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# Evaluation of the Best Slope Angle for a Flat-Plate Solar Collector

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## ABSTRACT:

The performance of flat plate solar collector is affected by the value of its slope angle with respect to horizontal plane, where the variation of slope angle changes the amount of incident solar radiation. So, using the solar tracking system for solar collector will get the maximum solar radiation, the application of the solar tracking system cost has high operation and maintenance. It is usually suitable to set the solar collector at a best fixed slope angle throughout the year with less reduction in solar radiation received on the collector surface. In this work, a best slope angles were calculated for solar collectors based on the monthly mean daily solar radiations on a horizontal surface over some Iraqi cities (Mosul, Rutba, and Basra). The total of rays flux incident upon a solar collector is mainly affected by the installation angle. The solar collector can be oriented at three different angle settings. The first angle setting is to adjust the collector monthly off to give highest incident solar radiation, while the second angle setting suggests the seasonally changes (Winter, Spring, Summer, Autumn) .The final adjustment for solar collector can be achieved using the mean value for the four seasons to get yearly averaged throughout the year.

Keywords: Solar radiation, Flat-plate collector, and collector best tilt angle.

## ايجاد أفضل زاوية ميل للمجمع الشمسي المسطح

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**الخلاصة:**

يتأثر أداء المجمع الشمسي المسطح بقيمة زاوية الميل المجمع الشمسي مع الأفق، حيث أن اي اختلاف في زاوية ميل المجمع الشمسي سوف تغير من كمية الإشعاع الشمسي الساقط على ذلك المجمع. وباستخدام نظام التتبع الشمسي لذلك المجمع الشمسي سوف نحصل على أقصى إشعاع شمسي، ولكن أنظمة التتبع الشمسية لديها تكاليف التشغيل والصيانة عالية وغير قابلة للاستخدام دائما. لذلك غالبا ما يكون من المناسب تثبيت زاوية ميل المجمع الشمسي لزاوية مثلى خلال أوقات من السنة لتقليل نسبة الخسائر في الإشعاع الشمسي الساقط على سطح المجمع الشمسي في هذا العمل، تم الحصول على أفضل زاوية ميل للمجمع الشمسي معتمدا قيم الإشعاع الشمسي للمعدل اليومي للشهر المقاسة على سطح أفقي لبعض المدن العراق (الموصل، الرطبة، والبصرة). ان قيمة الإشعاع الشمسي الساقط على سطح المجمع الشمسي تتأثر بشكل رئيسي بزاوية تثبيت المجمع، وان المجمع الشمسي يمكن تثبيته بثلاثة وضعيات مختلفة. الزاوية الأولى، يثبت المجمع الشمسي بزاوية ميل لكل شهر من شهور السنة لجمع أكبر مقدار من الإشعاع الشمسي ، في حين أن الزاوية الثانية، تشير إلى تثبيت المجمع لاربع مواسم من السنة (الشتاء، الربيع، الصيف، الخريف). والزاوية النهائية تكون ثابتة خلال السنة بأخذ المعدل الرياضي للفصول الأربعة على مدار السنة.

الكلمات الدالة: الإشعاع الشمسي، المجمع الشمسي المسطح، أفضل زاوية ميل للمجمع الشمسي.

## INTRODUCTION:

In many applications of solar panels, such as solar collectors and solar cells, the slope angle, describes the angle of collectors inclination relative to horizontal,

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which is considered the main variable affecting the collecting radiation of a set collector. In general, the best slope angle of a set collector is connected to the local climatic state, geographic latitude and the time of its use. Therefore, different places will have different best slope angles for a yearly-applied solar collector.

The maximum solar radiation is obtained by facing the southern hemisphere to the north with slope equal to its latitude and the maximum annual energy availability is obtained by (rules of thumb) in which the surface slope equal to latitude is the optimal [1]. The solar energy devices have to skewed to face south with a slope angle equals the latitude of the place in order to achieve the optimal performance all year round founded that at Jeddah by [2]. The horizontal radiation data registered in Hong Kong to find the best tilting angle found that a solar collector with the slope angle nearly equal to latitude of the place collects maximum yearly radiation [3]. An optimum tilt angle and insolation of BIPV panel are presented for different state capital of India by considering shadow effect of surrounding buildings [4]. The optimum slope angle for Izmir city in Turkey is calculated 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 [5]. The best setting angle in Taiwan was calculated according to three different radiation types, the extraterrestrial radiation, global radiation which predicted by empirical model [6]. A relationship between the optimum slope angles and the geographic latitude of the place from 36° to 46° was studied [7]. Monthly, seasonal and annual optimum tilt angles were estimated for Aligarh and New Delhi cities. The annual optimum tilt angle for Aligarh and New Delhi was found as 27.62o and 27.95o respectively (close to the latitude of the respective location [8]. Determination of the optimum collector tilt angles for low latitudes in Nigeria was investigated for monthly, seasonal and yearly average daily values of insolation for tilt angles ranging from 0-40o[9]. A mathematical model was included to evaluate the best slope angle of the collector by differentiate the incidence angle with relative to the slope angle. The results was compared to the work of (Tang, Duffle and Beckman's) equations, and this model gave good agreement to these equations [10].

Determination of the optimum collector slope angles of solar collectors for some cities in Iraq (Kirkuk, Baghdad, Nasiriyah) have been calculated depending on monthly mean daily solar radiation on flat surface for these cities. The results showed the annual optimum tilt angle is approximately equal to the latitude of these cities[11]. An investigation of PV panel optimum tilt angles for various cities in the Kingdom of Saudi Arabia were made to validate the theoretical requirement for negative tilt angles during Summer [12]. A measured data from nine measuring stations in the Southern African Universities Radiometric Network to measure the solar radiation values which is used to calculate the annual solar insolation on fixed collectors at all possible installation angles[13]. Different kinds of models and test methods of optimum tilt angle in different solar systems have been developed to calculate the angle of inclination, and the optimum tilt angle of the collecting surface [14]. An evaluation of optimum tilt angle for a prospective location is southern region of Sindh, Pakistan was made. The optimum tilt angle for monthly, seasonally, and yearly adjustment was determined. The yearly optimum tilt angle was found as 23°, which is close to latitude of investigated location (25°07′N) [15].

This paper investigates the optimum slope angle for the solar flat-plate collectors at each month of the year depending on the values of monthly mean daily radiation on flat surface for three different Iraqi cities (Mosul, Rutba, and Basra), which it recorded for time intervals (1981-1985) makes it as a reference to evaluate on how the composed energy can be greater than before by varying the slope angle seasonally (i.e. four times per year). An engineering equation solver software is used to simulate the maximum collected solar radiation as the tilt angle is varied.

METHODOLOGY:

Appreciation of Solar Rays on the Slanted Surface:

Monthly mean every day sum rays on a skewed surface is normally can be estimated considering the frontal ray, spread and reflected components of the ray on a slanted face. Thus the incident full amount rays on sloped flat can be calculated as follows [18]:

$$\overline{H}_T = \overline{H}_B + \overline{H}_D + \overline{H}_R \quad \ldots\ldots\ldots\ldots(1)$$

Where $\overline{H}_T$ is the entire rays happening on a slanted surface in MJ/m2-day, while $\overline{H}_B, \overline{H}_D, \overline{H}_R$ are monthly mean daily beam, scatter, and ground reflected rays event on a slanted surface in MJ/m2-day respectively.

The monthly mean daily beam radiation received on an inclined surface can be expressed as follows [18]:

$$\overline{H}_B = (\overline{H} - \overline{H}_d) \times R_b \quad \ldots\ldots\ldots\ldots(2)$$

Where $\overline{H}$ is the daily global radiation incident on a horizontal surface in MJ/m2-day, $\overline{H}_d$ is the everyday circulate radiation event on a flat surface in MJ/m2-day, and $R_b$ is the monthly average ratio of the daily beam rays on a skewed surface to that on a straight surface.

The ratio of the average daily beam radiation on a tilted surface to that on a horizontal surface for surfaces located at the northern hemisphere can be estimated as follows [1]:

$$R_b = \frac{\cos(\phi-\beta)\cos\delta\sin\omega'_s + \omega'_s \sin(\phi-\beta)\sin\delta}{\cos\phi\cos\delta\sin\omega'_s + \omega'_s \sin\phi\sin\delta} \quad \ldots\ldots\ldots\ldots(3)$$

Where $\phi$, $\beta$, and $\delta$ are the latitude of place, surface tilt, and sun declination angles in degrees respectively.

In the evening hour comer for the skewed flat for the middle day of the month can be rated from the following neutralization such that [1]:

$$\omega_s' = \min\{\cos^{-1}(-\tan\phi\tan\delta), \cos^{-1}[-\tan(\phi-\beta)\tan\delta]\} \quad \ldots\ldots\ldots\ldots(4)$$

The angle $\omega_s'$ is the sunrise hour angle for a sloped surface in degrees, and the ''min'' sign means the smaller of the two terms in the outside bracket.

The declination angle can be calculated from the following equation[1]:

$$\delta = 23.45 \times \sin[360(284+N)/365] \quad \ldots\ldots\ldots\ldots(5)$$

Where N is the Julian day ranging from 1 (at first of January) to 365 (at thirty one of December). The monthly mean daily ground reflected radiation $\overline{H}_R$ can be written as follows [18]:

$$\overline{H}_R = \overline{H} \times \rho(1-\cos\beta)/2 \quad \ldots\ldots\ldots\ldots(6)$$

Where $\rho$ is the coefficient ground reflection (albedo), which is given to be equal to 0.2 as mentioned in the literature for no snow locations [17].

The sky common rays on sloped surface can be described as follows [18]:

$$\overline{H}_D = R_d \times \overline{H}_d \quad \ldots\ldots\ldots\ldots(7)$$

Where $R_d$ is the monthly average ratio of daily circulate radiation on slanted surface to that on a flat surface and the amount of $R_d$ is calculate by the next neutralization as follow[18]:

$$R_d = [1+\cos\beta]/2 \quad \ldots\ldots\ldots\ldots(8)$$

So the sum rays $\overline{H}_T$ event on a south-meeting collector slanted at an angle $\beta$ with respect to the flat face can be intended as follow [18]:

$$\overline{H}_T = (\overline{H} - \overline{H}_d) \times R_b + \frac{\overline{H}_d}{2}(1+\cos\beta) + \frac{\overline{H}}{2} \times \rho(1-\cos\beta) \quad \ldots\ldots\ldots\ldots(9)$$

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## Observed Radiation Data for Horizontal Surface:

The notice information used in the present study was set in the type of monthly average daily overall ray on flat surface $\bar{H}$ from university of Mosul (college of science) which is recorded for time intervals (1981-1985) at three different Iraqi cities as mentioned in this paper.

The extraterrestrial global radiation $\bar{H}_o$ on straight face in MJ/m2-day can be intended for these sites as follow [16]:

$$\bar{H}_o = \frac{24 \times 3600}{\pi} I_{sc} \times E_o (\cos\delta \cos\phi \sin\omega_s + \frac{\pi\omega_s}{180} \sin\phi \sin\delta) \quad \ldots\ldots\ldots\ldots(10)$$

Where $I_{sc}$ is the solar constant value which is found equal to 1367 W/m2, and $E_o$ is the extraterrestrial solar radiation calculated on the horizontal surface at the nth day of the year in W/m2, which represents the relative range among ground and Sun as follows [16]:

$$E_o = \left[1 + 0.033 \times \cos\left(\frac{360 \times N}{365}\right)\right] \quad \ldots\ldots\ldots\ldots(11)$$

The angle $\omega_s$ is the sunrise or sunset hour angle in degrees, which is found equal to, [16]:

$$\omega_s = \cos^{-1}(-\tan\phi \tan\delta) \quad \ldots\ldots\ldots\ldots(12)$$

The monthly mean daily clearness ratio $K_T$ can be estimated as the ratio of terrestrial global radiation on horizontal surface to the extraterrestrial radiation on the horizontal surface as follows [16]:

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$$K_T = \frac{\overline{H}}{\overline{H}_o} \quad \text{.........................................(13)}$$

The monthly mean daily diffuse radiation on horizontal surface can be correlated to monthly mean daily global radiation as follows [17]:

For $\omega_s \le 81.4^o$, and $0.3 \le K_T \le 0.8$,

$$\frac{\overline{H}_d}{\overline{H}} = 1.391 - 3.56K_T + 4.189K_T^2 - 2.137K_T^3 \quad \text{..........................(14a)}$$

For $\omega_s \rangle 81.4^o$, and $0.3 \le K_T \le 0.8$,

$$\frac{\overline{H}_d}{\overline{H}} = 1.311 - 3.022K_T + 3.427K_T^2 - 1.821K_T^3 \quad \text{..........................(14b)}$$

Finally the monthly mean daily beam rays on flat roof $\overline{H}_b$ in MJ/m2-day can be rated as follows [16]:

$$\overline{H}_b = \overline{H} - \overline{H}_d \quad \text{.........................................(15)}$$

## RESULTS AND DISCUSSION:

An optimal collector slope angle has been evaluated for the three Iraqi cities (Mosul, Rutba, and Basra) depending on the measured value of monthly mean daily solar radiation on horizontal surface. The value of monthly mean daily solar radiation for the cities mentioned above which was obtained for an interval (1981-1985) from university of Mosul (college of science-physics department).

These values of global solar radiation together with extraterrestrial solar radiation may be used to estimate the optimum collector installation angle to receive maximum solar radiation throughout the year. The components of global solar radiation (beam and diffuse) were estimated in equation (15) as mentioned in Liu and Jordan model, [18] and the results for Mosul, Rutba, and Basra cities are presented in Figs. (1a,b,c) respectively.

As shown in these figures, in Winter, the ray and common motif are appearing close to each other due to inclination of earth rotation axis at northern hemisphere away from the sun, which make the sun rays incident on earth surface at very small acute angles. While, in Summer, the ray element is more than scatter part and thus the major help comes from the grin element.

The monthly value mean the total for every day radiation on a south opposite collector next to the slope angle from (0o-90o) for twelve months for the above three cities are shown in Figs.(2a,b), (3a,b) and (4a,b) respectively. The value of total radiation was increased and its reached to peak value at each month depending on a specified collector slope angle, and then it starts to decline for a value of (β) less than the optimum tilt angle.

Figs.(2a,b), (3a,b) and (4a,b) also show that the Summer which includes (June, July, and August) months has highest solar radiation value due to the high altitude of sun across the sky, while in Winter which includes (December, January, and February) months, the sun has the lowest altitude across the sky.

Fig. (5) Shows the solar collector optimal slope angle for Mosul, Rutba and Basra cites along the twelve months of the year. Because the earth has a spherical shape, then the solar radiation that comes from sun has shortest way and approximately perpendicular to the earth at equator plane (zero latitude). So as the collector location is stayed far away from the equator plane, the radiation will need more distance to reach the collector and to satisfy the normality condition the collector slope angle must be increased. So the collector that mounted in Mosul city (latitude of 36.33 deg.) needs a larger collector tilt angle than Basra city (latitude of 30.5 deg.).

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Fig. (6) Shows the monthly mean daily solar radiation corresponding to optimal tilt angle (βopt) for the mentioned cities. Basra has the highest radiation value while the Mosul has the lowest radiation value depending on the latitude value of each place. In other word, as the antenna oriented absent from the equator plane towards the North Pole, the sun appears close to horizon even the time is at solar noon. Moreover, in Winter it needs to set the collector at high tilt angles approximately between (50o- 60o) due to the low altitude of sun across the sky, while it needs to adjust at low angles for Summer between (10o-15o), due to the high elevation of sun in these months.

As mentioned above, the value of collector optimum slope angle depends on position of the sun across the sky (solar altitude angle) which depends on climate seasons and on latitude of the cities. So the optimal collector tilt angle becomes very small and approach to (10o) in Summer or especially in (June month), and its becomes very high and approach to (60o) in Winter especially in (January month) due to altitude of sun across these seasons. So the collector can be mounted in three settings, first: by make the collector tracks the sun at each month depending on the specified day number (N) for each month. Secondly: by make the collector tracks the sun seasonally or once at every season by taking the mathematical average for every three months which makes the tracking mechanism more simple and inexpensive. Thirdly: by making the collector track the sun once in year by taking the mathematical average for the four seasons which makes the collector fixed in place and has one optimal tilt angle during the year as shown in Fig.(7). The geographical coordinates of Mosul, Rutba, and Basra cities are presented in Table (1). In Table (2) show the monthly, seasonally, and the yearly average slope angles for the above stations.

CONCLUSION:

A model for calculating the optimum collector tilt angles for some Iraqi cities has been examined. The representation is described as a relative between the collector installation angle and the values of total radiation that incident on flat-plate collector.

Monthly, seasonally and annually changes in best tip angles for the astral collectors in some Iraqi cities were resolute by using the meteorological datasets of the average monthly and daily universal solar rays on flat surface for three cities (Mosul, Rutba, and Basra).

The optimum tilt angle for the solar collector was appeared to be lower in the summer and higher in the winter seasons. Annual based optimum tilt angle is approximately equal to latitude of the location as mentioned in literatures, like [1], [2] and [15]. The results show that for maximum solar radiation, the collector may be installed at high tilt angles during the Winter, may be installed at moderate tilt angles, and may be installed at small slope angles through the Summer to enable the solar antenna face to soak up the maximum amount of solar rays.

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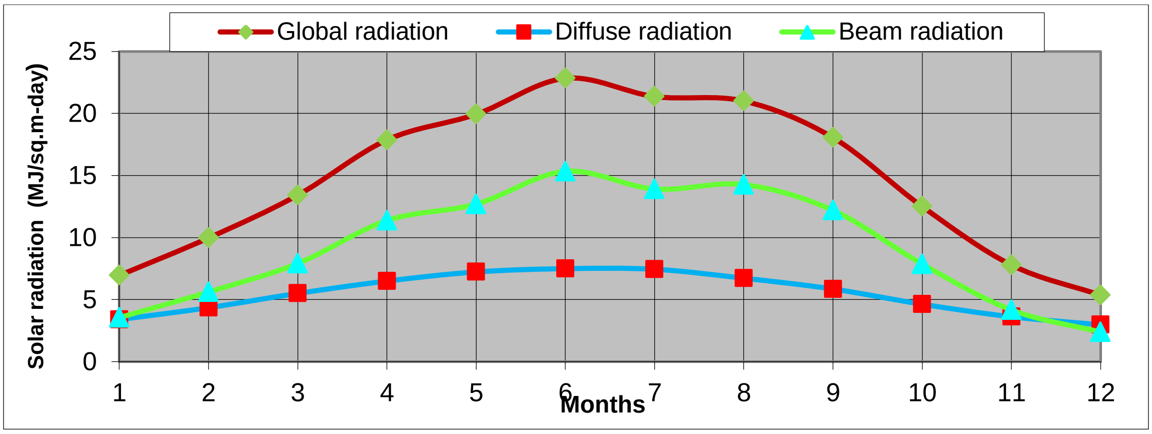


**Fig. (1a) Monthly average daily global radiation $\overline{H}$ , beam radiation $\overline{H}_b$ , and diffuse radiation $\overline{H}_d$ on a horizontal surface for Mosul city.**

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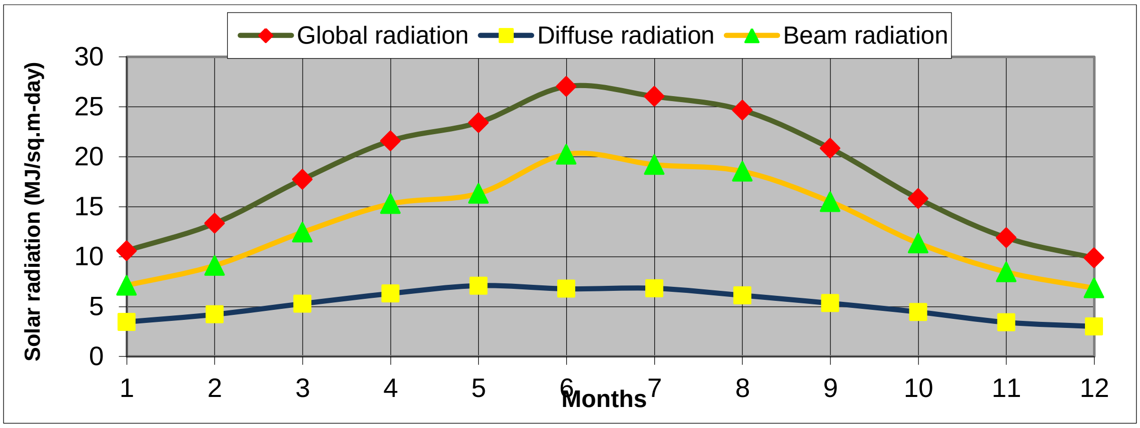


**Fig. (1b) Monthly average daily global radiation $\overline{H}$ , beam radiation $\overline{H}_b$ , and diffuse radiation $\overline{H}_d$ on a horizontal surface for Rutba city.**

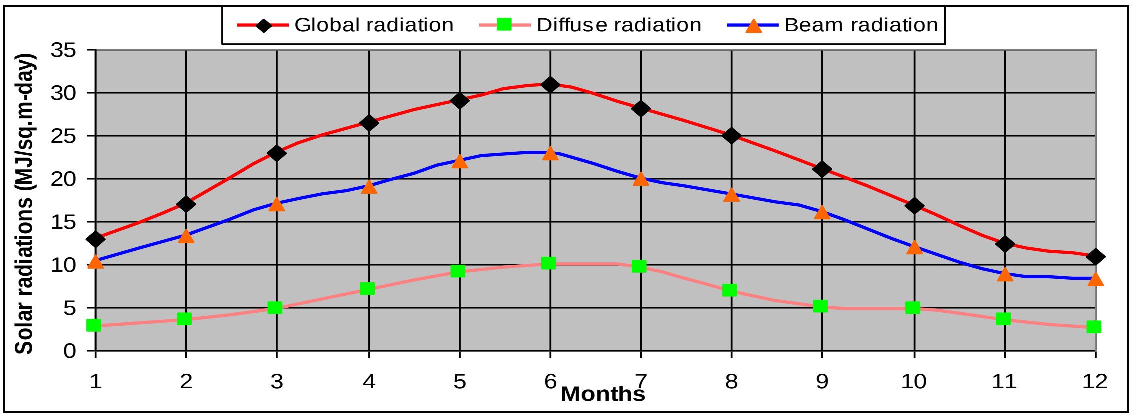


**Fig. (1c) Monthly average daily global radiation $\overline{H}$ , beam radiation $\overline{H}_b$ , and diffuse radiation $\overline{H}_d$ on a horizontal surface for Basra city.**

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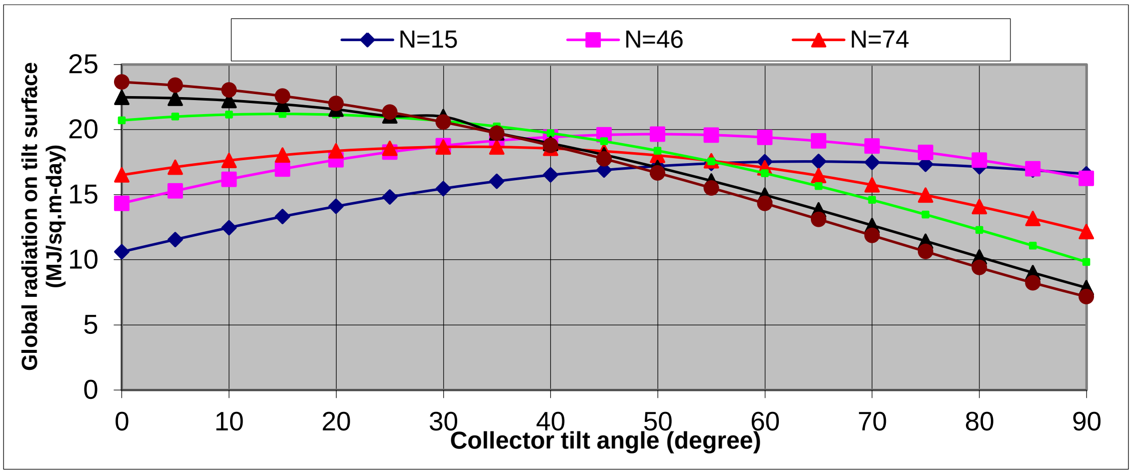


**Fig. (2a) Monthly mean daily total solar radiation $H_T$ on a south facing tilt collector for Mosul city for (January, February, March, April, May, June) months.**

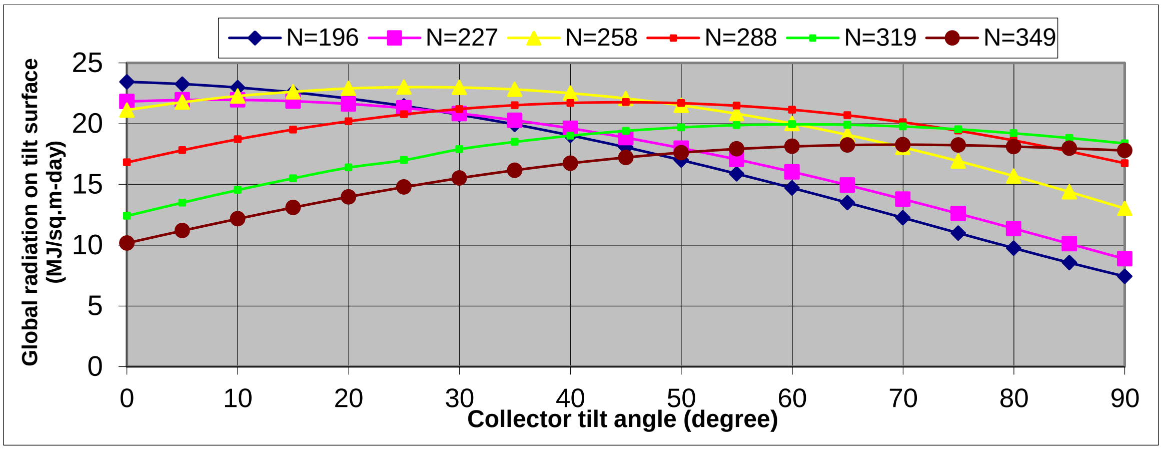


**Fig. (2b) Monthly mean daily total solar radiation $H_T$ on a south facing tilt collector for**

**Mosul city for (July, August, September, October, November, December) months.**

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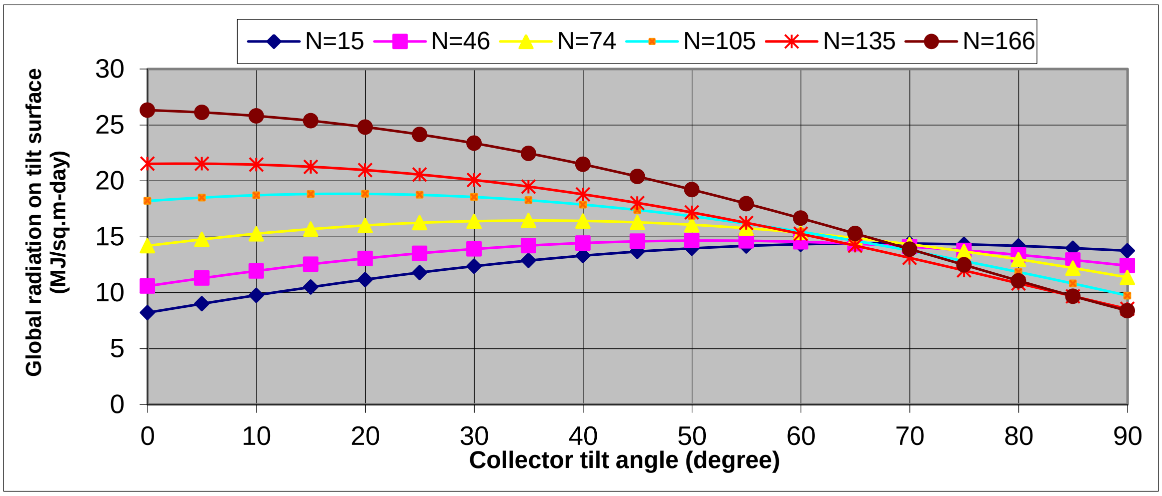


**Fig. (3a) Monthly mean daily total solar radiation $H_T$ on a south facing tilt collector for Rutba city for (January, February, March, April, May, June) months.**

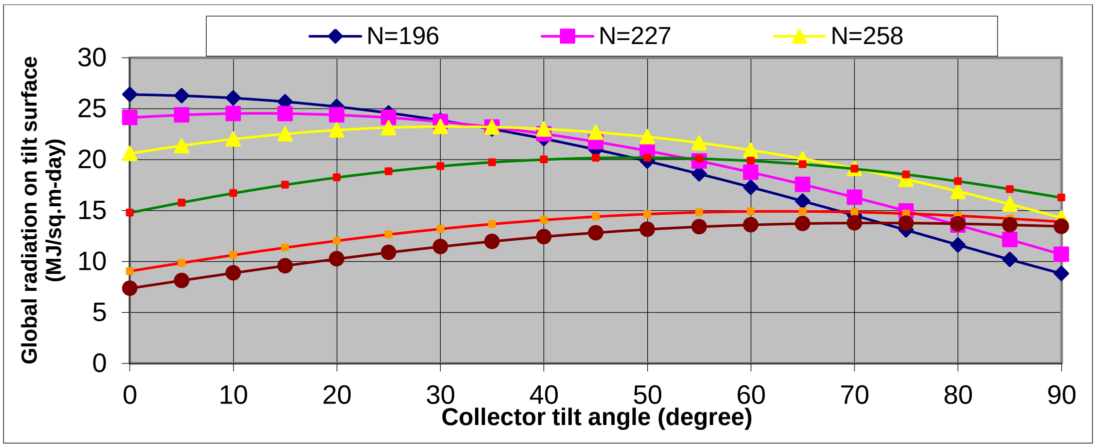


**Fig. (3b) Monthly mean daily total solar radiation $H_T$ on a south facing tilt collector for Rutba city for (July, August, September, October, November, December) months.**

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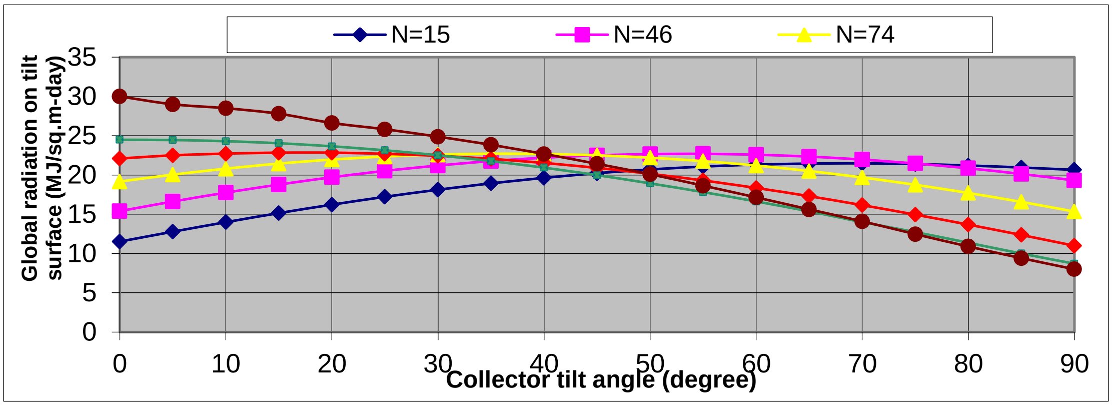


**Fig. (4a) Monthly mean daily total solar radiation $H_T$ on a south facing tilt collector for Basra city for (January, February, March, April, May, June) months.**

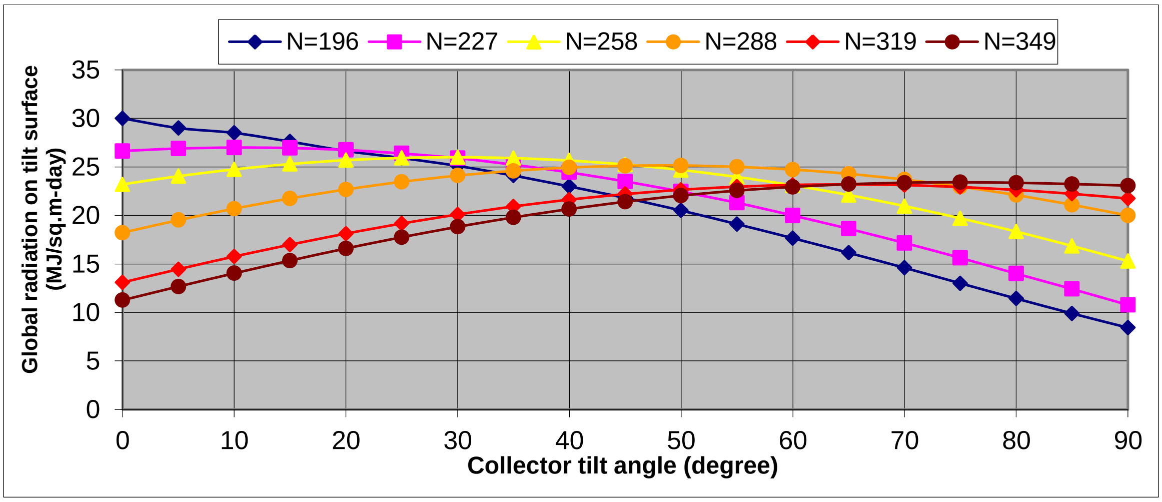


**Fig. (4b) Monthly mean daily total solar radiation $H_T$ on a south facing tilt collector for Basra city for (July, August, September, October, November, December) months.**

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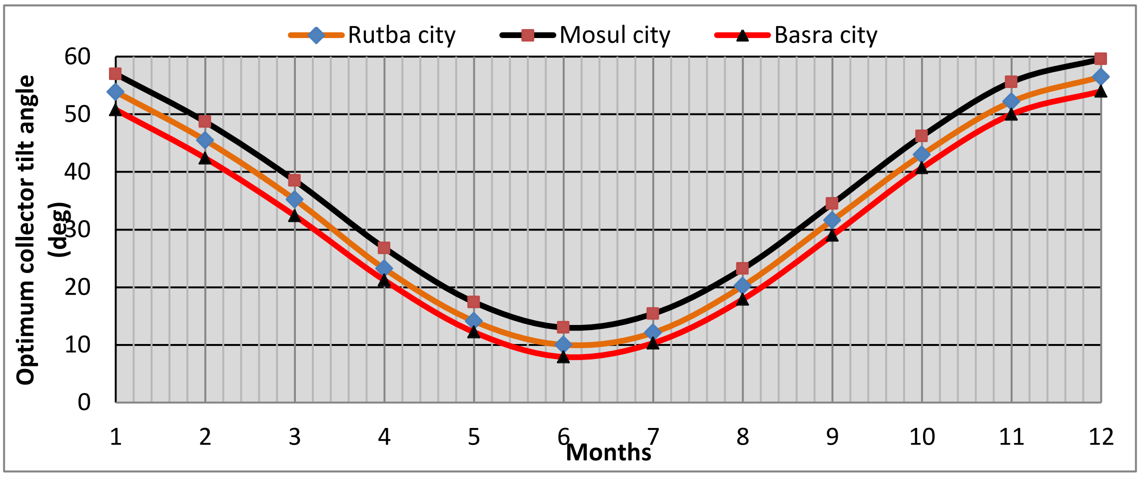


**Fig. (5) Monthly change in calculated optimum tilt angles for a south facing tilt collector for Mosul, Rutba and Basra cities.**

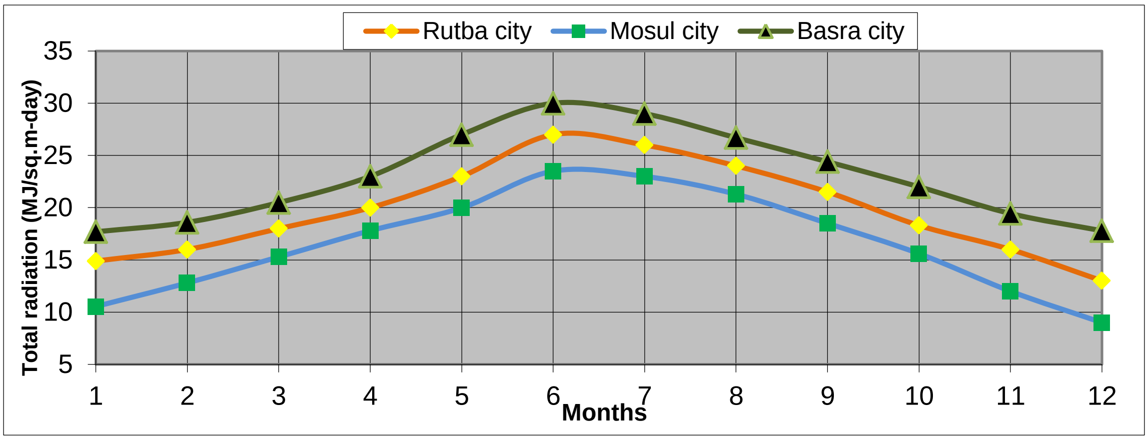


**Fig. (6) Monthly average daily total radiation corresponding to optimum collector tilt**

**angles** $\beta_{opt}$ **for a south facing tilt collector for Mosul, Rutba and Basra cities.**

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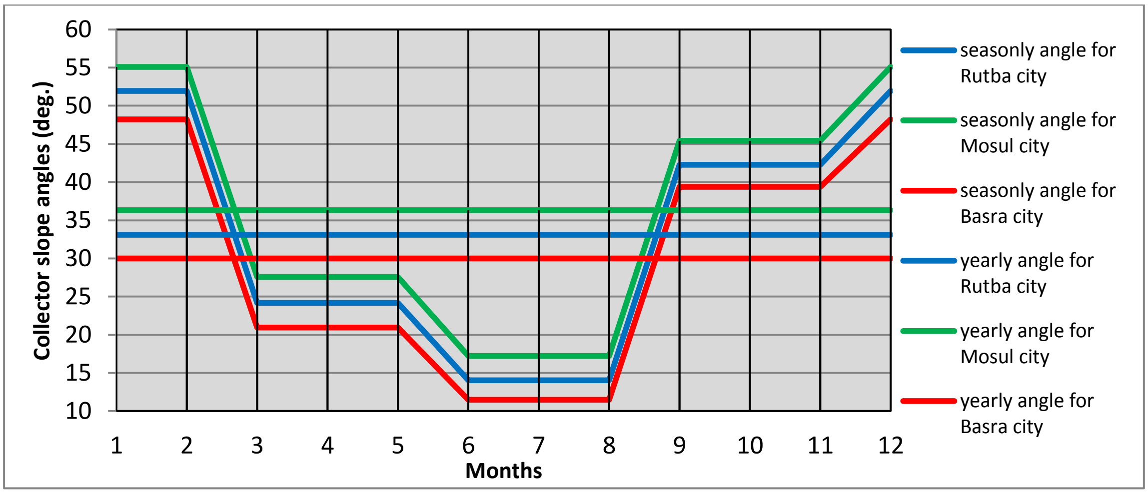


**Fig. (7) Seasonal and annual changes in calculated optimum tilt angles (degrees) for Mosul, Rutba, and Basra cities.**

**Table (1) Geographical Latitude and Longitudinal of the region locations.**

| City | Latitude (degrees) | Longitude (degrees) | Elevation (meter) |
|---|---|---|---|
| **Mosul** | 36.33N | 43.11E | 230 m |
| **Rutba** | 33.03N | 40.28E | 385m |
| **Basra** | 30.50N | 47.81E | 2 m |

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**Table (2) Optimum collector tilt angles for monthly, seasonally, and yearly average for south facing flat-plate solar collector for (Mosul, Rutba, and Basra) cities.**

| Tilt setting | City | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Radiation (MJ/m$^2$-day) | Mosul | 10.92 | 13.65 | 15.62 | 18.57 | 19.95 | 23.22 | 21.36 | 21.11 | 20.02 | 16.55 | 11.87 | 9.06 |
| $\beta_{opt}$ | | 57 | 48.7 | 38.5 | 26.8 | 17.4 | 13 | 15.4 | 23.2 | 34.5 | 46.2 | 55.6 | 59.6 |
| $\beta_{opt}$ for seasonal adjusted | | 55.1 | 55.1 | 27.56 | 27.56 | 27.56 | 17.2 | 17.2 | 17.2 | 45.43 | 45.43 | 45.43 | 55.1 |
| $\beta_{opt}$ for yearly average | | 36.32 | 36.32 | 36.32 | 36.32 | 36.32 | 36.32 | 36.32 | 36.32 | 36.32 | 36.32 | 36.32 | 36.32 |
| Radiation (MJ/m$^2$-day) | Rutba | 14.31 | 16.12 | 18.33 | 21.11 | 23.78 | 26.99 | 24.23 | 23.78 | 22.05 | 18.45 | 16.22 | 13.11 |
| $\beta_{opt}$ | | 53.9 | 45.5 | 35.2 | 23.2 | 14.1 | 9.8 | 12.1 | 20.2 | 31.6 | 43 | 52.2 | 56.5 |
| $\beta_{opt}$ for seasonal adjusted | | 51.96 | 51.96 | 24.16 | 24.16 | 24.16 | 14.03 | 14.03 | 14.03 | 42.26 | 42.26 | 42.26 | 51.96 |
| $\beta_{opt}$ for yearly average | | 33.1 | 33.1 | 33.1 | 33.1 | 33.1 | 33.1 | 33.1 | 33.1 | 33.1 | 33.1 | 33.1 | 33.1 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Radiation (MJ/m$^2$-day) | **Basra** | 17.69 | 18.61 | 20.48 | 23.12 | 27.16 | 30.19 | 29.04 | 26.71 | 24.45 | 22.09 | 19.44 | 17.79 |
| $\beta_{opt}$ | | 50.8 | 42.4 | 32.4 | 21.2 | 12.2 | 7.9 | 10.3 | 17.9 | 29.4 | 41.4 | 50.3 | 54.5 |
| $\beta_{opt}$ for seasonal adjusted | | 48.23 | 48.23 | 20.93 | 20.93 | 20.93 | 11.5 | 11.5 | 11.5 | 39.36 | 39.36 | 39.36 | 48.23 |
| $\beta_{opt}$ for yearly average | | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |