IJE TRANSACTIONS B: Applications Vol. 30, No. 8, (August 2017) 1197-1204

International Journal of Engineering

Journal Homepage: www.ije.ir

TECHNICAL NOTE

Estimating Solar Radiation and Developing Iran's Atlas Map of Optimum Monthly Tilt Angle

K. DolatiAsl*, Y. Bakhshan

Department of Mechanical Engineering, Hormozgan University, BandarAbbas, Iran

PAPER INFO

Paper history:
Received 23 February 2017
Received in revised form 07 May 2017
Accepted 07 July 2017

Keywords:
Solar Energy
Absorber Surface
Optimum Tilt angle
Atlas Map
Iran

ABSTRACT

Iran has great potential in utilizing solar energy. In order to maximize the amount of absorbed solar radiation to absorber surfaces, the surfaces should be installed at a suitable angle slope to the horizon that is discussed in this article. The calculations performed in this study was done using MATLAB software. In this study, radiation received on the ground in 31 provincial capitals of the country for 12 months of the year has been modeled. Then, the optimum tilt angle of absorbent surfaces with the maximum amount of radiation received on the surfaces of the absorber is estimated. Finally, after validating the results, using available software in the field of GIS, atlas map of optimum tilt angle with respect to the horizon for the installation of solar absorber surfaces and amount of absorbed solar radiation on surface mounted in the optimum tilt angle for Iran was presented for 12 months. It is observed that optimum tilt angle varies throughout the year between -10 to 62 degrees. The minimum value of optimum tilt angle in different months is related to North West provinces. The lowest amount of solar radiation is received on Caspian littoral, and its value varies between 9 and 19 MJ per square meter per day for different months. The highest amount of radiation in region of the provinces Yazd and Isfahan is received and its value varies between 19 to 31 MJ per square meter per day for different months. The figures presented in this paper eliminate the need for estimating clearness index, optimum tilt angle, and corresponding solar radiation in cities and regions on which no information is available. It provides researchers with the aforementioned values based on the mean of values of adjacent regions.

***doi**: 10.5829/ije.2017.30.08b.12*

1. INTRODUCTION

The need for energy is increasing day by day, and the continuous use of fossil fuels has destructive irreversible effects on planet Earth. Hence, utilization of renewable sources of energy is highly important. One of these renewable sources of energy is solar energy, which is accessible in many parts of the Earth and is used for different applications such as heating and power generation.

Iran is situated in an area more than 90% of which is sunny for over 280 days of the year. Iran map is shown in Figure 1. The total solar irradiance over a year varies between 1800 and 2200 kWh/m^2, which is higher than the global average [1]. Iran embraces various climates, and since the output power of photovoltaic modules is highly influenced by latitude, ambient temperature, and solar irradiance, it is necessary to simulate them precisely in selecting the best location for construction of a solar power plant. To increase solar irradiance on solar panels, these panels must be installed at the proper tilt angle. Solar panels can be angled along the horizontal and vertical axes. Jafar-Kazemi and Saad-Abadi [2] indicated that to increase solar irradiance, the optimum tilt angle to increase solar irradiance, the optimum tilt angle needs to be changed on a monthly basis. However, use of semiannual optimum tilt angles is more economic, because the tilt angle is changed only twice a year, whereas the solar irradiance only drops by 2% as compared to the use of monthly optimum tilt angles [2].

Talebizadeh et al. [3] determined the optimum tilt angle of a solar collector in some certain parts of the southeast of Iran and estimated the solar

*Corresponding Author's Email: *kianoush.dolati@gmail.com* (K. DolatiAsl)

Please cite this article as: K. DolatiAsl, Y. Bakhshan, Estimating Solar Radiation and Developing Iran's Atlas Map of Optimum Monthly Tilt Angle, International Journal of Engineering (IJE), TRANSACTIONS B: Applications Vol. 30, No. 8, (August 2017) 1197-1204

Figure 1. Average queue length vs λ

irradiance on a solar collector installed at the optimum tilt angle.

Using the genetic algorithm (GA), it was found that the optimum azimuth angle for installation of solar panels was the southward zero-degree angle. Talebizade et al. also reported the similarity of results of different radiation estimation models [3].

In another study, Moeini et al. [4] examined solar irradiance on a horizontal surface and proposed a 12-month potential map. Due to the shortage of pyranometric stations in Iran, they first selected 5 regions of Iran based on the weather information obtained from 139 synoptic stations and defined 5 factor groups for modeling. Other studies have examined and reported the yearly optimum tilt angle and the corresponding solar irradiance in Iran [5, 6]. To increase precision of calculations, the solar radiation data of 30 Iranian cities was used and monthly mean solar radiation and optimum monthly tilt angle were calculated accordingly [5].

Salari and Jahanshahi Javaran [7] determined the tilt angle for solar surfaces using different solar irradiation models in Yazd, Iran. Talebizadeh et al. examined the effect of tilt angle on absorbed solar energy of the flat collectors in Kerman, Tabas and Zahedan in Iran [8]. In a study carried out in Yazd, Iran, it was found that the use of the optimum monthly tilt angle in the late months of the year increases solar irradiance on solar collectors as compared to solar collectors placed horizontally. Khorasanizadeh and Muhammadi used 11 empirical models to estimate average daily solar radiation within a month in six Iranian cities. They reported that among the models studied, the one that was based on sunny hours yielded the best solar radiation estimate [9].

In some studies, to calculate the optimum tilt angle, following the mathematical modeling phase, the tilt angle is selected from the 0-90^o range, which increases the likelihood of error in estimation of the optimum tilt angle, because research results show a negative optimum tilt angle [10].

Keshavarz et al. prepared the atlas map of the maximum solar irradiance at optimum tilt angles of solar collectors in Iran, and introduced Yazd, Birjand, Kerman, Zahedan, and Shiraz as the most suitable places for construction of solar power plants [5].

In another paper, Basarati et al. [11] examined solar irradiance and prepared solar maps of surfaces installed on fixed and rotary bases. They studied five different states in a one-year period, and carried out calculations for 50 Iranian cities. They also simulated a 5MW photovoltaic power plant for different cities and indicated that Bushehr shows the highest capacity factor (=10.26%).

Bagheri Tolabi et al. [12] developed a technique for estimation of the monthly average daily global solar radiation on horizontal surface using a combination of intelligent water drops algorithm with linear and nonlinear empirical equations.

Bagheri Tolabi et al. [13] proposed a method based on the Angstrom model which estimates the monthly average daily global solar radiation on a horizontal surface by Bees Algorithm as a heuristic and population-based search technique. The experimental coefficients for Angstrom model are calculated for six different climate regions of Iran.

Kouhikamali and Hassani [14] after calculating maximum solar energy based on the best tilt angle investigated the possibility of using flat plate collectors in northern parts of Iran, especially in Rasht.

Since regions in the east and southeast of Iran are desert areas, these regions enjoy maximum solar irradiance. Alamdari et al. [1] indicated that the maximum solar irradiance on a horizontal surface is achieved in the center, east, and south of Iran. They also showed that the highest solar irradiance occurs during April in Iran.

Mansouri et al. studied the optimum tilt angle for placement of photovoltaic panels in Shiraz, San Antonio, Timimoun and Ihasa cities, which are in the 29°N geographical latitude. Since photovoltaic panels are immensely influenced by solar radiation and air temperature, it was found that Shiraz provides the best conditions for placement of photovoltaic panels as compared to other cities. In the end, they only presented the optimum tilt angle and global solar radiation for Shiraz [15].

One of the important parameters in modeling solar radiation is the clearness index. Bahadorinezhad and Mir-Husseini also estimated the clearness indices of capitals of all Iranian provinces in their article.

None of the previous studies provides the monthly optimum tilt angle map of Iran. However, some of these studies provide maps of potential of solar irradiance on collector surfaces, but these maps are prepared on a yearly basis and do not suit monthly periods. In this paper, considering the clearness indices of capitals of Iran provinces, solar irradiance on the Earth's surface and solar collector surface was simulated. In addition, the optimum solar collector tilt angle required to maximize monthly mean radiation was estimated. The maps of monthly optimum tilt angle and potential of solar irradiance on solar collector surfaces at the optimum monthly angle were prepared for Iran for monthly and yearly periods.

Another important parameter that has been undervalued in different studies is estimation of the optimum tilt angle and solar radiation in areas on which no weather information is available. Hence, estimated values must be used for adjacent regions, and using different averaging methods the values of the required regions must be calculated in a time-consuming costly process. This problem is solved in the figures included in this paper, and researchers are easily able to calculate optimum tilt angle and solar radiation for different regions in Iran.

2. MATHEMATICAL MODELING

The information of radiation on the horizontal surface are usually available and can be applied to calculate the energy received on an inclined surface. The total monthly average daily radiation $\overline{H}_T$ is the sum of direct, diffuse and reflecting components according to Duffie and Beckman [16]:

$$\overline{H}_T = \overline{H}_b + \overline{H}_d + \overline{H}_r \tag{1}$$

The method applied in this paper for calculating $\overline{H}_T$ is the KT method. The general form of this method considers both the slope and azimuth angles. According to Duffie and Beckman [16], the total monthly average daily radiation $\overline{H}_T$ in the KT method is defined as follows:

$$\overline{H}_T = \overline{H}\overline{R} \tag{2}$$

The equation for $\overline{R}$ is:

$$\overline{R} = D + \frac{\overline{H}_d}{\overline{H}}\left(\frac{1+\cos\beta}{2}\right) + \rho_g\left(\frac{1-\cos\beta}{2}\right) \tag{3}$$

where:

$$D = \begin{cases} \max\{0, G(\omega_{ss}, \omega_{sr})\} \text{ if } \omega_{ss} \geq \omega_{sr} \\ \max\{0, [G(\omega_{ss}, -\omega_s) + G(\omega_s, \omega_{sr})]\} \text{ else} \end{cases} \tag{4}$$

And the three values of G applied in the above equation are defined as:

$$G(\omega_1, \omega_2) = \frac{1}{2d}\left[\left(\frac{bA}{2} - a'B\right)(\omega_1 - \omega_2)\frac{\pi}{180} + (a'A - bB') \times (\sin\omega_1 - \sin\omega_2) - a'C(\cos\omega_1 - \cos\omega_2) - \left(\frac{bA}{2}\right)(\sin\omega_1\cos\omega_1 - \sin\omega_2\cos\omega_2) + \frac{bC}{2(\sin^2\omega_1 - \sin^2\omega_2)}\right] \tag{5}$$

Sunrise (ω_{sr}) & sunset (ω_{ss}) angles are introduced as:

$$|\omega_{sr}| = \min\left[\omega_s, \cos^{-1}\frac{AB + C\sqrt{A^2 - B^2 + C^2}}{A^2 + C^2}\right] \tag{6-a}$$

$$\omega_{sr} = \begin{Bmatrix} -|\omega_{sr}| \text{ if } (A > 0 \;\&\; B > 0) \text{ or } (A \geq B) \\ +|\omega_{sr}| \text{ otherwise} \end{Bmatrix} \tag{6-b}$$

$$|\omega_{ss}| = \min\left[\omega_s, \cos^{-1}\frac{AB - C\sqrt{A^2 - B^2 + C^2}}{A^2 + C^2}\right] \tag{7-a}$$

$$\omega_{ss} = \begin{Bmatrix} +|\omega_{ss}| \text{ if } (A > 0 \;\&\; B > 0) \text{ or } (A \geq B) \\ -|\omega_{ss}| \text{ otherwise} \end{Bmatrix} \tag{7-b}$$

and:

$$\omega_s = \cos^{-1}(-\tan\phi\tan\delta) \tag{8}$$

where:

$$A = \cos\beta + \tan\phi\cos\gamma\sin\beta \tag{9-a}$$

$$B = \cos\omega_s\cos\beta + \tan\delta\sin\beta\cos\gamma \tag{9-b}$$

$$C = \sin\beta\sin\gamma \,/\, \cos\phi \tag{9-c}$$

$$\delta = 23.45\sin(360(284 + n)/365) \tag{9-d}$$

and parameters a, a', b and d are defined as follows:

$$a = 0.4090 + 0.5016\sin(\omega_s - 60) \tag{10-a}$$

$$b = 0.6609 - 0.4767\sin(\omega_s - 60) \tag{10-b}$$

$$a' = a - \overline{H}_d/\overline{H} \tag{10-c}$$

$$d = \sin(\omega_s) - \frac{\pi\omega_s}{180}\cos(\omega_s) \tag{10-d}$$

The day of the year n is shown in Table 1. It is worth mentioning that the above equations for calculating monthly average daily radiation can also be applied for daily radiation $\overline{H}_T$ on inclined surface.

TABLE 1. n for average day of month [21]

Month	n	δ
Jan	17	-20.9
Feb	47	-13.0
Mar	75	-2.4
Apr	106	9.4
May	134	18.8
Jun	163	23.1
Jul	198	21.2
Aug	228	13.5
Sep	258	2.2
Oct	288	-9.6
Nov	319	-18.9
Dec	343	-23.0

In the above method, the monthly average clearness index $\overline{K}_T$ is applied for calculating $\overline{H}_d$ which is defined as the ratio of monthly average daily radiation on a horizontal surface to the monthly average daily extraterrestrial radiation. According to Duffie and Beckman [16]:

$$\overline{K}_T = \overline{H}/\overline{H}_o \tag{11}$$

and $\overline{H}_d$ and $\overline{H}_o$ for latitudes of +60° to -60° can be calculated for the average day of the month as:

$$\frac{\overline{H}_d}{\overline{H}} = \begin{cases} 1.391 - 3.560\overline{K}_T + 4.189\overline{K}_T^2 - 2.137\overline{K}_T^3 \\ \quad \text{for } (\omega_s \leq 81.4°) \\ 1.311 - 3.022\overline{K}_T + 3.427\overline{K}_T^2 - 1.821\overline{K}_T^3 \\ \quad \text{for } (\omega_s > 81.4°) \end{cases} \tag{12}$$

$$\overline{H}_o = \frac{24 \times 3600 G_{sc}}{\pi}\left(1 + 0.033\cos\frac{360n}{365}\right) \times \left(\cos\phi\cos\delta\sin\omega_s + \frac{\pi\omega_s}{180}\sin\phi\sin\delta\right) \tag{13}$$

3. CALCULATION

The best data leading to satisfactory results is experimental data, which can be obtained from the multiple year statistics provided by Iran Meteorological Organization. Given the lack of access to complete reliable information on different cities and parts of Iran, we had to use the existing relations to estimate solar radiation.

A computer code was used in MATLAB to carry out the calculations. The code used relations presented in the previous section to calculate total daily radiation on a tilted surface within a month at the -10° to 90° tilt angles. Afterwards, the angle corresponding to the maximum total radiation on a tilted surface was obtained and introduced as the optimum monthly tilt angle. Figure 2 depicts the computer calculations.

One of the important parameters contributing to improvement of solar radiation modeling is the clearness index. Figure 4 was prepared based on values reported by Alamdari et al. [1] for clearness indices of 12 Christian months.

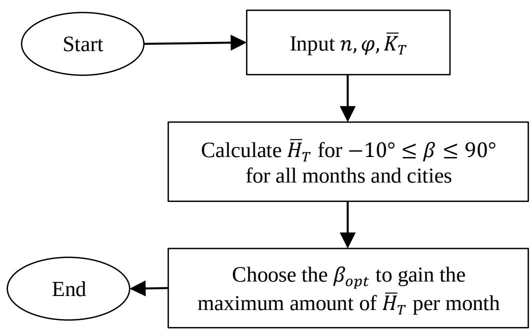

Figure 2. Computation flowchart

In this research, the reflection coefficient of the Earth's surface was determined to be 0.2, and the azimuth angle of the tilted surface was zero. Based on the information presented in the "Introduction" section on the optimum azimuth angle for installation of solar collectors, the azimuth angle was determined to be zero in this research.

To ensure accuracy of the research results, the global solar radiation on horizontal surface and optimum tilt angle was compared to the sample data reported by other researchers for 6 cities (Figure 3 and Table 2). As seen in Figure 3 and Table 2, the results of this research properly comply with the results reported by other researchers, and this conformity proves reliability of the resulted optimum tilt angle.

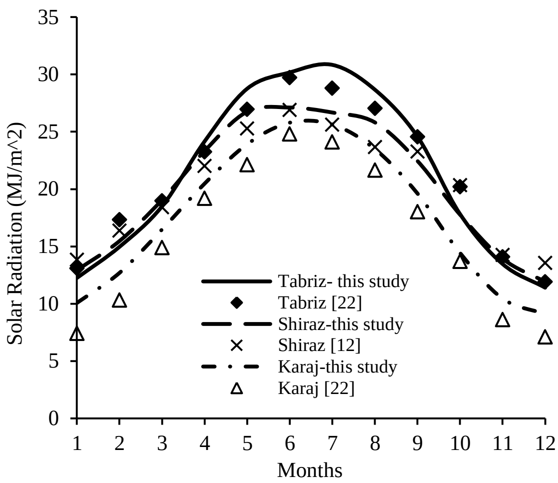

Figure 3. Global solar radiation on horizontal surface

TABLE 2. The optimum tilt angle for some cities

Month	Bandar Abbas		Yazd		Isfahan	
	This study	[3]	This work	[11]	This study	[8]
Jan	52	53	58	60	58	59
Feb	41	42	48	51	48	51
Mar	26	27	33	35	34	35
Apr	10	11	16	16	16	16
May	-4	-4	0	0	1	2
Jun	-8	-9	-7	-7	-6	0
Jul	-7	-7	-4	-4	-3	0
Aug	4	5	9	10	9	11
Sep	20	21	28	29	28	30
Oct	37	38	45	46	44	46
Nov	48	50	56	57	56	56
Dec	53	55	60	60	60	60

The difference between optimum tilt angles obtained in this research for Isfahan and the values reported by Khorasanizade and Meschi [8] was caused by the fact that Khorasanizade and Meschi obtained the optimum tilt angle by changing the tilt angle in the 0° to 90° range. Hence, the optimum tilt angles reported by these researchers for June and July were zero.

4. RESULTS

Figure 5 shows the monthly optimum tilt angle to horizon for installation of solar panels in Iran. As seen in Figure 5, in the early and ending months of the year (i.e. the cold months of the year), when the angle between the sun radiation and a line perpendicular to the Earth is larger, the optimum monthly tilt angle is higher all over the country as compared to warm months of the year. The smallest optimum monthly tilt angle is observed in the southeast and southwest of Iran. Due to the high levels of clearness index in Gilan Province, the direct solar irradiance on a photovoltaic module is extremely slight as compared to diffuse sky radiation, which results in an optimum tilt angle that allows for maximum utilization of the diffuse sky radiation.

As seen in Figure 5, the optimum tilt angle differs considerably in close parts of the country within a month, and no uniformity is observed in the optimum tilt angles of close areas. This is caused by the lack of inclusion of geographical coordinates and extreme effect of weather conditions of the region on the optimum tilt angle. But it can be seen that in the southern half of the country and in areas with similar latitude, the optimal tilt angle has uniform changes. The negative values indicate that to obtain the maximum solar irradiance it is better to install the solar panels northward.

In Figure 5, the range of monthly variations of the optimum tilt angle in different parts of Iran is approximately 10°. The optimum tilt angle in different parts of this country and different months varies between -10° (in June) and 62° (in January).

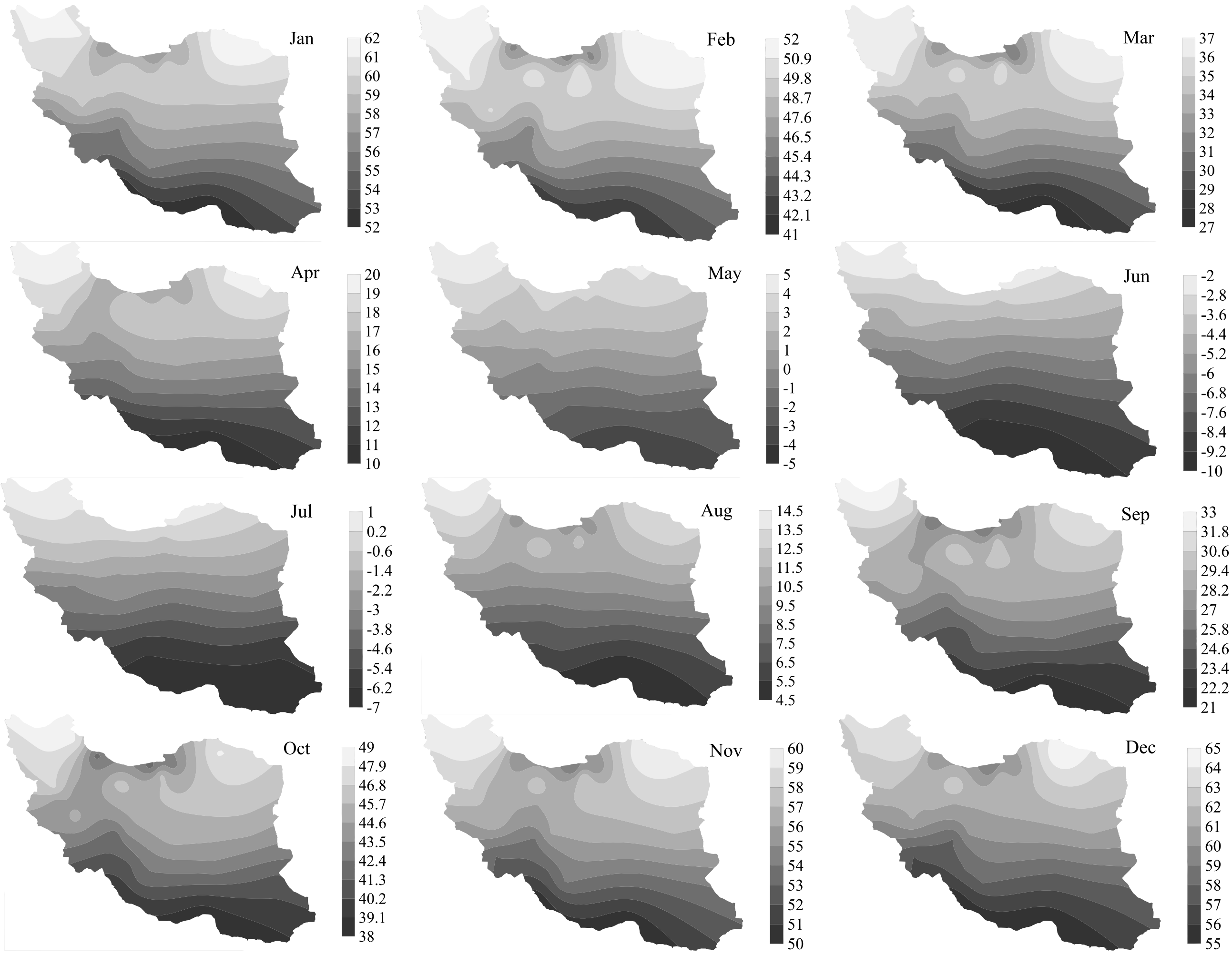

Figure 5. Monthly optimum tilt angle (β_{opt})

For instance, the optimum tilt angle for Gilan Province ranges between -3° (in June) and 60° (in December).

According to Figure 5, of latitude, Earth's reflection coefficient, and clearness index are taken into account, the optimum tilt angle to the horizon will differ from the latitude in each region. In other words, optimum tilt angle to the horizon varies for areas with equal latitudes in Iran. Hence, it will be more useful to utilize solar radiation simulation models that consider geographical coordinates and weather conditions of the region simultaneously.

Figure 6 also depicts solar irradiance on a tilted surface at the monthly optimum tilt angle to the horizon. According to Figure 6, the solar irradiance in the warm months of the year was higher than other months as expected. Moreover, maximum radiation on tilted surfaces occurs in the east and center of Iran. The lowest radiation also occurs in the coastline areas of the Caspian Sea, because given the special weather conditions in this region within a year cloudiness is more frequent than other parts of the country. As expected, solar irradiance on a tilted surface is higher in the intermediary warm months of the year.

By examining Figure 6 and comparing it to Iran's topographical map it is found that solar irradiance is lower in the mountainous regions of Iran than the central and eastern parts of the country. As seen, the largest difference between levels of solar irradiance in different parts of the country varies between 11 and 15 MJ/m^2.

The daily solar irradiance in the country during a year varies between 9 MJ/m2 (in January and December) and 31 MJ/m^2 (in June and July). Solar irradiance on a tilted surface in the coastline areas of the Caspian Sea also varies from 9 MJ/m^2 (in January) to 19 MJ/m^2 (in July).

Figure 7 depicts solar irradiance on a tilted solar panel. In preparing this figure it was assumed that the solar panel tilt angle was adjusted based on the monthly optimum tilt angle in each month.

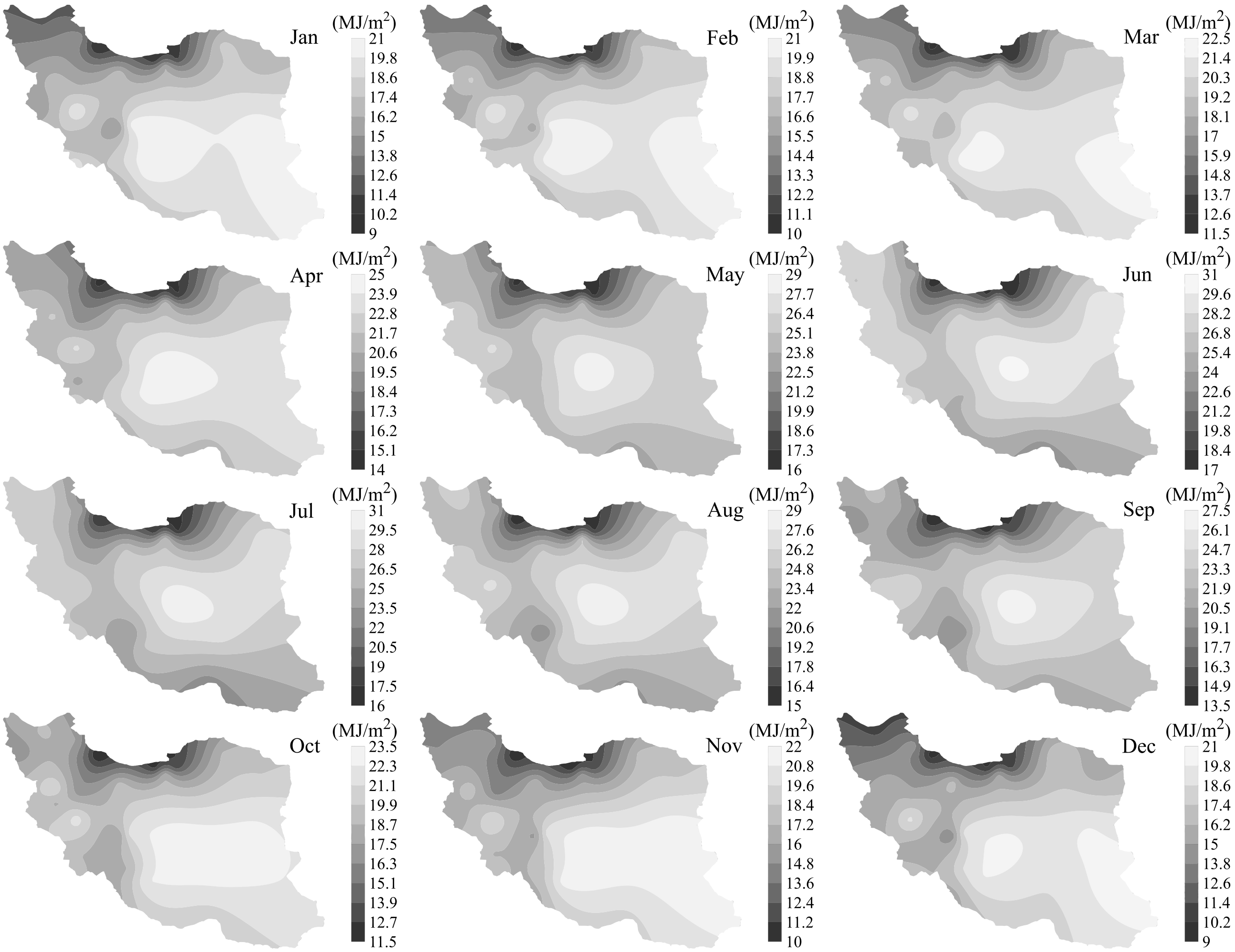

Figure 6. The total solar radiation received by the inclined surface mounted in the monthly optimum tilt angle ($\overline{H}_T$)

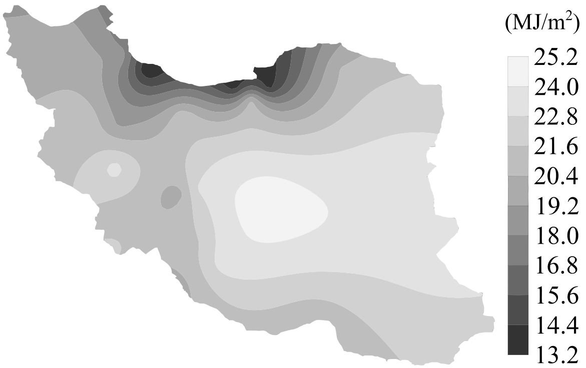

Figure 7. Solar irradiance during a year at the monthly optimum tilt angle

As seen in Figure 7, the highest solar radiation during the year is received in Yazd Province while the lowest solar radiation is received in the coastline areas of the Caspian Sea. Although the coastline areas of the Persian Gulf and Oman Sea have lower latitudes, solar irradiance during the year is lower in these areas than desert areas due to high humidity levels and low clearness indices in these regions.

Based on the research results and hypotheses it could be stated that desert areas of Iran are more suitable for construction of solar power plants as compared to other parts of Iran for collecting solar energy.

5. CONCLUSION

Due to the high importance of selecting a suitable location for installation and operation of a solar power plant, the monthly optimum tilt angle and total solar irradiance on the surface of solar panels installed at the monthly optimum tilt angle were studied in this research. Calculations were carried out using a code prepared in MATLAB for 12 years and information on 31 province capitals. The primary research goal was to prepare the solar radiation potential map of solar collectors installed at the optimum monthly tilt angle in different parts of Iran to enable researchers find the values easily and without calculations.

Research results can be summarized as follows:

Based on the calculations conducted in this research, the optimum tilt angle for installation of flat plate solar collectors was presented in the form of Iran’s atlas map of optimum tilt angles.

- Monthly optimum tilt angles in different parts of Iran differ approximately by 10°.
- The optimum monthly tilt angle varies between -10° and 62° to the horizon.
- The lowest optimum tilt angle is obtained in North West of Iran, and the maximum optimum tilt angle occurs in different months and different parts of Iran and varies by geographical conditions of the regions.
- Based on the proposed optimum tilt angle, solar irradiance on a tilted surface was estimated and presented in the form of Iran’s maximum radiation atlas map.
- The lowest solar irradiance on a tilted surface was observed in the coastline areas of the Caspian Sea, which can be partly attributed to the small clearness index of this region.
- Solar irradiance on a tilted surface in the coastline areas of the Caspian Sea varies from 0 MJ/m^2 (in January) to 19 MJ/m^2 (in July).
- The highest solar irradiance on a tilted surface in different months was observed in the regions between capitals of Yazd and Isfahan provinces as well as the desert areas in eastern Iran.
- Solar irradiance on a tilted surface in different months of the year and regions between capitals of Yazd and Isfahan provinces varies between 19 and 31 MJ/m^2 a day.

If tilted solar panels are installed at the monthly optimum angle of each month, the lowest and highest solar irradiance on solar panels will be observed in the coastline areas of the Caspian Sea and Yazd Province, respectively.

6. REFERENCES

1. Alamdari, P., Nematollahi, O. and Alemrajabi, A.A., "Solar energy potentials in iran: A review", ***Renewable and Sustainable Energy Reviews***, Vol. 21, (2013), 778-788.
2. Jafarkazemi, F., Ali Saadabadi, S. and Pasdarshahri, H., "The optimum tilt angle for flat-plate solar collectors in iran", ***Journal of Renewable and Sustainable Energy***, Vol. 4, No. 1, (2012), 110-118.
3. Talebizadeh, P., Mehrabian, M. and Abdolzadeh, M., "Determination of optimum slope angles of solar collectors based on new correlations", ***Energy Sources, Part A: Recovery, Utilization, and Environmental Effects***, Vol. 33, No. 17, (2011), 1567-1580.
4. Moini, S., Javadi, S. and Dehghan Manshadi, M., "Feasibility study of solar energy in iran and preparing radiation atlas", ***Recent Advances in Environment, Energy Systems and Naval Science***, Vol. 2011, (2011), 1-7.
5. Keshavarz, S.A., Talebizadeh, P., Adalati, S., Mehrabian, M.A. and Abdolzadeh, M., "Optimal slope-angles to determine maximum solar energy gain for solar collectors used in iran", ***International Journal of Renewable Energy Research (IJRER)***, Vol. 2, No. 4, (2012), 665-673.
6. Kashani, A.H., Izadkhast, P.S. and Asnaghi, A., "Mapping of solar energy potential and solar system capacity in iran", ***International Journal of Sustainable Energy***, Vol. 33, No. 4, (2014), 883-903.
7. Salari, M. and Jahanshahi Javaran, E., "Optimising the tilt angle for solar surfaces using different solar irradiation models in yazd, iran", ***International Journal of Ambient Energy***, (2017), 1-9.

8. Abdolzadeh, M., "Effect of solar angles on incident energy of the flat collectors", ***Energy Engineering Management***, Vol. 2, No. 4, (2013), 12-23.
9. Khorasanizadeh, H. and Mohammadi, K., "Introducing the best model for predicting the monthly mean global solar radiation over six major cities of iran", ***Energy***, Vol. 51, (2013), 257-266.
10. Khorasanizadeh, H., Mohammadi, K. and Mostafaeipour, A., "Establishing a diffuse solar radiation model for determining the optimum tilt angle of solar surfaces in tabass, iran", ***Energy Conversion and Management***, Vol. 78, No., (2014), 805-814.
11. Besarati, S.M., Padilla, R.V., Goswami, D.Y. and Stefanakos, E., "The potential of harnessing solar radiation in iran: Generating solar maps and viability study of pv power plants", ***Renewable energy***, Vol. 53, (2013), 193-199.
12. Tolabi, H.B., Hosseini, R., Shakarami, M., Ayob, S. and Rizwan, M., "A novel intelligent water drops optimization approach for estimating global solar radiation", ***International Journal of Engineering-Transactions B: Applications***, Vol. 28, No. 5, (2015), 701-709.
13. Tolabi, H.B., Moradib, M. and Tolabia, F.B., "New technique for global solar radiation forecast using bees algorithm", ***International Journal of Engineering***, Vol. 26, No. 11, (2013), 1104-1111.
14. Kouhikamali, R. and Hassani, M., "The possibility of using flat plate solar collector based on the best calculated tilt angle in the city of rasht as a case study", ***International Journal of Engineering-Transactions B: Applications***, Vol. 27, No. 8, (2014), 1297-1305.
15. Mansouri, E., Pirsalami, M., Nasiri, N., Farrizi, M., Hashemizadeh, M. and Alihosseini, H., "Optimum tilt angle for fixed-array solar panels at a constant latitude of 29 to receive the maximum sunlight", ***Bull. Env. Pharmacol. Life Sci.[Spl. Issue 1]***, Vol. 26, (2016), 30-39.
16. Duffie, J.A. and Beckman, W.A., "Solar engineering of thermal processes", (1980).

Estimating Solar Radiation and Developing Iran’s Atlas Map of Optimum Monthly Tilt Angle

TECHNICAL NOTE

K. DolatiAsl, Y. Bakhshan

Department of Mechanical Engineering, Hormozgan University, BandarAbbas, Iran

P A P E R I N F O

Paper history:
Received 23 February 2017
Received in revised form 07 May 2017
Accepted 07 July 2017

Keywords:
Solar Energy
Absorber Surface
Optimum Tilt angle
Atlas Map
Iran

چکیده

کشور ایران دارای پتانسیل بالایی در بهره‌گیری از انرژی خورشیدی است. به‌منظور بیشینه شدن مقدار تابش جذب شده توسط سطوح جاذب انرژی خورشیدی، سطوح را باید در زاویه شیب مناسب نسبت به افق نصب نمود که در این مقاله مورد بررسی قرار گرفته است. محاسبات انجام شده در این مطالعه با استفاده از نرم‌افزار متلب انجام شده است. در این مطالعه ، تابش دریافتی بر روی سطح زمین در 31 مرکز استان کشور برای 12 ماه سال میلادی مدل‌سازی شده است، سپس مقدار زاویه شیب بهینه کلکتورهای خورشیدی به همراه مقدار تابش بیشینه دریافتی بر روی سطح جاذب انرژی خورشیدی متناظر با زاویه شیب بهینه، تخمین زده شده است. درنهایت، پس از اعتبارسنجی نتایج به‌دست‌آمده، با استفاده از نرم‌افزارهای موجود در زمینه نقشه-برداری، نقشه اطلس زاویه شیب بهینه نسبت به افق برای نصب جاذب‌های انرژی خورشیدی به همراه مقدار تابش خورشیدی دریافتی برای سطوح نصب شده در زاویه شیب بهینه برای کشور ایران ارائه شده است. مشاهده شده است که زاویه شیب بهینه در طول سال بین 10- تا 62 درجه متغیر است و کمترین مقدار زاویه شیب بهینه در ماه‌های مختلف، مربوط به استان‌های شمال غربی است. کمترین مقدار تابش خورشیدی دریافتی در حاشیه دریای خزر اتفاق افتاده است و مقدار آن بین 9 تا 19 مگاژول بر مترمربع در روز برای ماه‌های مختلف، متغیر است. بیشترین مقدار تابش دریافتی در مناطق استان‌های یزد و اصفهان اتفاق می‌افتد که مقدار آن بین 19 تا 31 مگاژول بر مترمربع در روز برای ماه‌های مختلف متغیر است. همچنین شکل‌های ارائه شده در این مقاله، نیاز به تخمین مقدار ضریب صافی هوا، زاویه شیب بهینه و مقدار تابش خورشیدی متناظر با آن را برای شهرها و مناطقی که هیچ‌گونه اطلاعاتی از آن‌ها در دسترس نیست را از بین می‌برد و مقدار آن‌ها را به‌صورت میانگینی از اطلاعات مناطق مجاور در اختیار پژوهشگران قرار می‌دهد.

***doi**: 10.5829/ije.2017.30.08b.12*