Study on Inclination Angles of Fixed Solar Systems

Ahmed A.A. Attia
Mechanical Engineering Department, Benha University, Faculty of Engineering at Shoubra, 108-Shoubra Street, Cairo, Egypt,
Tel. 0020-2-22050175-4111, Fax +20-2-2202336,
Email: Ahmed_attia72@yahoo.com or Ahmed.attia@feng.bu.edu.eg

Abstract

Solar system converts solar energy into usable energy form. Total energy gain depends on the total amount of radiation that strikes radiation collecting surface and this amount depends strongly on tilt angle. In the present study, the radiation collecting surface tilt angle was studied through two approach of study. First approach through getting the tilt angle of fully tracking solar system and then developed best tilt angle yearly and seasonally. Second approach depends on getting the evaluating the total solar radiation incident on surface tilt by certain angle then evaluating best angle. The first approach results show that tilt angle for latitudes from equator up to Cancer tropic is not equal to latitude angle while it approximately equal to latitude angle for latitudes started from Cancer tropic this is for one yearly fixed tilt angle. A correlation, for yearly best tilt angle as a function of latitude angle, was presented for both two cases single tilt angle and two tilt angles through year and a comparison between them was done. For latitudes next to Cancer tropic, the results showed that the value of enhancement, when using two tilt angles per year, may reach to 7.11% more than using single tilt angle per year and this value is directly proportional with latitude angle. Finally, using two tilt angles per year is more convenient. Results from first approach compared with data from second approach. Data extracted from other references are also compared with results of the two present approaches.

Key words: Solar Energy, Solar Collector, Inclination Angle,

1.0 Introduction

The total amount of radiation coming to collecting surface of the solar system is divided into two types of radiation, direct beam and diffused beam. Direct beam radiation is the major quantity of radiation that arrived or observed by the collecting surface. The amount of radiation arrived to solar collecting surface is highly influenced by relative position and orientation of collecting surface with respect to sun beam radiation. According to solar system ability to movement there are two types of solar systems. First one is fully tracking systems, and second is fixed systems. Fully tracking system is preferable due to high energy gain by making radiation beam vertical on collecting surface but cost of this system is major obstacle in its wide use. For large solar systems, fixed system is always used, where fully tracking systems will be very expensive. Tilt angle of collecting surface is very important in determining quantity of total energy gained.

Tilt angle collecting surface always formed as follow $\beta_{best} = \emptyset + C$ where $\emptyset$ is latitude angle where solar system was installed. Different values were assigned for constant (C) according to model assumption and the used technique. Some authors suggested a negative value for tilt angle although that the latitude of this location is located at northern part above Cancer tropic Ref. [1]. Other authors studied a specified location and cities. Ref. [2, 3, 4, 5, and 6] Also optimization of tilt angle for reflection plate relative to radiation surface was studied. Ref [7].

Techniques to evaluate best tilt angle of radiation surface mainly depend on two ideas. First idea uses mathematical models to calculate radiation on collecting surface. These models mix between correlation and geometrical approaches for calculating value of radiation intensity that striking radiation collecting surface. This technique suffers from deviation errors and constant which may not be valid over all regions. Second technique depends on actually measured data from stations installed in a certain places. This stations record data over measurements days for different tilt angles. This data is used to compare and determine optimum tilt angle. This technique suffers from effect of weather troubles; sky clearance and cite conditions. Finally most of researches concerned on certain location.

2.0 Methodology

In the present work two approaches will be used to evaluate the optimum title angle first one mainly depends on getting the value of daily optimum tilt angle through certain evaluating parameter. The second approach depends on the traditional equation that used to evaluate the solar incident radiation on surface tilted by a specified angle and comparing seasonal radiation and yearly radiation for each tilt angle then evaluating best seasonal tilt angle or yearly tilt angle. For each approach two techniques for inclination angle. First technique is one tilt angle through the year. Second technique used two angles through the year specified angle for summer season from 21 March up to 21 September and the other angle for winter season from 21 September up to 21 March. These techniques called seasonal angle. Both techniques will discuss for each approach.

2.1 First approach:

The solar system with fully tracking mechanism has two paths through them system could moves. These two paths are daily path from east to west (east–west axis) and seasonal path which depends on day number (north-south axis). The second path depends on sun location with respect to earth which could be expressed as radiation collection surface tilt angle which faces south for northern earth part. In the following a work is simply depends on determining the best tilt angle β_n which makes sun rays always perpendicular on radiation collection surface through days of the year. The procedure will concern on seasonal path (north-south axis) by assuming that radiation collection surface tilts by angle (β) the value P which $P = \cos(\beta_n - \beta)$ will be used to determine best inclination angle. The parameter P is assigned as evaluation parameter

At figure (1) geometry of angles that formed from relative position of earth to sun is presented. Earth axel inclination angle on Solar System plan is changed by $23^{o}45^{\backslash\backslash}$ during period from winter to spring and it comes back again from spring to summer to be vertical on solar system plan. Then tilts with the same angle in opposite direction from summer to autumn finally it comes back again from autumn to winter to be vertical. That means the changes of inclination angle by this value are four times through days of the year. So that daily inclination angle could be estimated from following equation.

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

At 21 Dec (Day No. 355) winter season in earth northern part is started and sun radiation is vertical on Cancer tropic. At location on earth northern part which has latitude angle ($\emptyset$), angle (β_n), is the angle by which the radiation collection surface should be tilt to make sun ray vertical on it at noon time, where it could be estimated from equation (4).Tilt angle is function of location latitude angle ($\emptyset$) and day number (Julian day number).

$$\beta_n = \emptyset + \delta = \emptyset + 23.45 sin\left(\frac{360}{365}(n + 284)\right) \qquad (2)$$

The value of β_n at latitudes starting from Equator up to latitude 40 with step 5^{o} through all year days is shown in the figure (2) for northern part of the earth.

When value of β_n is negative, it means that the radiation collection surface should face north direction instead of facing south for locations at northern earth part. For Equator tropic tilt angle becomes zero at 21 March and 21 Sept. Tilt angle for Cancer tropic is equal to zero at 21 Jun, at which summer starts at northern earth part.

With fact that, the relative position for Sun and earth, is changed, daily. It could be stated that angle (β_n) is the angle that fully tracking system should attain daily. When surface tilts with another angle (β), these mean that the angle between line vertical on surface and solar radiation beam is equal to $(\beta_n - \beta)$. The vertical component is the actual component from the direct beam which the collection surface could absorb it. The vertical radiation component could be estimated from the relation.

$$I_N = I\cos(\beta_n - \beta) \qquad (3)$$

Where

Total solar radiation comes to the surface through the day light.

$$\sum_{Tss}^{Tsr} I_N = \cos(\beta_n - \beta)\sum_{Tss}^{Tsr} I \qquad (4)$$

2.1.1 One tilt angle through the year:

The value of evaluation parameter $p = \cos(\beta_n - \beta)$ is constant for each operation day. The average value of evaluation parameter (p) through the year will be an indication for collecting surface best tilt angle. The average value of yearly evaluation parameter P_{Yearly} is

$$P_{Yearly} = \frac{\sum_{i=1}^{365}\cos(\beta_{n_i} - \beta)}{365} \qquad (5)$$

The value of yearly evaluation parameter P_{Yearly} is major scale which will be used to evaluate best tilt angle through days of the year. Value of evaluation parameter (P) is calculated at different inclination angles for specified latitude. Equation of trend line for yearly evaluation parameter at specified latitude is introduced in the following form.

$$P_{Yearly} = a\beta^2 + b\beta + \text{c} \qquad (6)$$

The value of constants, a , b , and c are listed in table(1)

Then angle which has a maximum value of parameter P_{Yearly} is estimated by derivatives.

$$\frac{dp_{yearl}}{d\beta} = 2 * a * \beta + b \qquad (7)$$

Then tilt angle which has a maximum value of parameter P_{Yearly} calculated from the following equation

$$\beta_{best} = (-b/2a) \qquad (8)$$

$$\beta_{best} = 0.0173(\emptyset)^2 + 0.0308(\emptyset) + 14.527 \qquad (9)$$

2.2.1 Two tilt angle through the year:

Another suggestion is using two inclination angles per year one angle for winter season and another for summer season. Using the same procedure for one tilt angle per year with getting the maximum value of yearly evaluation parameter during the summer season which starts from 21 March up to 20 Sept. and for the winter months starts from 21 Sept. and ended 20 March.

Summer tilt angle:

The parameter P_{Summer} is Major criterion which used to evaluate the best tilt angle through the days of summer season. The value of P_{Summer} is calculated for different inclination angles at specified latitude then equation of trend line for each latitude is formed.

$$P_{Summer} = \frac{\sum_{i=80}^{264} \cos(\beta_{n_i} - \beta)}{185} \quad (10)$$

Then tilt angle which has a maximum value of parameter P_{summer} calculated

$$P_{summer} = a_s\beta^2 + b_s\beta + c_s \quad (11)$$

With the same procedure for yearly calculations the value of derivative is.

$$\beta_{summer\ best} = (-b_s/2a_s) \quad (12)$$

Winter tilt angle:

The same procedure for winter is done but with another range of days.

$$P_{Winter} = \frac{\sum_{i=264}^{365} \cos(\beta_{n_i} - \beta) + \sum_{i=1}^{97} \cos(\beta_{n_i} - \beta)}{180} \quad (13)$$

$$P_{winter} = a_w\beta^2 + b_w\beta + c_w \quad (14)$$

With the same derivations sequence

$$\beta_{winter\ best} = (-b_w/2a_w) \quad (15)$$

The trend line equation for summer and winter inclination angle plotted in figure (4) is as follow.

For summer $\beta_{best} = 0.0296(\emptyset)^2 - 0.9262(\emptyset) + 15.273$ (16)

For winter $\beta_{best} = -0.0008(\emptyset)^2 + 1.0431(\emptyset) + 14.723$ (17)

The value of extraterrestrial radiation on radiation collection surface inclined by β_{best} at different latitudes for the purpose of comparing between single and double tilt angle is calculated as follow

$$I = I_O * cos(\theta) \quad \text{W/m}^2 \quad (18)$$

Where

$$cos(\theta) = sin(\delta)\sin(\emptyset)\sin(\beta) - \sin(\delta)\cos(\emptyset)\sin(\beta)\cos(\gamma) + \cos(\delta)\cos(\emptyset)\cos(\beta)\cos(\omega) + \cos(\delta) sin(\emptyset)\sin(\beta)\cos(\gamma)\cos(\omega) + \cos(\delta)\sin(\beta)\sin(\gamma)\sin(\omega) \quad (19)$$

$$\omega = 15(12 - h) \quad (20)/8+$$

The total solar radiation coming per day is calculated from equation (22) using developed program by lab-view software. The value of I is calculated every minute then multiplied by 60 sec.

$$I_T = I * 60 \quad \text{J/m}^2 \quad (21)$$

$$I_{Day} = \sum_{T=t_{ss}}^{T=t_{sr}} I_T \ dt \quad \text{J/m}^2 \quad (22)$$

$$I_{year} = \sum_{i=1}^{365} I_i \quad \text{J/m}^2 \quad (23)$$

$$I_{summer} = \sum_{i=80}^{264} I_i \quad \text{J/m}^2 \quad (24)$$

$$I_{winter} = \sum_{i=265}^{365} I_i + \sum_{i=1}^{97} I_i \quad \text{J/m}^2 \quad (25)$$

The percentage of enhancement (E) if two angles used instead of one angle is calculated as follow.

$$E = \left(\frac{(I_{summer} + I_{winter}) - I_{year}}{I_{year}}\right) X\ 100 \quad (26)$$

Second approach:

This approach is traditional approach used by the most common previous studies. It mainly depends on calculating the daily radiation incident on the surface inclined with a specified tilt angle using equations from equation No (18) up to equation No (26). The total radiation is calculated daily and monthly for each tilt angle then evaluation for best tilt angle is done by comparing the seasonal total radiation for each angle with that for other angles and evaluating the best tilt angle. A program is developed to compare between the total seasonal and total yearly radiation for each tilt angle then evaluate a best inclination angle for latitudes starting from 0^o up to 45^o with step 5^o.

Result and discussion:

Figure (2) shows the daily best tilt angle for latitudes starting from equator up to 45^o latitude with step 5^o. The negative values of tilt angle mean that the face of the tilt surface is facing north instead of facing south. The negative value is only for latitude from equator up to Cancer tropic behind this latitude no negative values for tilt angle found i.e. the collecting surface always facing south.

Figure (3) shows the best yearly fixed inclination angle using two approaches. Also a comparing with data extracted from Ref [14, 17 and 18] is presented. From figure, it could be conclude that the best yearly tilt angle for radiation collection surface(β_{ybest}) changes dramatically from latitude to another. The best tilt angle for latitudes lies between Equator and Cancer tropic is not equals latitudes angle. For equator, best inclination angle is 14.5 Radian facing south in winter and north in summer. The best inclination angle increases with increase in latitude angle up to Cancer tropic. After this latitude best inclination angle is approximately the same as latitude angle. A trend line for correlation could be estimated and plotted as illustrated in equation 9. The data extracted from ref [14] and

In Figure (4) the seasonal tilt angle for summer and winter is represented at different latitude. For first and second approach the best tilt angle is approximately constant up to Cancer tropic in summer season. In winter season the relation is linear between latitude angle and best tilt angle for two used approaches. The difference between results of the two used approaches from that the second approaches suffer from phenomena of sun track crossing the latitude for latitudes. i.e. the local summer time is differ from the summer time in northern part of the earth. Also the same phenomena are applied in winter season. The results for second approach are approximately verified with results from ref [17] and slightly differ from ref [14] this due to that they used the same techniques for evaluating the best tilt angle and constant may differ than that used in second approach.

Data in table (4) represents percentage of enhancement when using two tilt angles. Some of values have negative sign. That means that using one tilt angle is more efficient than two tilt angles through days of the year. The percentage of enhancement when using two angles reaches about 7.1 % of total energy when using single angle. The enhancement percentage increases with the increase in latitude angle.

Data in table (5) compares between present work first approaches and models used by ref (17) and ref (14).The results show the validity of proposed method with other used model for estimating radiation collecting surface tilt angle for fixed solar system. The deviation in total energy received causes by the difference in parameters used by different model. In present work the total energy calculated is based only on normal radiation beam coming direct from the sun. Some other models take in consideration diffused radiation coming from the sky. Comparing between results of present work and results from ref [18] at the same latitude (24.5^O) is represented in table (6). The results show good agreements of results of present work and results of ref [18]. Which means that majority of radiation is coming from direct beam radiation.

3.0 Conclusion

A present work is conducted by using two approaches for evaluating the best tilt inclination angle for solar system radiation collecting surface. In the first approach earth position geometry relative to sun was used to calculate inclination angle for fully tracking solar system. An evaluating parameter is suggested to be used instead of complex equation in traditional techniques. This evaluating parameter is depending on the difference between the daily best inclination angle and the target best tilt angle for fixed solar system. The second approach used the traditional equation in calculation of incident radiation on the surface at certain tilt angle at different latitudes. For the first approach and based on the evaluation parameter, inclination angle for fixed solar systems was calculated for two cases, single tilt angle through days of the year and two inclination angles through days of the year. A correlation for best inclination angle as a function of latitude angle is introduced for both two cases single inclination angle and two inclination angles through days of the year. Comparison between using two inclination angles through days of the year and using single inclination angle is done. Also a comparison between first approach and second approach is done. The results show that when using two angles per year the value of enhancement could reach to 7.11% than using single angle. The enhancement value increases with increase in latitude angle. Using two inclination angles for latitudes next to Cancer tropic is favorable. Majority of radiation is coming from direct beam radiation. Verification for first approach with data extracted from ref [14], [17] and [18] was done. Good validity is noticed and the comparing show that the first approach could be used to investigate the best tilt angle.

4.0 Nomenclature

a	Constant	
b	Constant	
c	Constant	
θ	The angle of incident between the solar radiation beam and the imaginary line normal to such a surface.	Degree
$\emptyset$	Latitude angle.	Degree
δ	Declination angle of the celestial sphere measured northward or southward from the celestial equator plane.	Degree
ω	Hour angles.	Degree
β	Inclination angle of the collector w.r.t. horizontal surface	Degree
γ	Surface –azimuth angle (how far the solar collector deviates from the north-south axis.	Degree
n	Day Number according to Julian days	
I	Solar radiation intensity	W/m^2
E	Enhancement Percentage.	
β_{ybest}	Yearly best inclination angle	Degree
β_{sbest}	Summer best inclination angle	Degree
β_{wbest}	Winter best inclination angle	Degree

Subscript

y	yearly
S	summer
w	summer

5.0 References

[1] Hiroshi Tanaka, "Solar thermal collector augmented by flat plate booster reflector: Optimum Inclination of collector and reflector", Applied Energy 88 (2011) 1395–1404

[2] Runsheng Tang, "Optimal tilt-angles for solar collectors used in China", Applied Energy 79 (2004) 239-248.

[3] J. A. Martinze, "The optimization of the angle of inclination of a solar collector to maximize the incident solar radiation", Renewable Energy 17 (1999) 291-309.

[4] Hamdy K. Elminir, Ahmed E. Ghitas, F. El-Hussainy, R. Hamid, M.M. Beheary, Khaled and M. Abdel-Moneim, "Optimum Solar Flat-plate Collector slope: Case study for Helwan Egypt" Energy Conversion and Management 47(2006) 624-637.

[5] M.Benghanem, "Optimization of tilt angle for solar panel: Case study for Madinah Saudi Arabia" Applied Energy 88 (2011) 1427–1433

[6] Emanuele Calabro, "Determining Optimum tilt Angles of Photovoltaic Panel at Typical North-tropical latitudes",Journal of Renewable and Sustainable Energy 1033101 (2009).

[7] T.T. Chow, "Numerical study of desirable solar collector orientations for the coastal region of South China", Applied Energy 79 (2004) 249–260

[8] Adnan Shariah, M-Ali Al-Akhras, and I.A. Al-Omari, "Optimizing the tilt angle of solar collectors", Renewable Energy 26 (2002) 587–598

[9] D. Ibrahim, "Optimum tilt angle for solar collectors used in Cyprus", Renewable Energy, Vol. 6, No. 7, pp. 813 819, 1995.

[10]Abdul Jabbar and N. Khalifa, " On the effect of cover tilt angle of the simple solar still on its productivity in different seasons and latitudes",

[11]S. Karatasou M. Santamouris and V. Geros, "On the calculation of solar utilize ability for south oriented flat plate collectors tilted to an angle equal to the local latitude", Solar Energy, 80 (2006) 1600–1610.

[12]Moh.Azmi bin HjMohd Yakup, and A.Q. Malik, "Optimum tilt angle and orientation for solar collector in Brunei Darussalam", Renewable Energy 24 (2001) 223–234.

[13]Hiroshi Tanaka, "Monthly optimum inclination of glass cover and external reflector of a basin type solar still with internal and external reflector", Solar Energy 84 (2010) 1959–1966

[14]Kamal Skeiker, "Optimum tilt angle and orientation for solar collectors in Syria", Energy Conversion and Management 50 (2009) 2439–2448

[15]A. Farouk Kothdiwala., B. Norton and P.C. Eams "The Effect of Variation of Angle of Inclination on the Performance of Low-concentration-ratio Compound Parabolic Concentrating Solar Collectors", Solar Energy, Vol. 55, No. 4, pp. 301-309, 1995.

[16]E.P. Sakonidou, T.D. Karapantsios, A.I. Balouktsis and D. Chassapis, "Modeling of the optimum tilt of a solar chimney for maximum air flow " Solar Energy, Volume 82, Issue 1, January 2008, Pages 80-94

[17]Hamid Moghadam, Farshad FarshchiTabrizi and Ashkan Zolfaghari Sharak, "Optimization of solar flat collector inclination", Desalination, 265(2011) 107-111.

[18]L.E. Hartley, J.A. Martinez-Lozano, M.P. Utrillas, F. Tena and R. Pedros ,'The optimization of the angle of inclination of a solar collector to maximise the incident solar radiation', Renewable Energy 17 (1999) 291-309.

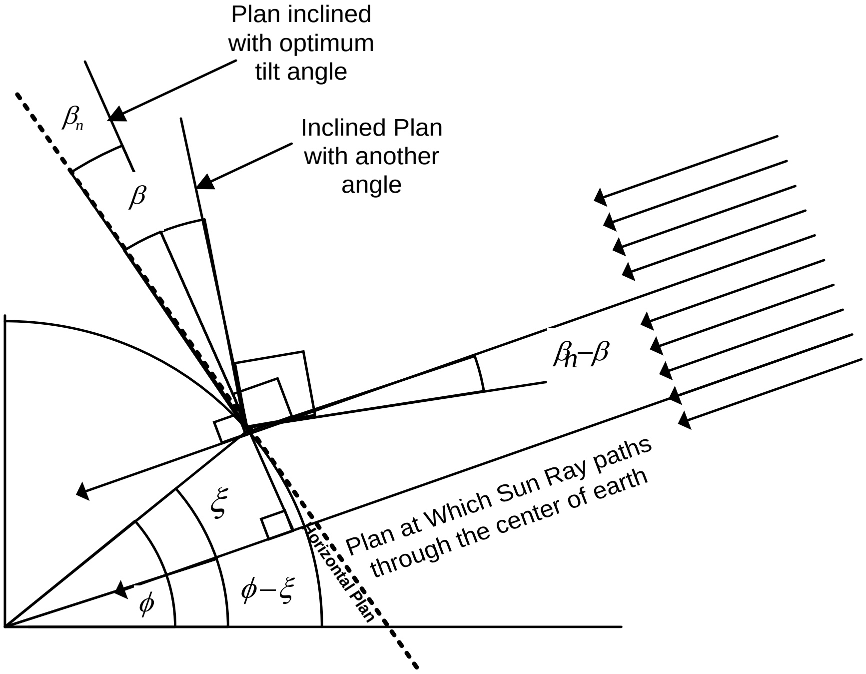

Figure 1: Angles formed from relative position of earth w.r.t. sun rays.

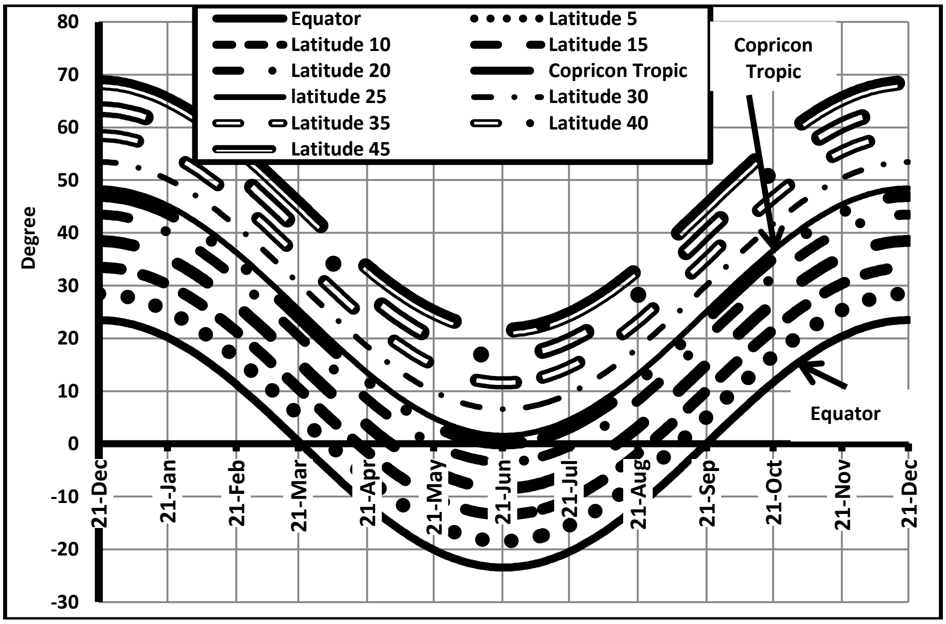

Figure (2): The angle β_n at different days through the year at different latitudes for northern earth part.

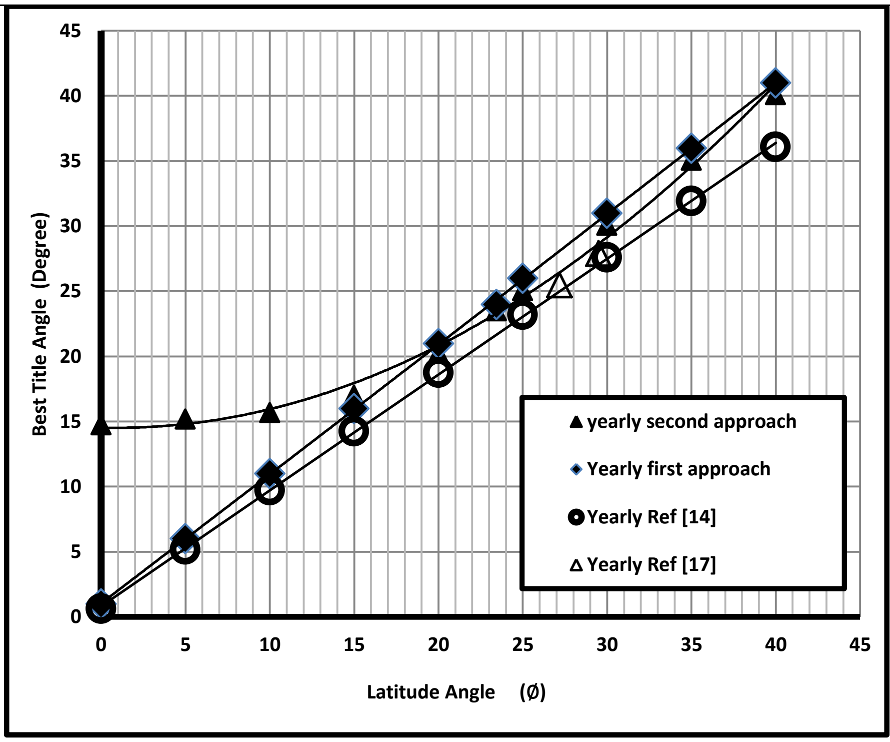

Figure (3): The best tilt angle at different latitudes when using one tilt angle through the year. (For earth northern part)

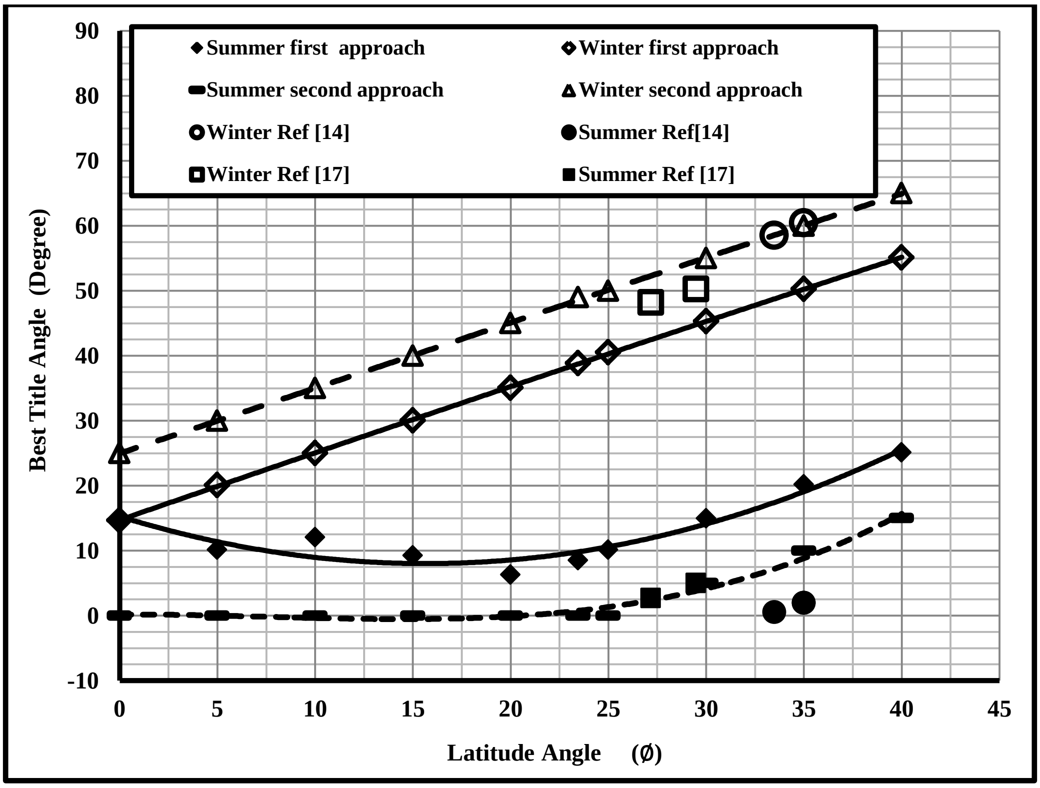

Figure (4): The best tilt angle versus latitude for summer and winter (For northern earth part)

Table (1) values of constant a, b, and c (equation (6)) Yearly best inclination angle using first approach

Latitude angle	a	b	c	R^2	β_{ybest}	Direction	P_{Yearly}
0	-1.37E-04	4.03E-03	0.962	0.997	14.8	**In local winter facing south**	0.991
5	-1.48E-04	4.49E-03	0.955	1.000	15.2		0.991
10	-2.67E-04	8.37E-03	0.921	0.966	15.7		0.991
15	-1.99E-04	6.76E-03	0.916	0.984	17.0	**In local Summer facing north**	0.990
20	-1.52E-04	6.13E-03	0.899	0.998	20.2		0.987
23.45	-1.45E-04	6.80E-03	0.879	1.000	23.5		0.981
25	-1.45E-04	7.25E-03	0.868	1.000	25.0	**Always facing south**	0.977
30	-1.44E-04	8.63E-03	0.829	1.000	30.1		0.742
35	-1.43E-04	1.00E-02	0.783	1.000	35.0		0.939
40	-1.41E-04	1.13E-02	0.731	1.000	40.1		0.910

Table (2) values of constanta_s, b_s and c_s (equation (11)) Summer best inclination angle using first approach

Latitude angle	a_s	b_s	c_s	R^2	β_{sbest}		P_{summer}
0	-1.24E-04	3.65E-03	0.964	0.987	14.69	**Facing North**	0.9908
5	-1.46E-04	2.97E-03	0.978	1.000	10.16		0.9883
10	-3.83E-04	9.22E-03	0.944	1.000	12.03		0.9899
15	-2.48E-04	4.59E-03	0.973	1.000	9.26		0.9872
20	-1.56E-04	1.96E-03	0.987	1.000	6.27		0.9820
23.45	-1.45E-04	2.47E-03	0.981	0.999	8.49	**Facing South**	0.9861
25	-1.46E-04	2.96E-03	0.977	1.000	10.12		0.9882
30	-1.44E-04	4.31E-03	0.959	0.999	14.98		0.9908
35	-1.45E-04	5.86E-03	0.932	0.999	20.19		0.9870
40	-1.40E-04	7.03E-03	0.901	1.000	25.09		0.9774

Table (3) values of constanta_w, b_w, and c_w (equation (14)) Winter best inclination angle using first approach

Latitude angle	a_w	b_w	c_w	R^2	β_{wbest}		P_{winter}
0	-1.48E-04	4.40E-03	0.964	1.000	14.81	**Facing South**	0.9965
5	-1.50E-04	6.02E-03	0.932	1.000	12.22		0.9829
10	-1.50E-04	7.49E-03	0.898	0.965	14.34		0.9751
15	-1.49E-04	8.92E-03	0.858	0.989	16.33		0.9641
20	-1.47E-04	1.03E-02	0.811	0.989	20.15		0.9591
23.45	-1.44E-04	1.12E-02	0.775	1.000	23.45	**Facing South**	0.9582
25	-1.43E-04	1.16E-02	0.758	0.999	25.00		0.9581
30	-1.43E-04	1.30E-02	0.697	1.000	30.00		0.9580
35	-1.41E-04	1.42E-02	0.632	1.000	35.00		0.9575
40	-1.42E-04	1.56E-02	0.559	0.999	40.00		0.9574

Table (4) Comparing between total energy received when using one tilt angle through the year and total energy received when using two tilt angles through the year for latitude at northern earth part using first approach for calculating yearly , summer and winter best tilt angle.

Two tilt angles							**Single tilt angle**			
Latitude angle	Summer β_{sbest}	Summer Total Energy received (MJ/m2)	Orientation	Winter β_{wbest}	Winter Total Energy received (MJ/m2)	Orientation	Yearly β_{ybest}	Total Energy received through the year (MJ/m2)	**Orientation**	E%
0	15.27	5829.81	**Facing North**	14.92	6434.24	**Facing South**	14.53	12307.20	**In winter facing south**	-0.352
5	11.38	6373.31		20.11	6437.93		14.81	12496.00		2.522727
10	8.97	6720.90		25.27	6439.74		15.95	12593.60		4.502604
15	8.04	6924.97		30.38	6441.54		17.96	12633.50		5.802113
20	8.59	7033.81		35.46	6443.32		20.84	12642.90		6.598407
23.45	9.84	7073.38	**Facing South**	38.94	6444.20		23.33	12493.80	**Always facing south**	8.194304
25	10.62	7085.00		40.50	6445.08		24.58	12640.80		7.034998
30	14.13	7104.19		45.49	6443.32		29.19	12639.10		7.1873
35	19.12	7104.30		50.45	6443.32		34.66	12641.10		7.171211
40	25.59	7085.43		55.36	6441.54		40.99	12642.70		6.994313

Table (5) Comparing between present work first approach and model used by ref (17) and ref (14).

Two tilt angles					Single tilt angle	
Latitude angle	Summer β_{best}	Summer Total Energy received (MJ/m2)	Winter β_{best}	Winter Total Energy received (MJ/m2)	Yearly β_{best}	Total Energy received through the year (MJ/m2)
Present work first approach Latitude(30)	14.30	7102.22	45.5	6445.08	29	12639.10
Ref(14) Latitude (30)					27.5	12960.00
Present work second approach Latitude(29.5)	13.72	7103.15	45	6445.08	28.6	12638.60
Ref (17) Latitude (29 .49)	5	7198.15	50	6712.222	28	12914.43

Table (6): Comparing between present work optimum tilt angle using first approach and ref [18] optimum tilt angle

Two tilt angles			
Latitude angle	Summer β_{best}	Winter β_{best}	Yearly β_{best}
Present work at Latitude (24.5)	10 Using equation (16)	40 Using equation (17)	24 Using equation (9)
Ref (18) Latitude (24.5)	12	37	23.5