Resources and Environment 2020, 10(1): 10-17
DOI: 10.5923/j.re.20201001.03

Total Solar Radiation and Ideal Incline Angles of a South-Facing Solar Panel in Qena/Egypt

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Abstract The total Solar Radiation (SR) and the Ideal Incline Angles (IIA) of a south-facing solar panel have been calculated in Qena (26.20° N; 32.75° E; 97m asl), Egypt to maximize the performance of solar energy transformers and photovoltaic (PV) panels. Calculations of the IIA were performed at daily, monthly, seasonal and annual time scales. The Egyptian Meteorological Authority measured the used global and diffuse SR data for five years (2012–2016) in the campus of South Valley University in Qena. Results indicated that the monthly IIA varied from 0° in June and July to 58.9° in December. The seasonal IIA values are 56.3°, 29.7°, 0.1°, and 22.3° during winter, spring, summer, and autumn, respectively. The annual IIA was 27.1°. Besides, for surfaces adjusted at monthly, seasonal and annual IIA, the percentage gains in annual average total SR were 13.64%, 12.78%, and 6.57%, respectively. The percentage losses resulted in using surfaces adjusted at seasonal and annual IIA were 0.78% and 6.24%, respectively in comparison to that adjusted at monthly IIA.

Keywords Solar energy, Solar panels, Ideal incline angle, Percentage gain, Percentage loss

1. Introduction

The solar radiation is abundant in most parts of the world, especially between latitudes 20o and 30o in the north and south of the equator due to the lake of cloud cover in these regions. This abundant solar radiation will enhance using solar photovoltaic (PV) panels and solar collectors to generate electricity and heat energy and to fill the deficit in the traditional energies such as oil, coal, and gas. Also, curb the continuous increase in carbon dioxide concentration, which leads to global warming and harmful environmental effects. [1-3].

The amount of solar energy falling on a specific surface depends on the climate characteristics of the region and many other parameters such as clearness index, turbidity coefficients, angle of inclination and direction of the surface. Therefore, it is necessary to calculate the IIA of solar collectors and panels for each location separately. [4,5].

Many studies on the estimation of the IIA of solar collectors and panels have been performed. [6] calculated the IIA of south-facing solar panels in Madina in Saudi Arabia, using measured data of daily global and diffuse SR on a horizontal surface, results indicated that using monthly IIA led to collect the maximum solar energy. The annual IIA was found to be almost equal to the site latitude. Besides, It was found that using the yearly IIA results in an annual loss in the amount of collected energy about 8% in comparison with that collected using the monthly IIA. [7] used a mathematical model to determine IIA and orientation in the high latitudes zone in the southern hemisphere. Results indicated that using daily and monthly IIA maintained almost the same total amount of SR and that the percentage gain of the yearly adjusted surface was 1.8. Also, [8] used a mathematical model to determine the SR on an inclined surface and determined the IIA and surface azimuth angle for the solar collector in the main Syrian zones. Results indicated that the monthly IIA and the daily IIA lead to approximately near the maximum amount of total SR. [9] determined the IIA and azimuth angle of solar PV in the continental United States and compared the yearly global irradiation incident on a panel at optimum orientation with the SR received by a flat horizontal panel and a 2-axis tracking panel. Results indicated that irradiation at ideal fixed-incline increased with increasing latitude by 10%–25% per year. Also, the Irradiation incident on a 2-axis tracking panel in one year was 25%–45% higher than irradiation received by a panel at an ideal fixed orientation. In Turkey, [10] determined the IIA using measured SR data. Results indicated that the daily IIA varied from 0° to 65°. Also, he correlated the IIA with the declination angle by three models. [11], in Abu Dhabi, UAE determined the IIA and the azimuth angle for solar panels and collectors. Results indicated that the IIA was close to the latitude of the location and the best azimuth angle was to the

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Published online at http://journal.sapub.org/re

south direction [3]. IIA of a south-facing solar surface in Tabass, Iran were estimated for each month and different periods by [12]. They used nine diffuse models to estimate the horizontal diffuse component. Results showed that the monthly IIA varies from 0° to 64°, the yearly IIA was found to be 32°, which is close to the latitude of Tabass (33.36°). They indicated also that the gain in annual solar energy is almost the same for surfaces adjusted at IIA in all periods. [13] Studied PV array performance in Brisbane, Australia. They found that the modelled and measured data are in good agreement. Therefore, they used the model to estimate PV system performance at different incline angles and azimuths. [14] studied the effect of changing azimuth angle in the performance of the photovoltaic system in Ritsumeikan University, Japan. They found that due to the superior output performance of amorphous silicon solar cells for thermal recovery effect in summer, the amorphous silicon solar cells installed at the horizontal side produce the output of 104% as high as that of single crystalline silicon solar cells at the south side. Also, they found that the total output power from June 2000 to May 2001 from poly Si north side is 67% of that from the south side.

For calculating the IIA of the flat-plate solar collectors in Cyprus, [15] employed theoretical models to calculate the beam and the diffuse SR components using the measured daily global SR. He calculated the SR on an inclined surface as an inclined angle varied from 0° to 90°. Results indicated that almost maximum energy can be collected by seasonally adjusted surfaces. [16] used hourly measured data of global SR, in Burgos, Spain and tested three different models to estimate the IIA and the intensity of SR incident on a south-facing inclined surface for different periods. Results revealed that the IIA ranged from 7° in June to 70° in December and January. In Toronto, Canada, [17] used isotropic and anisotropic models to calculate the IIA and orientation of Photovoltaic Thermal System. They found that the collector incline should be changed four times a year to receive more solar radiation. In addition, they found that the solar panel should be installed with orientation west or east of due south with a flatter tilt angle. [18] reviewed the role of tilt angles and particularly locating the optimum tilt angle using different methods. Generally, the IIA reported for locations exactly on the equator line ranges between −2.5° and 2.5°, for 71°–90° N, it is 41°–45°.

In Egypt, the IIA and the azimuth angles for solar collectors were calculated in Assiut, Egypt. The results show that the yearly gain in total SR can achieve 6.85% as the IIA adjusted eight times in a year while achieving 29.81% when adjusting the incline angle 6 times and the azimuth angle 12 times in a year. [19-21]. [22] studied the IIA and orientation for flat-plate solar heaters at Giza, Egypt. They found that the solar heater worked with the most efficiency when adjusted to the sun’s rays each half an hour. PV module's performance depends on the azimuth angle and the tilt angle as found in Cairo by [23]. They found that the yearly performance of PV is maximum when incline angles between 20° and 30° and azimuth angle equals 0o. In Helwan, Egypt, [24] compared statistically three anisotropic models called Tamps–Coulson, Perez, and Bugler to recommend the most accurate one for estimating the SR arriving on an inclined surface. Then, they used that model to determine the IIA. Results indicated that Perez’s model shows the best performance.

In Qena, some studies have been done related to solar radiation components on a horizontal surface; see for example [25-28]. No study has been done in Qena for estimating the total SR on an inclined surface and determining the IIA for maximizing the output of the PV and the solar heaters.

In this study, the total SR and IIA of a south-facing flat surface in Qena (26.20° N; 32.75° E; 97m asl), Egypt will be determined for different time scales: daily, monthly, seasonal and annual. Also, maximum total SR received on a surface with incline angle adjusted at horizontal, and at monthly, seasonal and annual IIA will be estimated. Besides, the percentage gain in annual average total SR for surfaces adjusted at monthly, seasonal and annual IIA will be predicted. The percentage losses resulting in using surfaces adjusted at seasonal and annual IIA will be estimated in comparison with that fixed at the monthly IIA. The national weather authority measured the used hourly global and diffuse SR data for five years (2012–2016) in the campus of the South Valley University in Qena.

2. Solar Radiation Data and Climate of the Region

Data are measured by the Egyptian national weather authority in the atmospheric laboratory located in the campus of the South Valley University in Qena (26.20 N°; 32.75 E°). Global SR data on a horizontal surface has been measured using the Precision Spectral Pyranometer (PSP) No. 16317IS, with a spectral range of 0.285 to 2.8 μm.

The diffuse component of the SR is measured by shading the direct beam from the pyranometer measuring global radiation. The Shadow Band Stand, model SBS is used to shade the pyranometer. The Combilog Datalogger (No.1020, TH. Friedrichs & CO “Germany”) recorded the values of hourly global and diffuse solar radiation data. These instruments are calibrated each year. The absolute accuracy of calibration is ±3–4%.

The beam radiation is estimated by subtracting the diffuse component from the global SR. The hourly average data of global, diffuse and beam components (MJ/m^2) over five years (2012–2016) have been used in this study. From these data, daily averages and monthly average daily data have been calculated.

Egypt is located north-eastern Africa, so it consists mostly of a desert through which the Nile passes to divide it into the relatively small Eastern Desert and the relatively large Western Desert. The desert and the location in subtropical latitudes control Egypt's climate. It is mostly semi-continental, except for the northern coasts, where the climate is the Mediterranean Sea climate. The whole year is divided into two main seasons, hot one from May to September and the other is cool from November to March. [29]

Qena is a small city in Upper Egypt (26.20 N, 32.75 E, 97 m asl). It is characterized by a very hot and dry summer and relatively cold winter. The average daily maximum temperature reaches 40℃ in summer and 25o in winter. The average daily minimum relative humidity is about 17% in summer and 26% in winter [30,31]. There is almost no rain in Qena. The winter average maximum mixing height, defined as the height of the layer adjacent to the ground over which pollutants or any constituents emitted within this layer or entrained into it become vertically dispersed by convection or mechanical turbulence (Seibert, P, et al., 2000), is 1418 m while the summer average maximum mixing height is 2481 m [32]. The area receives a large amount of SR, especially in the summer, where the monthly average daily global SR reaches about 27 MJ/ m2 in July as shown in table 1.

3. Methodology

The daily total SR on an inclined surface H_T is a sum of three components: the daily beam SR, $H_{T,b}$, diffuse SR, $H_{T,d}$, and reflected SR, $H_{T,r}$. Thus, according to Liu and Jordan, H_T can be estimated as follows [33,34]

$$H_T = H_{T,b} + H_{T,d} + H_{T,r} \quad (1)$$

To calculate the ideal incline angle (β_{IIA}), eq. (1) may be differentiated with respect to the incline angle β as,

$$\left(\frac{d}{d\beta}(H_T)\right) = 0 \quad (2)$$

In this study the β_{IIA} is determined by searching for the incline angle corresponding to maximum total SR received by the surface. The three components $H_{T,b}$, $H_{T,d}$, and $H_{T,r}$ can be estimated as follows:

The daily beam SR on an inclined surface, $H_{T,b}$, can be obtained from the daily beam SR, on a horizontal plane as

$$H_{T,b} = H_b R_b \quad (3)$$

Where H_b is the beam SR incident on a horizontal plane, R_b is the beam SR conversion factor, which can be defined as the ratio of the average daily beam SR on an inclined plane to that on a horizontal plane [33,35,21].

According to [33], R_b can be estimated as:

$$R_b = \frac{\cos(\varphi-\beta)\cos(\delta)\cos(\omega) + (\pi/180)\omega \sin(\varphi-\beta)\sin(\delta)}{\cos(\varphi)\cos(\delta)\cos(\omega_s) + (\pi/180)\omega_s \sin(\varphi)\sin(\delta)} \quad (4)$$

where φ is the latitude of the location, ω is the sunrise hour angle for the tilted surface which can be estimated as [35]

$$\omega = min\begin{cases}\omega_s \\ -arcos[\tan(\varphi-\beta)\tan(\delta)]\end{cases} \quad (5)$$

The solar declination δ can be calculated as follows, [36]

$$\delta = 23.45\sin\left(360\frac{284+n}{365}\right) \quad (6)$$

where n is the day number in the year, January 1 = 1. The reflected component of radiation falling on an inclined surface can be calculated from the relation:

$$H_{T,r} = H_g R_r \quad (7)$$

where H_g is the global SR falling on a horizontal plane. R_r is the conversion factor of reflected radiation, calculated as

$$R_r = \rho\left(\frac{1-\cos\beta}{2}\right) \quad (8)$$

where $\rho = 0.38$ is the ground reflectivity, calculated from measured daily values of ground albedo in the site during January–Decemeber 2003 (data is not shown).

Many models, isotropic and anisotropic, can be used for estimating the diffuse component on an inclined surface; for isotropic models see [37-39,33]. Also, for anisotropic models see [40-44]. In this work, the diffuse component of radiation falling on an inclined surface is calculated using Liu and Jordan's model [33] as

$$H_{T,d} = H_d R_d \quad (9)$$

where H_d is the diffuse component of the SR falling on a horizontal surface. R_d is the conversion factor of the diffuse SR, known as the ratio of diffuse SR incident on an inclined plane to that on a horizontal plane. R_d can be estimated as [21]

$$R_d = \left(\frac{1+\cos\beta}{2}\right) \quad (10)$$

4. Results and Discussion

Monthly average daily SR components measured in Qena during the period from 2012 to 2016 are shown in Table 1. It is seen from that table that the maximum SR occurs in summer and spring seasons, while the minimum SR occurs in winter seasons. Maximum global SR ranged from 21 MJ/m^2-day in June and July 2005 to 27 MJ/m^2-day in July 2012, while the minimum value occurred in winter and ranged from 12 MJ/m^2-day to 13 MJ/m^2-day in December for the entire period and in January in 2014. The maximum direct SR ranged from 15 MJ/m^2-day in July 2015 to 21 MJ/m^2-day in July 2012, while the minimum value varied from 4 MJ/m^2-day in March 2012 to 8 MJ/m^2-day in December and January 2015 and December 2014. The maximum diffuse SR varied from 7 MJ/m^2-day in May and March 2016 to 18 MJ/m^2-day in March 2012. The minimum values of diffuse SR varied from 3 MJ/ m2-day in January 2016 to 4 MJ/m^2-day in March 2012.

In this work, the β_{IIA} is estimated by searching the angle at which maximum solar energy occurs on the inclined surface. So that, calculations of the diffuse SR and the reflected SR as well as the beam SR conversion factors are made each 0.5° through the incline angle rang from 0° to 90°. Conversion factors of diffuse SR and reflected SR are shown in Fig 1 and Fig 2, respectively. It is clear that the value of the diffuse radiation conversion factor varies from 1 to 0.5 at incline angles of zero and 90°, respectively, while the reflected SR conversion factor varies from 0 to 0.19 at 0° and 90°, respectively. Comparing these results with that obtained in other sites in similar latitudes, the maximum value of the reflected SR conversion factor is almost twice that obtained in Aligarh/India (27.89°N, 78,08°E), where its value varied from 0 to 0.19 in Qena/ Egypt and from 0 to 0.1 in Aligarh/India. This result may be attributed to the difference in the value used for the albedo in the two sites. The used albedo values were 0.38 in Qena and 0.2 in Aligarh/India [45].

Figure 3 depicts the relationship between the beam conversion factor and the surface incline angles that ranged from 0° to 90° with increments of 0.5° in Qena. 180 curves can be illustrated in the figure, but for clarity and simplicity, only 10 curves at increments of 10 degrees of incline angles are shown. At an incline angle 0°, the beam conversion factor is equal to unity for all days of the year because the surface is horizontal. As the incline angle gradually increases from 0° to 90°, the beam conversion factor becomes greater than the unity for the days of winter and autumn, while, its value becomes less than the unity for the days of spring and summer. This may be attributed to the relatively small values of the sun elevation angles in winter and relatively large values of the sun elevation angles in summer.

Substituting from the equations (3), (7) and (9) in the equation (1), the monthly average total SR is calculated for a south-facing flat surface at each 0.5° of incline angles as varying from 0° to 90°. The results are shown in Fig.4a for the first half of the year, January to June, and in Fig.4b for the second half of the year, July - December. From Fig.4a, b it is obvious that the total SR is a rigorous function of the incline angle. For most months, the calculated SR increases as the incline angle increases to a certain value, after which it decreases. The results revealed that the β_{IIA} varies with the months of the year, as shown in Fig. 5 and table 2. The β_{IIA} decreases from January to May, remains at zero from Jun to July, and then increases from August to December.

Figure 6 shows the daily β_{IIA} for a south-facing flat surface in Qena. These β_{IIA} were found by searching for the values for which the total SR on the inclined plane is at maximum for a particular day. Results indicate that the daily β_{IIA} varies from 59.5° in January 4 to 0.5° in May 4. β_{IIA} were negative for the period from May 5 to August 10. However, a zero value is suggested for such days, since a negative tilt to the north has no significance. There are other studies with the same results such as [45]. From August 11to Dec. 31, the β_{IIA} varied from 0.18° to 58.7°.

Table 2 shows the β_{IIA} for each month, season and the total year calculated for Qena. Seasonal β_{IIA} are calculated by averaging the corresponding monthly β_{IIA}. It is clear that the summer is characterized by the least seasonal β_{IIA} being 0.1°, while winter has the most β_{IIA} of 56.3°. Spring and autumn β_{IIA} are 29.7° and 22.3°, respectively. The annual value of the β_{IIA} is 27.1°, which is relatively close to the latitude of Qena, 26.20°. So that, south-facing flat surfaces can be fixed seasonally at seasonal β_{IIA} and annually at an annual β_{IIA}.

For assessing the validity of the determined IIA in Qena, the resulted yearly IIA, 27.1, is compared with the calculated values using linear equations stated by [46,47] and by polynomial equation stated by [48]. The calculated values were 22.2°, 25.3° and 24.4°, respectively. It is clear that the value estimated by our study is better than that estimated by [46] and [48]. Estimated value by this study increases only by 0.9° than the value of the latitude 26.20°. This deviation is convenient with that stated by the linear model used by [47], where it gives less value by 0.9°.

Table 1. Monthly average daily global (H_g), direct (H_D) and diffuse (H_d) solar radiation MJ/m^2-day for a horizontal surface during the period 2012–2016 in Qena

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Max	Min
H_g 2012	15	15	22	25	26	25	27	26	22	18	15	13	27	13
H_g 2013	14	18	21	25	26	24	24	22	20	17	13	12	26	12
H_g 2014	12	14	19	22	24	24	24	22	20	17	14	12	24	12
H_g 2015	13	14	17	20	20	21	21	19	18	16	13	12	21	12
H_g 2016	13	16	17	21	22	23	23	21	18	15	12	12	23	12
H_D 2012	8	8	4	12	17	19	21	20	17	13	11	10	21	4
H_D 2013	9	11	16	19	17	18	18	17	15	12	9	8	19	8
H_D 2014	8	10	13	15	10	19	18	17	16	12	10	8	19	8
H_D 2015	9	7	11	13	12	14	15	12	11	10	9	8	15	7
H_D 2016	10	11	10	15	15	17	18	15	15	11	8	8	18	8
H_d 2012	7	8	18	13	9	6	6	5	5	5	4	4	18	4
H_d 2013	5	6	6	6	8	6	6	5	5	4	4	4	8	4
H_d 2014	4	5	6	7	15	6	5	6	5	5	4	4	15	4
H_d 2015	4	7	7	7	8	7	5	7	7	6	4	4	8	4
H_d 2016	3	5	7	6	7	6	5	6	4	5	4	4	7	3

Table 2. Ideal incline angles for each month, season and the whole year of a south-facing surface in Qena

Month	β_{IIA} (deg)	Season	β_{IIA} (deg)	Annual	β_{IIA} (deg)
Jan	56.8				27.1
Feb	45.7				
Mar	31.4	Spring	29.7		
Apr	12.1				
May	0.2				
Jun	0.0	Summer	0.1		
Jul	0.0				
Aug	4.5				
Sep	21.9	Autumn	22.3		
Oct	40.4				
Nov	53.3				
Dec	58.9	Winter	56.3		

The monthly average daily measured values of SR at a horizontal surface and the calculated total SR at β_{IIA} for each month, season, and the whole year are shown in Table 3. It is obvious that the monthly values are at maximum during the period from April to August, with the maximum occurs in June (20.90 MJ/m^2-day). At the seasonal β_{IIA}, the calculated total SR was found to be at maximum in summer, with the value reaching 20.90 MJ/m^2-day) in June, the minimum value was in spring, with a value of 16.62 MJ/m^2-day. Values of the total SR incident at an annual ideal incline angle ranged from 16.50 MJ/m^2-day in February to 19.76 MJ/m^2-day in April.

The percentage gain in the SR incident on an inclined surface can be calculated as:

$$\text{Percentage gain } \% = \left(\frac{H_T \text{ at } \beta = \beta_{IIA_i}}{H_T \text{ at } \beta = 0} - 1\right) x100 \qquad (11)$$

where i refers to month, season and annual.

As stated in Table 3, for the surfaces adjusted at monthly, seasonal and annual β_{IIA}, the percentage gains in annual average total SR were 13.64%, 12.78%, and 6.57%, respectively. These values are close to the percentage gain found in Aligarh, India [45].

The estimated annual average total SR on a horizontal surface and inclined surface at β_{IIA} of each month, season and annual inclined angles are shown in Figure 7. From this figure, we can see that the annual average total SR estimated at monthly β_{IIA} is the most (19.24 MJ/m^2-day), followed by the annual average total SR estimated at seasonal (19.09 MJ/m^2-day), annual (18.04 MJ/m^2-day) and horizontal (16.93 MJ/m^2-day) β_{IIA}.

The loss in total SR incident on a south-facing flat surface fixed on seasonal β_{IIA} and annual β_{IIA} in comparison to the total SR incident on a surface fixed at a monthly β_{IIA} can be calculated as

$$\text{Percentage gain } \% = \left(\frac{H_T \text{ at } \beta = \beta_{IIA_i}}{H_T \text{ at } \beta = 0} - 1\right) x100 \qquad (11)$$

where j refers to season and annual.

The estimated percentage loss of total SR was found to be 0.78% and 6.24% for surfaces adjusted at seasonal and annual β_{IIA} in comparison with a surface fixed at a monthly β_{IIA}.

Table 3. Maximum monthly average daily total solar radiation MJ/m2-day incident on a surface with incline angles adjusted to that of horizon, each month, each season, and the whole year in Qena

	H_T (MJ/ m^2-day)			
Month	$\beta = 0$	β_{IIA} = Monthly	β_{IIA} = Seasonal	β_{IIA}= Annual
Jan	12.61	19.13	19.13	17.28
Feb	14.02	16.90	16.62	16.50
Mar	17.15	18.68	18.69	18.68
Apr	19.96	20.23	19.60	19.76
May	19.96	19.96	19.96	18.17
Jun	20.90	20.90	20.90	18.14
Jul	20.51	20.51	20.51	17.96
Aug	19.33	18.94	18.76	18.42
Sep	18.06	19.02	19.02	18.98
Oct	15.59	18.75	18.09	18.37
Nov	13.12	19.07	19.05	17.51
Dec	11.94	18.79	18.78	16.71
Average	16.93	19.24	19.09	18.04
Gain %		13.64	12.78	6.57

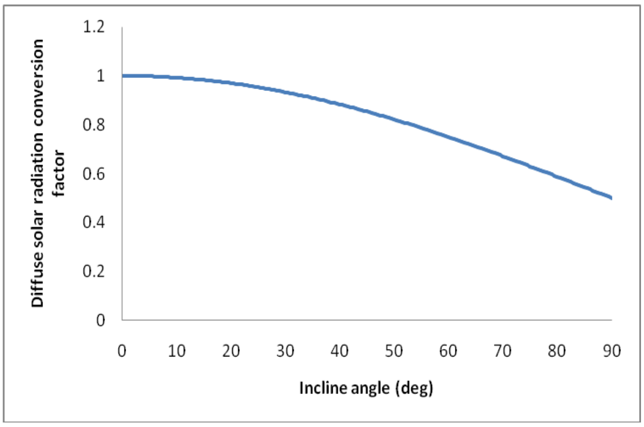

Figure 1. Conversion factor of diffuse solar radiation at different incline angles in Qena

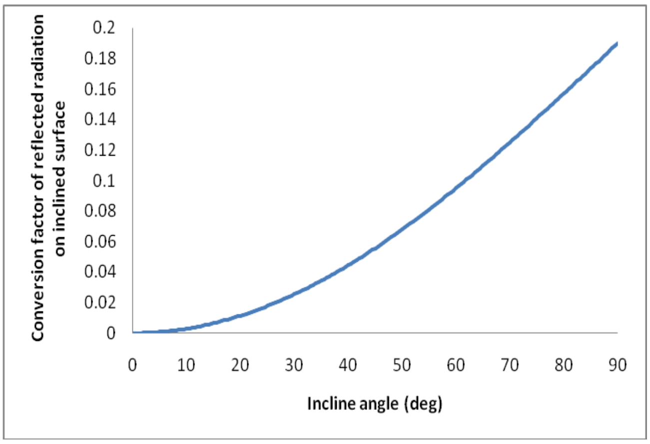

Figure 2. Conversion factor of reflected solar radiation at different incline angles in Qena

According to the calculated total SR incident on a south-facing flat surface fixed at β_{IIA} for each month, season, and year, it is better to fix the surface at the monthly β_{IIA} to gain the maximum solar energy, or on a seasonal β_{IIA}, which experiences only a small percentage loss (0.78%). Using surfaces fixed at an annual β_{IIA} causes a loss of total energy of 6.24%.

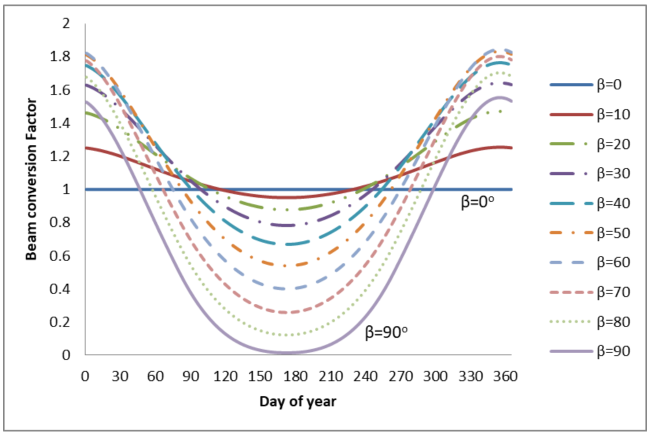

Figure 3. Conversion factor of beam solar radiation at different incline angles ranging from 0° to 90° in Qena

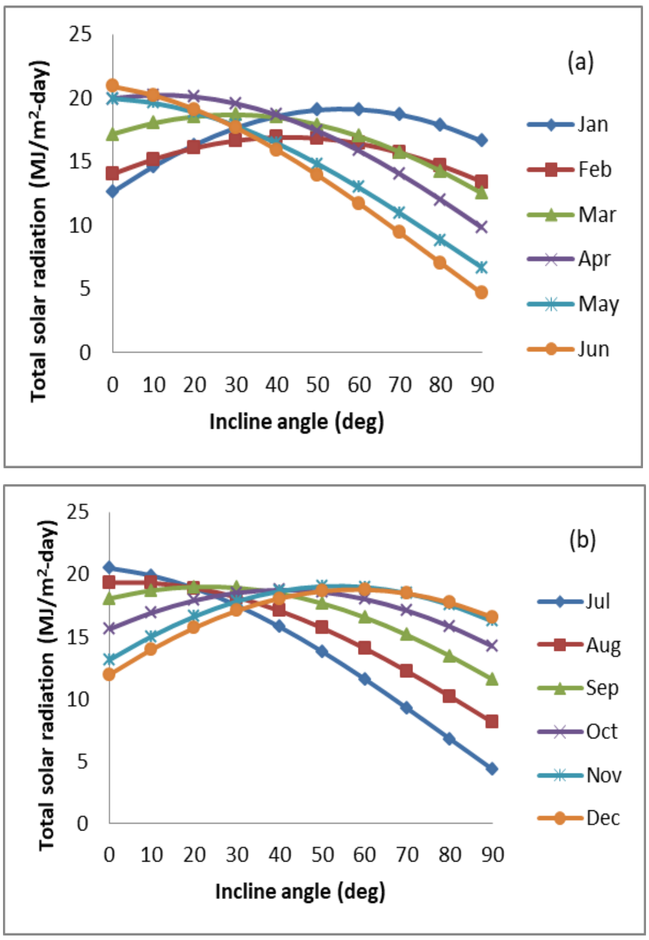

Figure 4. Monthly average daily total solar radiation versus incline angle for a south-facing surface in Qena, (a) for the months from Jan. to Jun. and (b) for the rest months of the year

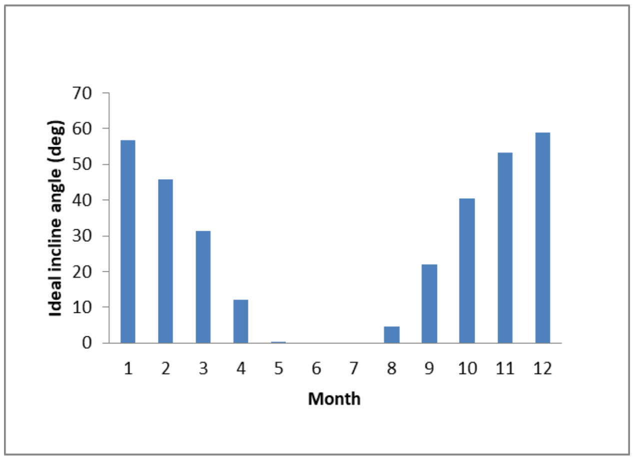

Figure 5. Monthly variation of ideal incline angle for a south-facing flat surface in Qena

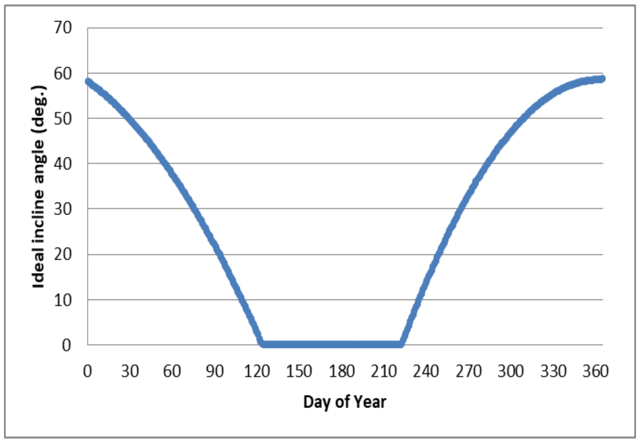

Figure 6. Daily values of the ideal incline angle for a south-facing surface in Qena

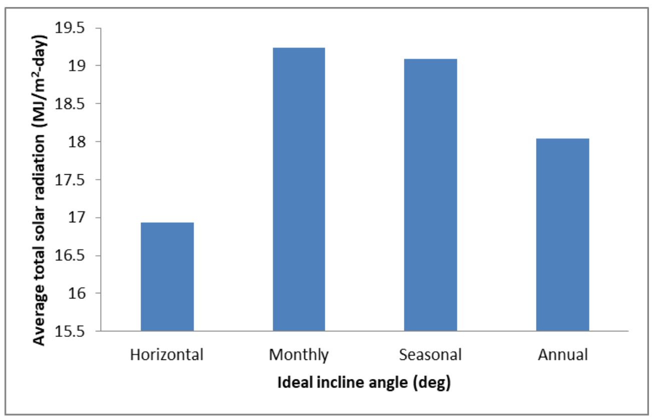

Figure 7. Comparison of annual average total solar radiation for a surface fixed horizontally and a south-facing surface at monthly, seasonal and annual ideal incline angles

5. Conclusions

In this study, five years of hourly data of global and diffuse horizontal SR measured in Qena/Egypt were used for the calculation of the total solar radiation and the IIA of a south-facing flat surface.

According to the climate characteristics of Qena and its geographical position, the daily values of IIA vary from 0° to 59.5°. The monthly values vary from 0° to 58.9°. Seasonally, summer season was characterized by the least IIA, 0.1°, while winter has the most IIA, 56.3°. Spring and autumn IIAs are 29.7° and 22.3°, respectively. The annual value of the IIA is 27.1°, it is relatively close to the latitude of Qena, 26.20°N.

This study suggests fixing the surface on the monthly IIAs in Qena to gain the maximum solar energy, or at the seasonal IIAs, with an insignificant loss (0.78%). Using surfaces fixed at an annual IIA causes a loss of total energy of 6.24%.

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