seasonal average, and the yearly average. The seasonal average was calculated by finding the average value of the tilt angle for each season, and the implementation of this requires that the collector tilt be changed four times a year. In winter (December, January, and February) the tilt should be 58° and the total solar radiation falling on the collector plane during this season is 390 (Kw.h/m^2). In spring (March, April, and May), the optimal tilt angle is 20° with the total solar radiation of about 533.1 (Kw.h/m^2) intercepted by the collector s' tilted at this angle .The optimum angle of tilt of flat collector in summer (June, July, and August) is 5°, and the total solar radiation is 678.9

(Kw.h/m^2). During autumn (September, October, and November) the optimal tilt angle is 46.3° and the total solar radiation incident on a collector tilted at this angle is 497 (Kw.h/m^2). The yearly average tilt was calculated by finding the average value of the tilt angle for all months of the year. The yearly average of this value found to be 32.33°, the total solar radiation reaching the collector plane tilted at this angle is 1994 (kW.h/m^2). Figure (7) shows the monthly average solar energy collected when the angle of the tilt is optimum, and when the seasonal and yearly average angles are used.

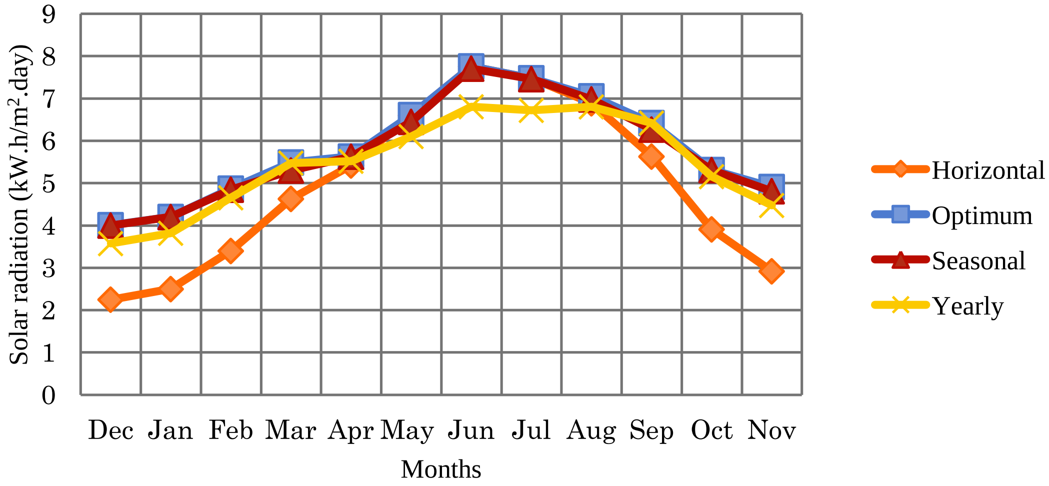
This amount of yearly solar radiation 1994 (kW.h/m^2) is enough for heating water for average family in Kurdistan.

Table (3): Seasonal and yearly average tilt angle and monthly-average daily solar radiation on a tilted south facing surface in Duhok city

Seasonal average				H(kW.h/m^2.season)	Yearly average	
Month	Season	β^o	H (Kw.h/m^2.day)		β^o	H (Kw.h/m^2.day)
Dec			4.001		32.33	3.5749
Jan	Winter	58	4.202	390		3.819
Feb			4.848			4.656
Mar			5.301			5.475
Apr	Spring	20	5.629	533.1		5.520
May			6.450			6.104
Jun			7.708			6.807
Jul	Summer	5	7.460	678.9		6.722
Aug			6.982			6.804
Sep			6.269			6.422
Oct	Autumn	46.3	5.311	497		5.156
Nov			4.812			4.475
						Yearly Total 1994.365 (kW.h/m^2)



Fig(6): Optimum,Seasonal average, Yearly average tilt angles for each month of the year



Fig(7): Monthly average-daily solar radiation on horizontal surface and optimum, seasonal and yearly tilt angles in Duhok

Conclusions:

In the light of the preceding results, the following conclusions can be drawn:

1- The results show that the average optimum tilt angle for the summer months is 5° (Ø – 31.5°), for the winter months 58° (Ø + 21.5°), for spring months 20° (Ø-16.5) and for autumn months 46.33° (Ø+9.83).With the yearly fixed angle 32° (Ø -4.5).

2-Desiging solar collector in which the tilt angle can be changed on monthly basis provides better efficiency.

3- When the solar collector is set on horizontal there is a reduction of 14.7% as compared to monthly, but when the solar collector is set at the seasonal tilt angle there is a reduction of

1.13% as compared to monthly, similarly there is a reduction of 6.0% the collector is set at yearly tilt angle.

4-It is important to record the solar spectrum during these four seasons period and you have to compare with daily spectrum during each day of winter, spring, autumn and summer with the calculated solar data of this paper.

5-This theoretical total yearly solar energy (1944 Kw.h.m^2) is enough for heating water for average family in Kurdistan.

References

Can Ertekin , Fatih Evrendilek and Recep Kulcu (2008). *Modeling Spatio- Temporal Dynamics of Optimum Tilt Angles for Solar Collectors in Turke*. Sensors 8:2913-2931

D. IBRAHIM. (1995). *Optimum titlt angle for solar collector used in Cyprus.* Renewable Energy. 6:813-819.

Duffie, J.A. & Beckman, W.A. (1991). *Solar Engineering of Thermal Processes*, 2nd ed., Wiley Interscience, New York (USA).

Engineering. John and Wiley Sons, USA.

Gilbert M. Masters. (2004). *Renewable and Efficient Electric Power Systems,*

Hamdy K. Elminir , Ahmed E. Ghitas , F. El-Hussainy , R. Hamid , M.M. Beheary and Khaled M. Abdel-Moneim. (2006). *Optimum solar flat-plate collector slope: Case study for Helwan, Egypt,* Energy Conversion and Management. 47:624–637

http://eosweb.larc.nasa.gov/sse/RETScreen/

John Wiley & Sons, Inc., Hoboken, New Jersey.

K.N Liou . (1992). *Radiation and Cloud Processes in the Atmosphere*, Oxford

KORAY ULGEN. (2006). *Optimum Tilt Angle for Solar Collectors*, Taylor & Francis Group

Liu, B. Y. H., and Jordan, R. C. (1960). *The interrelationship and characteristics and distribution of direct, diffuse, and total solar radiation*. Solar Energy 4:1–10.

Luque and S.Hegedus. (2003). *Handbook of Photovoltaic Science and*

NASA Surface Meteorology and Solar Energy ,RET Screen Data(1997):

of a solar collector in the northern hemisphere, Solar Energy .83 :1274–1284.

Page, JK. 1964. The estimation of monthly mean values of daily short wave radiation on vertical and inclined surface from sunshine records of latitude 40 degree N to 40 degree S. Proc. of UN-Conf. on New Sources of Energy. l:4 paper s/98. 378.

Salem Nijmeh and Rustom Mamlook. (2000) . *Testing of two models for computing global solar radiation on tilted surfaces*, Renewable Energy : 20. 75-81

Tian Pau Chang. (2009). *The Sun's apparent position and the optimal tilt angle*

University Press, Inc.

پوختە

ئێك ژ پارامیتەرێن گرنگ یێن کو کارتێکرنێ لسەر کارێ کومکەرێ تیشکا روژێ دکەت ئەو گوشەیە یا دناڤبەرا کومکەری رویێ زەڤیێ دا یە ئەڤە ژبەرکو گهورینا ڤێ گوشێ کارتێکرنێ لسەر برێ تیشکا روژێ دکەت ئەوێ دگەهیتە سەر کومکەری. تیشکا روژێ یا هە موکی بو شارێ دهوکێ کو ژ سالا 1990تاکو سالا 2007 هاتە بکار بو دەرئینانا باشترین گوشە بو کومکەرێ روژێ ل شارێ دهوکێ .پشتی شیتلەل کرنا تیشکا روژێ یا هە موکی بوهەرسێ بەشێن وێ لسەر کومکەری بو مە وەسا دیاربو باشترین گوشە دماوێ سالێدا دکەڤیتە دناڤبەرا (0پلە) بو مەها خزیرانێ و (62پلە) بو مەها کانینا دووێ . دوەرزێ زڤستانێد مەهێن (کانینا ئێکێ،کانینا دووێ،سباتێ) باشترین گوشە دبیتە(58پلە) بومەهێن بهارێ (ئادار ،نیسان، گولان) باشترین گوشە دبیتە(20پلە) بومەهێن هاڤینێ (خزیران،تەباخ،تیرمەه) باشترین گوشە دبیتە(5پلە) بومەهێن پائیزێ (تشرینائێکێ،تشرینا دووێ،ئەیلول) باشترین گوشە دبیتە(46.33پلە) تێکرایێ سالانە بوباشترین گوشە دبیتە (32.33پلە).