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Attaining Optimum Tilts of Flat Solar Surfaces Utilizing Measured Solar Data: Case Study for Ilam, Iran

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Abstract: The efficiency of the flat solar surfaces, such as thermal collectors and photovoltaic (PV) panels, depends on the received beam and diffuse radiation components and the angle of the beam incidence. In this study, based on the long term measured data tilt angle optimization of the flat solar surfaces in the city of Ilam, Iran, for the daily, monthly, seasonal and annual fixed adjustments have been performed. Study of characteristics of solar radiation showed that Ilam has 220 days in the year with horizontal global radiation in the range of 15-35 MJ/m^2 and 182 sunny or very sunny days having daily clearness index higher than 0.6. The optimum tilt for the fixed daily adjustment throughout the year varies between zero and 61° and the optimum tilt for the fixed monthly adjustment varies between 0° in June and July up to 60.1° in December. The optimum tilt for the fixed annual adjustment is 26°, which is close to latitude of Ilam (33.38°). Furthermore, the optimum tilt for the fixed seasonal adjustment in winter and autumn are 12.3 and 20° higher than the latitude of Ilam, respectively; whereas in spring and summer they are 30.3 and 21.1° less than the latitude, respectively.

Key words: Solar radiation · Optimum tilt angle · Flat solar surfaces · Collectors · Ilam

INTRODUCTION

Solar energy is the most important clean, free and unending renewable energy source which can be utilized in many parts of the world. The limitation and shortage of fossil fuels and the issues resulted from changes of world environmental and weather conditions have created a good opportunity for solar energy to compete with fossil based fuels. This is more important, in countries with high potential of solar radiation to be benefited from green and clean energy. Utilization of different kinds of solar energy technologies such as solar photovoltaic, concentrating solar thermal power, solar hot water/space heating systems, solar dryers, solar stills and solar ovens are becoming rapidly widespread. Aligned with recent augmented deployment of these technologies, many studies have been undertaken to enhance the performance of such technologies [1-5].

Flat-plate solar surfaces, such as thermal collectors and PV panels, have wide applications in domestic and industrial solar systems. A solar system, like any other system, must perform with the highest possible efficiency. This needs the correct design, manufacturing and installation of different components of the system. As for flat solar collectors, the best possible angle of the radiation incidence depends on their orientation and tilt angle; thus determining the proper installation is very vital in order to improve their performance. The optimum tilt angle is influenced by different factors such as the latitude, the clearness index, the air pollution and the distribution of the sunny days throughout the year [6-8]. Therefore, in order to design a solar energy system utilized by flat collectors in a region, performing solar radiation evaluation is essential for attaining suitable information about these factors. A study of this type has recently been undertaken by Khorasanizadeh *et al*. [9] for Yazd province of Iran.

There have been many studies on the optimum tilt and azimuth angles of solar surfaces around the globe, from which references are made here only to some of

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them. Kern and Harris [10] explained the calculations related to the optimum slope angle based on the beam radiation. Chiou and EI-Naggar [11] carried out an investigation for many regions of the world using different techniques to attain the relation between the optimum slope angle and the latitude. Lewis [12] suggested two theoretical models for determining the optimum angle. In one model, he considered the cloudy and clearness indexes as variables and in another one he used Kern and Harris's model [10]. El-Kassaby [13] introduced an analytical equation for finding the optimum slope angle in any latitude and showed that it can be integrated to calculate the optimum slope angle for any period of time. Hj Mohd Yakup and Malik [14] and Skeiker [6], studied the issue of optimum slope angle in Brunei and Syria, respectively. They mentioned that in northern hemisphere the best orientation for the collectors is tilting them toward the south and the optimum tilt is only dependent on the latitude. Skeiker [6] developed an equation for calculating the optimum daily slope angle and computed the optimum daily slope angle for some cities in Syria. Hussein *et al.* [15] used the software TRNSYS and showed the optimum slope angle for annual fixed adjustment of collectors in Cairo, Egypt, is φ- 10. Ulgen [16] used a mathematical model and determined the monthly, seasonally and yearly optimum slope angles for collectors in Izmir, Turkey. He mentioned that the optimum slope angle varies between 0 and 61° for different months of the year. Gunerhan and Hepbasli [17] recommended that if a collector in Izmir is adjusted fixed for the whole year, its optimum slope angle is equal to the latitude. Furthermore, for seasonal fixed adjustment, they reported that the optimal slope angle is φ+15 for winter and φ-15 for summer. Calabro [18] showed the annual optimum slope angle in the area of southern-Italy (Sicily) is φ-10. Chenga *et al.* [19] indicated that the annual slope angle is approximately equal to the latitude for the regions below the equator line and for higher latitudes the angle is less than the latitude.

Using the genetic algorithm technique, Talebizadeh *et al.* [20] theoretically determined the surface azimuth and optimum tilt angles of collectors for installation in Kerman. By assuming that the collector surface is always facing toward the equator, Benghanem [21] determined the optimum slope of flat solar collectors in Madinah, Saudi Arabia. In order to calculate the optimum tilt angle, he used the measured values of daily total and diffuse solar radiations on a horizontal surface. He reported that annual optimum tilt angle is approximately equal to latitude, i.e. 23.5°. Also, he found that the optimum seasonal tilt angle in winter and summer are 37° and 12°, respectively. He reported that the loss of receiving energy is around 8% when adjusting the collector fixed with the annual optimum tilt angle compared with that of a collector adjusted monthly with the optimum tilt angle. In a recent study, Khorasanizadeh *et al*. [22] developed a horizontal diffuse radiation model for city of Tabass in Iran and determined the optimum tilt angle for south-facing solar surfaces for the fixed monthly, seasonal, semi-yearly and yearly adjustments.

Iran is located in a sunny region of the world enjoying high amount of solar radiation with 240-250 sunny days in the year. Tilt angle optimization of flat solar surfaces in the city of Ilam, the center of Ilam province of Iran, has not been yet carried out. Hence, in this study the seven years measured solar data have been utilized firstly to obtain the averaged daily horizontal total radiation (HGR) throughout the year. Then, based on these HGR values the daily clearness index, the monthly averaged HGR and clearness index values have been achieved. Finally, optimum tilt angles of flat solar surfaces have been obtained for the fixed daily, monthly, seasonal and annual tilt adjustments.

MATERIALS AND METHODS

In this section, the study region and the method utilized for applying the measured solar data are explained first. Then the mathematical models used for obtaining the solar radiation on inclined surfaces as well as well as clearness index are presented.

Figure 1 portrays the geographic location of the city of Ilam on the map of Iran, with the latitude of 33.38° and the longitude of 46.25°. The total daily solar radiation on horizontal surface, measured for seven years (2004-2010) in Ilam meteorological station, have been employed to obtain the average total daily radiation values, H, for all of days of the year. Then these values have been used to obtain the monthly averaged daily total radiation on horizontal surface for all of the months of a year. All further calculations for obtaining the daily as well as monthly averaged daily clearness indexes and optimum tilts of flat solar collectors are based on these averaged values.

Most of the solar radiation data are measured for horizontal surfaces; therefore it is necessary to calculate the solar radiation on a tilted surface through mathematical modeling. The total daily solar radiation on a tilted surface consists of [23].

Fig. 1: Geographic location of the city of Ilam on the map of Iran.

$$H_T = H_{bT} + H_{dT} + H_{gT} \tag{1}$$

where H_T is the average daily radiation on tilted surface and H_{bT}, H_{dT} and H_{gT} are the averaged daily beam, daily diffuse and ground-reflected radiations on the tilted surface, respectively. For calculating these terms, a method presented by Klein [24] has applied, by which the diffuse and the ground-reflected radiations are calculated using the isotropic model, stated as follows:

$$H_T = H_b R_b + H_d \left(\frac{1+\cos\beta}{2}\right) + H\rho_g\left(\frac{1-\cos\beta}{2}\right) \tag{2}$$

β is the collector slope angle and ρ_g is the ground reflectivity coefficient which is dependent on the kind of the ground around the tilted surface. H_b is the beam daily radiation on a horizontal surface and R_b is the ratio of the beam radiation on the tilted surface to that on a horizontal surface. For the northern hemisphere R_b is expressed as [24]:

$$R_b = \frac{\cos(\phi-\beta)\cos\delta\sin\omega'_s + \left(\frac{\pi}{180}\right)\omega'_s\sin(\phi-\beta)\sin\delta}{\cos\phi\cos\delta\sin\omega_s + \left(\frac{\pi}{180}\right)\omega_s\sin\phi\sin\delta} \tag{3}$$

where φ is the latitude and ω_s is the sunset hour angle for a horizontal surface, defined as [23]:

$$\omega_s = \cos^{-1}(-\tan\varphi\tan\delta) \tag{4}$$

δ is the declination angle defined as the angular position of the sun at solar noon with respect to the plane of the equator. δ is determined from following expression [24]:

$$\delta = 23.45\sin\left(360\frac{284+n}{365}\right) \tag{5}$$

n is the day number from the first of January. ω'_s is the sunset hour angle for an inclined surface and is defined as [24]:

$$\omega'_s = \min\begin{bmatrix}\cos^{-1}(-\tan\varphi\tan\delta)\\ \cos^{-1}(-\tan(\varphi-\beta)\tan\delta)\end{bmatrix} \tag{6}$$

To calculate H_b and H_d in equation (2), the K_T method [25] is used. K_T is the daily clearness index and is defined as the ratio of the terrestrial global daily radiation on a horizontal surface to the extraterrestrial radiation on a horizontal surface at the same latitude as [23]:

$$K_T = \frac{H}{H_o} \quad (7)$$

H_o is extraterrestrial radiation obtained from [23]:

$$H_o = \frac{24 \times 3600\, G_{sc}}{\pi}(1 + 0.033\cos\frac{360n}{365})(\cos\varphi\cos\delta\sin\omega_s + \frac{\pi\omega_s}{180}\sin\varphi\sin\delta) \quad (8)$$

G_{sc} is the solar constant equal to 1367 (W/m^2) [23]. After calculating K_T, H_d can be determined from [25]:
For $\omega_s \le 81.4°$:

$$\frac{H_d}{H} = \begin{cases} 1.0 - 0.272K_T + 2.4495K_T^2 - 11.9514K_T^3 + 9.3879K_T^4 & \text{for } K_T < 0.715 \\ 0.143 & \text{for } K_T \ge 0.715 \end{cases} \quad (9)$$

and for $\omega_s \le 81.4°$:

$$\frac{H_d}{H} = \begin{cases} 1.0 + 0.2832K_T - 2.5557K_T^2 + 0.8448K_T^3 & \text{for } K_T < 0.722 \\ 0.175 & \text{for } K_T \ge 0.722 \end{cases} \quad (10)$$

Then H_b is obtained from:

$$H = H_b + H_d \quad (11)$$

To calculate the monthly averaged daily radiation on a tilted surface a similar procedure must be carried out, except that for obtaining R_b the values of ω_s, ω_s' and δ are calculated for the average day of that month. The average day of each month and the corresponding day number from the beginning of the year are presented in Table 1.

For each month, the monthly averaged daily radiation on a tilted surface is defined as [25]:

$$\bar{H}_T = \bar{H}_b\bar{R}_b + \bar{H}_d(\frac{1+\cos\beta}{2}) + \bar{H}\rho_g(\frac{1-\cos\beta}{2}) \quad (12)$$

$\bar{H}_d$ and $\bar{H}_b$ are the monthly averaged daily diffuse and beam radiations on a horizontal surface, respectively and $\bar{R}_b$ is the ratio of the beam radiation on the tilted surface to that on a horizontal surface on the average day of the corresponding month. For calculating $\bar{H}_d$, the monthly average clearness index is used, which is [26]:

$$\bar{K}_T = \frac{\bar{H}}{\bar{H}_o} \quad (13)$$

Table 1: The monthly average day of every month and its related day number [25].

Month	Monthly average day	n, for monthly average day
January	17	17
February	16	47
March	16	75
April	15	105
May	15	135
June	11	162
July	17	198
August	16	228
September	15	258
October	15	288
November	14	318
December	10	344

$\bar{H}_o$ is the monthly average daily extraterrestrial radiation calculated via Eq. (8) for the average day of each month for the latitudes in the range of $-60 \le \varphi \le 60$.

For $\bar{K}_T$ in the range of 0.3 to 0.8, $\bar{H}_d$ could be obtained from [25]:
for $\omega_s \le 81.4°$:

$$\frac{\bar{H}_d}{\bar{H}} = 1.391 - 3.560\bar{K}_T + 4.189\bar{K}_T^2 - 2.137\bar{K}_T^3 \quad (14)$$

and for $\omega_s \le 81.4°$:

$$\frac{\bar{H}_d}{\bar{H}} = 1.311 - 3.022\bar{K}_T + 3.427\bar{K}_T^2 - 1.821\bar{K}_T^3 \quad (15)$$

After calculating $\bar{H}_d$ from the above equations, $\bar{H}_b$ can be determined from:

$$\bar{H} = \bar{H}_b + \bar{H}_d \quad (16)$$

To calculate the optimum tilt angle for different adjustment strategies a computer program was prepared in FORTRAN software.

This program utilizes the calculated values of averaged daily global radiation on a horizontal surface to obtain the beam and diffuse components via Eqs. (7) to (11). Then for obtaining the optimum slope angle for the fixed daily adjustment it changes β from 0° to 90° with interval of 0.1°. In order to obtain H_T for every day and every β, the program employs Eqs. (3) to (6) to calculate the terms in right hand side of Eq. (1). At last the β which causes the maximum value of H_T is chosen by the program as the optimum tilt angle for that day. For the fixed monthly adjustment the program firstly utilizes the calculated values of monthly mean daily global radiation to obtain the beam and diffuse components on a horizontal surface via Eqs. (13) to (16). Then for obtaining the optimum slope angle for the fixed monthly adjustment the program employs Eq. (12) and changes β from 0° to 90° with interval of 0.1°. In the end the β which causes the maximum value of $\bar{H}_T$ is chosen by the program as the optimum tilt angle for that month. The same procedure is followed to obtain the optimum tilt angle for the fixed seasonal adjustment, except that $\bar{H}_T$ is computed for every β but for all of the months of that season. The angle for which the summation of $\bar{H}_T$ values related to all of the months of that season becomes maximum is considered as the optimum tilt angle of that season. Also for the fixed annual adjustment and after following the same procedure, the angle for which the summation of $\bar{H}_T$ values related to all of the months of a year becomes maximum is considered as the annual optimum tilt angle. The program makes an output file containing the optimum tilt for every selected individual adjustment period as well as the values of H_T for all of days of the year for the fixed daily adjustment and $\bar{H}_T$ for all of the months for the fixed monthly, seasonal and annual adjustment periods. In Ilam province most of the region are bare grounds, therefore ρ_g is considered to be 0.2 in all of the calculations [12].

RESULTS AND DISCUSSION

In this section, the results for the optimum tilt angle of flat solar surfaces in Ilam, for the fixed daily, monthly, seasonal and annual adjustments are presented.

Table 2 illustrates the frequency distribution of daily global radiation on horizontal surface, H, in different ranges in Ilam. There are 220 days in a year which have approximately solar radiation in the range of 15-35 MJ/m^2.

Passing through the earth atmosphere, the solar radiation is subjected to the atmosphere absorption and diffusion, the cloudy conditions, air pollution and other parameters. The impact of these parameters on solar radiation characteristics can be surveyed by studying the clearness index. To classify the level of clearness of sky, four different intervals for K_T have been recognized [27] as:

Cloudy	:	$0< K_T<0.2$
Partly cloudy	:	$0.2 \le K_T<0.6$
Sunny	:	$0.6\le K_T<0.75$
Very sunny	:	$0.75 \le K_T< 1$

The frequency distribution of K_T in different ranges throughout the year is presented in Table 3. As shown in Table 3, there are 182 sunny or very sunny days in Ilam

Table 2: The frequency distribution of$H$ in different ranges in Ilam.

Range of H (MJ/m^2)	Frequency distribution (days)
5-10	61
10-15	83
15-20	58
20-25	68
25-30	87
30-35	7
35-40	1

Table 3: The frequency distribution ofK_T in different ranges in Ilam.

Range of K_T	Frequency distribution (days)
0.3-0.4	8
0.4-0.5	52
0.5-0.6	123
0.6-0.7	142
0.7-0.8	35
0.8-0.9	4
0.9-1.0	1

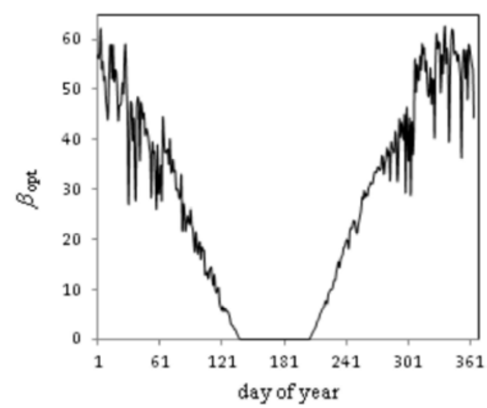

Fig. 2: The optimum slope angle for the fixed daily adjusted surface in Ilam.

with a K_T higher than 0.6. This indicates the appropriate condition of this region for solar energy applications particularly utilization of flat plate solar thermal and photovoltaic collectors; hence the optimization of tilt angles of these solar surfaces is important.

Figure 2 shows the optimum tilt angle for different days of the year. The variation of the daily optimum tilt angel throughout the year between zero and 61° is notable. Winter, spring, summer and autumn seasons in the northern hemisphere consist of: (1) January, February and March; (2) April, May and June; (3) July, August and September; (4) October, November and December, respectively. In autumn and winter, the angle of the solar beam radiation has more deviation from the normal extension of the horizon because the solar declination angle is negative, thus the collector should be mounted toward south with a greater slope from the

Table 4: Optimum tilt angles and the corresponding monthly mean total solar radiations for different tilt adjustments in Ilam.

Monthly	$\bar{H}$ (MJ/m^2)	βopt (°)	$\bar{H}_T$ (MJ/m^2)	Seasonal	βopt (°)	$\bar{H}_T$ (MJ/m^2)	Yearly	βopt (°)	$\bar{H}_T$ (MJ/m^2)
Jan	9.79	57.70	15.86	Winter	45.7	15.56	Whole year	26.0	13.92
Feb	11.69	47.4	15.58			15.55			14.74
Mar	17.91	34.5	20.73			20.32			20.55
Apr	21.59	16.9	22.27	Spring	3	21.71			22.06
May	25.23	1.6	25.23			25.12			23.71
Jun	29.21	0.0	29.21			29.05			26.36
Jul	27.13	0.0	27.13	Summer	12.3	26.45			24.99
Aug	25.38	11.2	25.76			25.66			25.18
Sep	20.49	28.3	22.58			21.79			22.51
Oct	13.60	43	17.15	Autumn	53.4	16.84			16.57
Nov	11.22	56.2	17.90			17.78			15.84
Dec	9.15	60.1	15.80			15.61			13.51

horizon. In spring and summer, deviation of the solar beam radiation from the normal extension is less (declination is positive), thus the collector should be mounted with a lesser slope such that it is zero in the last days of May, the whole days of June and most days of July. The difference between the optimum angle of the first day and that of the last day of the year noticed in Figure 2 is related to the difference between the averaged values of the measured daily solar radiations in these days.

Figure 3 shows the monthly mean daily clearness index for different months of the year. The maximum $\bar{K}_T$ is 0.866 which corresponds to June. In general, the $\bar{K}_T$ values related to the middle months of the year (i.e. May, June and July) demonstrate a better clear sky, because they are higher than those related to other months.

Skeiker [6] computed the optimum tilt angle of solar collectors in the major Syrian zones for the fixed daily adjustment as well as other adjustment strategies such as monthly and seasonal. His results indicated that changing the tilt angle once every month (12 times in the year) keeps the total annual solar radiation received approximately near that of received by daily adjustment. Therefore, in the absence of utilizing a tracking system, the monthly adjustment of solar collectors and PV panels is a preferred strategy. The monthly optimum tilt angle along with the corresponding monthly mean daily total solar radiation on the optimally monthly adjusted surface together with the monthly mean daily total radiation on a horizontal surface in Ilam have been presented in Table 4. As shown, the maximum and minimum values of daily solar radiation on a horizontal surface are 29.2 and 9.15 MJ/m^2 which corresponds to June and December, respectively. However, the monthly optimum tilt is zero for June, while it is 60.1° in December and the total daily radiation received by the tilted surface in December is

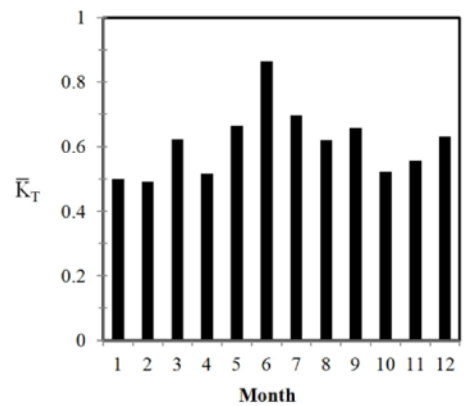

Fig. 3: The monthly averaged daily clearness index in Ilam.

73% more than that of a horizontal surface. As explained before, for the months of summer and spring seasons the solar declination angle is positive, thus their optimum monthly angles are lower compared to those of other months.

To show the effect of optimal tilt adjustment, the monthly averaged daily radiation on a horizontal surface and on an optimally tilted surface are shown together for different months of the year in Figure 4. As shown in Figure 4, employing the monthly adjustment demonstrates its maximum effect on the first and the last four months of the year. By utilizing this strategy the total gain of the monthly optimally tilted surface in these 8 months is 28% more than that of received by a horizontal surface in the same period. However, the relative annual extra gain of the monthly optimally tilted surface compared to that of horizontal surface is 14.75%.

For making comparison, the seasonal optimum tilts as well as the optimum tilt for the fixed annual adjustment along with the corresponding monthly mean daily total solar radiations on optimally adjusted surfaces are also presented in Table 4. It is observed from Table 4 that for

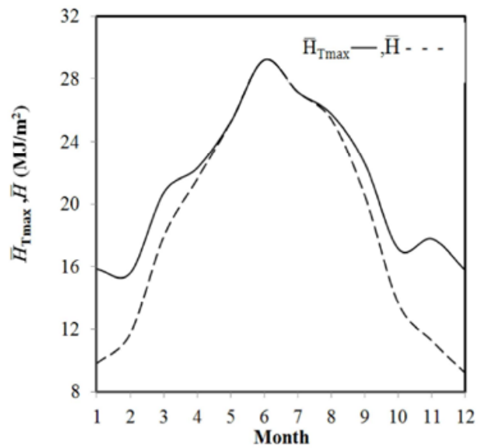

Fig. 4: The monthly averaged daily total radiation on horizontal and on optimally monthly adjusted surfaces in Ilam.

achieving the maximum radiation in autumn and winter the tilts of the collector should be approximately 20 and 12.3° higher than the latitude of Ilam (33.38 °), respectively and in spring and summer they should be 30.4 and 20.1° less than the latitude, respectively. The optimum angle for the fixed annual adjustment is 26°, which is close to the latitude of Ilam. Comparing the values of the monthly mean daily radiation on the optimally tilted surface in every month attained for different tilt adjustment strategies reveal the dependency of the received radiation to the selected tilt strategy. Therefore, the corresponding total annual solar gain is also dependent on the selected tilt adjustment strategy. The relative total annual extra solar gain of the seasonal optimally adjusted surface compared to that of horizontal surface is 13.06%, whereas for the optimally annually adjusted surface it is just 7.89%.

CONCLUSION

In this work, the solar data recorded for a period of seven years have been utilized to obtain the averaged daily horizontal total radiation (HGR) throughout the year in Ilam. Then, based on these HGR values the daily clearness index, the monthly averaged daily HGR and clearness index values have been obtained. At last optimum tilt angles of flat solar surfaces have been obtained for the fixed daily, monthly, seasonal and annual tilt adjustments. In Ilam, there are 220 days in the year with solar radiation in the range of 15-35 MJ/m^2 and 182 sunny and very sunny days with a K_T higher than 0.6; thus appropriate status of this region for utilization of flat plate solar thermal and photovoltaic flat collectors confirmed the necessity of tilt optimization. The optimum tilt for the fixed daily adjustment throughout the year varies between zero and 61° and the maximum optimum tilt for the fixed monthly adjustment is 60.1° for January and the minimum is zero for June as well as July, respectively. The optimum tilts for the fixed seasonal adjustment are 3°, 12.3°, 53.4° and 45.7° for spring, summer, autumn and winter, respectively. The optimum tilt for the fixed annual adjustment is 26°, which is close to the latitude of Ilam. Total yearly extra solar gain of the monthly, seasonal and annually optimally adjusted surfaces compared to that of horizontal surface are 14.75, 13.06 and 7.89%, respectively.

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Nomenclature:

G_{sc} = Solar constant
H = Daily global radiation on horizontal surface (MJ/m^2)
$\overline{H}$ = Monthly mean daily global radiation on horizontal surface (MJ/m^2)
H_b = Daily beam radiation on a horizontal surface (MJ/m^2)
H_{bT} = Daily beam radiation on tilted surface (MJ/m^2)
$\overline{H}_b$ = monthly mean daily beam radiation on a horizontal surface (MJ/m^2)
H_d = Daily diffuse radiation on horizontal surface (MJ/m^2)
H_{dT} = Daily diffuse radiation on tilted surface (MJ/m^2)
$\overline{H}_d$ = Monthly mean daily diffuse radiation on a horizontal surface (MJ/m^2)
H_g = Daily ground-reflected radiation on horizontal surface (MJ/m^2)
H_{gT} = (MJ/m^2)
H_o = Daily extraterrestrial on horizontal surface (MJ/m^2)
$\overline{H}_o$ = Monthly mean daily extraterrestrial on horizontal surface (MJ/m^2)

H_T = Daily global radiation on a tilted surface (MJ/m^2)
$\overline{H}_T$ = Monthly mean daily global radiation on tilted surface (MJ/m^2)
K_T = Daily clearness index
$\overline{K}_T$ = Monthly mean daily clearness index
n = Number day
R_b = The ratio of the beam radiation on tilted surface to that on a horizontal surface

Greek Letters:
δ = Solar declination angle (°)
φ = Latitude of the location (°)
β = Tilt angle of the collector
β_{opt} = Optimum tilt angle of the collector
ρ_g = Ground reflectivity coefficient
$\boldsymbol{\omega_s}$ = Sunset hour angle on horizontal surface (°)
ω_s = Sunset hour angle on a tilted surface (°)

Persian Abstract

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چکیده

راندمان سطوح تخت خورشیدی، شامل کلکتورهای حرارتی یا پانل‌های فتوولتاییک، به مولفه‌های تابش مستقیم و پخشی و همچنین به زاویه برخورد تابش مستقیم خورشیدی بستگی دارد. در این مطالعه، با استفاده از داده‌های اندازه‌گیری‌شده درازمدت، بهینه سازی شیب سطوح تخت خورشیدی در شهر ایلام برای تنظیم‌های ثابت روزانه، ماهیانه، فصلی و سالیانه انجام شده است. بررسی مشخصه‌های تابش خورشیدی نشان داد که ایلام دارای ۲۲۰ روز با تابش خورشیدی بین ۱۵ و $35\ MJ/m^2$ و همچنین ۱۸۲ روز آفتابی یا خیلی‌آفتابی با شاخص روزانه صافی هوا بیشتر از ۰/۶ می‌باشد. زاویه بهینه شیب برای تنظیم ثابت روزانه در طول سال بین صفر و ۶۱ درجه تغییر می‌کند و این زاویه برای تنظیم ثابت ماهیانه از صفر در خرداد و تیر تا ۶۰/۱ درجه در آذر متغیر است. زاویه بهینه شیب برای تنظیم ثابت سالیانه برابر ۲۶ درجه و به عرض جغرافیایی ایلام (۳۳/۳۸ درجه) نزدیک است. همچنین زوایای بهینه شیب برای تنظیم فصلی در زمستان و پاییز به ترتیب ۱۲/۳ و ۲۰ درجه بیشتر از عرض جغرافیایی ایلام و در بهار و تابستان به ترتیب ۳۰/۳ و ۲۱/۱ درجه کمتر از عرض جغرافیایی ایلام هستند.