Optimal Slope-Angles to Determine Maximum Solar Energy Gain for Solar Collectors Used in Iran

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Abstract- The aim of this paper is providing atlases to determine maximum solar energy gain and optimum slope angle of solar collectors for Iran. To achieve this purpose, first, the daily, monthly, seasonally and yearly optimum slope and azimuth angles of solar collectors are determined for 30 Iranian cities and the gain of energy is calculated in the mentioned conditions. Then, the atlas of the optimum slope angle and the contour atlas of the maximum energy gain is provided. The Geographic Information System (GIS) is used to outline the maps. These atlases are essentials tools to find the best location for constructing different solar systems. The results show that the energy gain of the collector when it is adjusted at the daily optimum slope angle is almost the same compared with the case at the monthly optimum slope angle. Therefore, the map is provided for the energy gain when the collectors are mounted at the monthly optimum slope angle. The map of optimum slope angle is outlined for the fixed collector used for the entire year due to the high use of fixed collectors. Furthermore, the results show that Iran can be divided into five zone and the areas with the same latitude and climate have almost the same optimum slope angle.

Keywords- Solar energy, Solar collectors, Slope angle, Atlas, Geographic Information System.

1. Introduction

Solar energy as an alternative source of energy is one of the most important sources of renewable energy in recent years due to the oil crisis. Solar heat flux in different zones of the earth is related to the orientation, the weather condition and solar hours. The location of Iran is suitable for constructing various solar systems as well as solar collectors. For receiving maximum solar energy, the collector's surface should be perpendicular to the sun's rays, and this can be accomplished when the solar trackers are used to follow the sun instantaneously. The main problem in this regard is however the high cost of this kind of trackers, so instead of employing solar trackers, the angles of collector's surface could be changed manually every day or month or season in order to adjust the collector almost perpendicular to the sun's rays. The majority of past studies in this field investigated the monthly slope angle of the solar collectors and the results showed that the slope angle depends on latitude. The slope angle is defined as the angle of collectors with respect to horizontal. As an example, Heywood [1] obtained the yearly optimum angle as $\beta_{opt(y)} = \phi - 10$, Londe [2] achieved this angle as $\beta_{opt,y} = \phi \pm 15$ and Duffie and Beckman [3] calculated this angle as $\beta_{opt(y)} = (\phi + 15) \pm 15$. Qiu and Riffat [4] found the yearly optimum tilt angle of solar collectors as $\beta_{opt(y)} = \phi \pm 10$ at a location with latitude of ϕ and the solar energy gain calculated based on the above angles had a relative error below 1.5%. In the above equations, the plus sign is for the northern hemisphere and the minus sign is for the southern hemisphere. Nijegorodov [5] presented 12 equations for calculating the monthly optimum slope angle which is used in subsequent studies for validation of other researchers' results. He used the atmospheric transmittance models to obtain analytical formulae for the optimum slope angle. The atmospheric transmittance models may not be accurate for all climates. He also used some simplifying assumptions for employing the equations. The equations are therefore not too accurate and have a big deviation from the exact values in some latitudes and especially in some months. In fact, the optimal slope angle is related to the local climatic condition, geographic latitude and the period of its use. Hence, different places will have different optimal tilt angles for a yearly-used solar collector.

Moncos [6] obtained a mathematical model for calculating the total radiation on a sloped surface and determined the optimum tilt angles for a flat plate collector in Assiut, Egypt on a daily basis. The results show that changing the tilt angle eight times in a year is necessary to receive the total radiation on the collector near its maximum value and this achieved a yearly gain of 6.85% in total radiation when compared with a flat plate collector fixed at slope of 27º, which is equal to the latitude of Assiut. Mujahid Abdulaziz [7] computed the optimum slope angle for latitudes of 10º to 50º north and concluded that if the collector adjusted by the seasonally optimum angles, a gain of 10% in energy is received compared with the zero slope angle. Hartley et al. [8] calculated the optimum slope angle for Valencia, Spain. They showed that the amount of irradiation loss received using the yearly average optimum tilt angle is only 6% when compared with the monthly average tilt angle, and thus using the yearly optimum angle may be preferred because it would involve cheaper equipment and less work to keep the tilt angle the same all year round. Oladiran [9] determined the average global radiation on flat surfaces for three zones in Nigeria. The total radiation was obtained while the surface azimuth angle was varied between 0° and 75º at 15º intervals and he presented the results for three slope angles of the collector surface and found that the mean annual radiation increased for a surface with the slope angle of 10° less than the latitude angle. Azmi et al. [10] computed the monthly optimum slope angle for Brunei, Darussalam. Their results had significant difference with Nijegorodov equations in some months because the ambient condition of Hartley et al. [8] is not the same as assumptions of Nijegorodov. Shariah et al. [11] by employing the computer program TRNSYS (Transient System Simulation) found the optimum slope angle for a thermosyphon solar water heater installed in northern and southern parts of Jordan. Runsheng Tang et al. [12] presented an estimation of the optimal tilt angle for maximizing its energy based on the monthly global and diffuse radiation on a horizontal surface. They employed a mathematical model for the estimation of the optimal tilt angle of a collector and presented a contour map of the optimal tilt angles of the south-facing collectors used for the whole year in China, based on monthly horizontal radiation of 152 places around the country. Ulgen [13] computed the monthly, seasonally and yearly optimum slope angles for Izmir, Turkey with a mathematical model. He found that the optimum tilt angle changes between 0 (June) and 61 degrees (December) throughout the year. Elminir et al. [14] studied the optimum slope angle theoretically in Helwan, Egypt and compared the results of different mathematical models with experimental results. The results have a little deviation with the experimental results. Gopinathan et al. [15] presented the monthly average daily global radiation on surfaces tilted towards the equator and also inclined at various azimuth angles for three locations in the South African region. They found that Maximum energy occurs at an azimuth of 180º (facing equator) at any slope, because these African cities are located at the southern hemisphere. Gunerhan and Hepbasli [16] calculated the daily optimum slope angle for Izmir, Turkey and compared the results with the results achieved from Nijegorodov equations, even though, the ambient condition in Izmir is different from Nijegorodov assumptions. They offered for increasing the efficiency of solar collectors, they should be mounted at the monthly average tilt angle. Skeiker [17] obtained an equation for calculating the optimum daily slope angle and employed it to compute this angle for some cities in Syria. Talebizadeh et al. [18] presented new correlations to determine the daily, monthly, seasonally, and yearly optimum slope angles of solar collectors for latitudes between 20° to 40° north.

In this paper, a simple mathematical procedure for estimating the optimal slope and azimuth angles of solar collectors is presented. The aim of this work is to outline the map of the optimal slope angle of collectors used in Iran and then provide an atlas of maximum gain of solar energy. The optimum daily, monthly, seasonally and yearly optimum slope angle of 30 cities are determined based on the horizontal daily radiation. The results of these 30 cities are used in order to provide the maps. Note that the optimum angles are determined with employing numerical methods.

2. Mathematical Modelling

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 [3].

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

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 [3], the total monthly average daily radiation $\overline{H}_T$ in the 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

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

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

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

Sunrise angle ω_{sr} and sunset angle ω_{ss} are introduced as:

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

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

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

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

and

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

where

$$A=\cos\beta+\tan\phi\cos\gamma\sin\beta \quad (9\text{-a})$$

$$B=\cos\omega_s\cos\beta+\tan\delta\sin\beta\cos\gamma \quad (9\text{-b})$$

$$C=\frac{\sin\beta\sin\gamma}{\cos\phi} \quad (9\text{-c})$$

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

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

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

$$a'=a-\frac{\overline{H}_d}{\overline{H}} \quad (10\text{-c})$$

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

It is worth mentioning that the above equations for calculating monthly average daily radiation can also be applied for daily radiation H_T on inclined surface.

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 [3],

$$\overline{K}_T=\frac{\overline{H}}{\overline{H}_0} \quad (11)$$

and $\overline{H}_d$ is calculated as:

$$\begin{array}{l} for\ \omega_s\leq 81.4°\ and\ 0.3\leq\overline{K}\leq 0.8\\ \frac{\overline{H}_d}{\overline{H}}=1.391-3.56\overline{K}+4.189\overline{K}^2-2.137\overline{K}^3\end{array} \quad (12\text{-a})$$

$$\begin{array}{l} for\ \omega_s>81.4°\ and\ 0.3\leq\overline{K}\leq 0.8\\ \frac{\overline{H}_d}{\overline{H}}=1.311-3.022\overline{K}+3.427\overline{K}^2-1.821\overline{K}^3\end{array} \quad (12\text{-b})$$

and $\overline{H}_0$ for latitudes of $+60°$ to $-60°$ can be calculated for the average day of the month as:

$$\begin{array}{l}\overline{H}_0=\frac{24\times 3600\,G_{sc}}{\pi}\times(1+0.033\cos\frac{360n}{365})\\ \times(\cos\phi\cos\delta\sin\omega_s+\frac{\pi\omega_s}{180}\sin\phi\sin\delta)\end{array} \quad (13)$$

The daily clearness index K_T is defined as:

$$K_T=\frac{H}{H_0} \quad (14)$$

where H_0 can be calculated by Eq. 15 when n and δ depend on each day of the month and H_d is calculated according to Duffie and Beckman [3]:

$$\begin{array}{l} for\ \ \omega_s\geq 81.4°\\ \frac{H_d}{H}=\begin{cases}1+0.2832\,K_T-2.5557\,K_T^{\,2}+\\ 0.8448\,K_T^{\,3}\ \ for\,K_T<0.722\\ 0.175\ \ for\ \ K_T\geq 0.722\end{cases}\end{array} \quad (15)$$

$$\begin{array}{l} for\ \ \omega_s\leq 81.4°\\ \frac{H_d}{H}=\begin{cases}1-0.2727\,K_T-2.4495\,K_T^{\,2}+11.9514\,K_T^{\,3}+\\ 9.3879\,K_T^{\,4}\ \ for\,K_T<0.722\\ 0.175\ \ for\ \ K_T\geq 0.722\end{cases}\end{array} \quad (16)$$

3. Results and Discussion

For calculating radiation components on an inclined surface, they should be at hand on a horizontal surface first. These information are borrowed from the Iranian Meteorology Organization (IMO) in 30 Iranian cities for a period of 22 years from 1983 to 2005. For receiving maximum solar radiation, the solar collector should be mounted at the optimum angles recommended according to the present calculations.

In this paper, the daily solar radiation data for 30 cities were borrowed from IMO and used to determine the daily optimum angles. The mean daily solar radiation is calculated for each month and applied to determine the monthly optimum angles.

3.1. Calculating the Optimum Angles of Solar Collectors

The majority of researchers didn't take into account the azimuth angle and only considered it equal to zero for northern hemisphere according to Duffie and Beckman [3]. The KT method which calculates the amount of energy received on the collector considering both slope and azimuth angles is used here for finding the optimum azimuth angle in addition to the optimum slope angle. These angles are illustrated in Fig. 1.

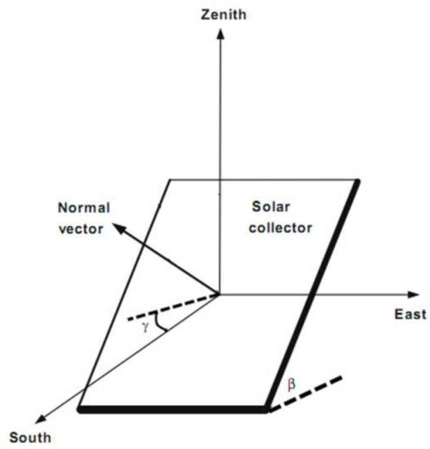

Fig. 1. The schematic view of solar collectors with the characteristic angles

As shown in Fig. 1, β is the angle between the plane of the surface and the horizontal and is the deviation of the projection on a horizontal plane of the normal to the surface from the local meridian, with zero due south, east negative and west positive [3].

The optimum azimuth angle at different days and months of a year in Kerman and Karaj are calculated and shown in Figs. 2 and 3, respectively. It's worth mentioning that because of page limitation only the figures regarding γ_{opt} for Kerman and Karaj are shown.

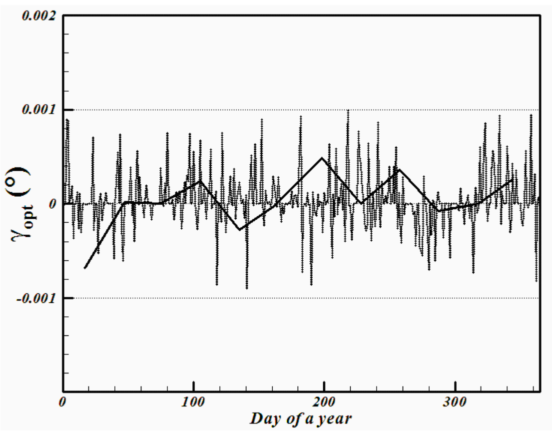

Fig. 2. The optimum azimuth angle at different days and months of a year for Kerman

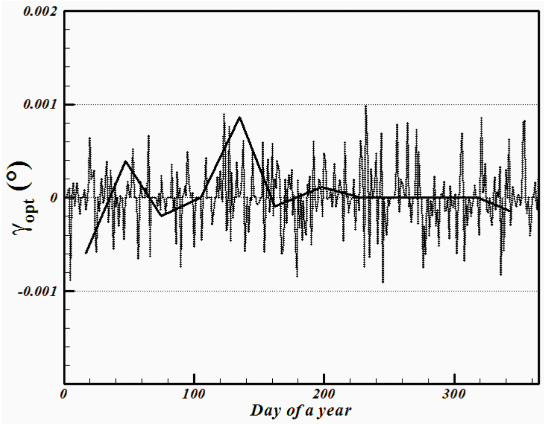

Fig. 3. The optimum azimuth angle at different days and months of a year for Karaj

As Illustrated in Figs. 2 and 3, the azimuth angle is equal to zero according to Duffie and Beckman [3]. Note that the convergence value of the numerical method is considered 10^{-3}.

Now, the results of optimum slope angle are investigated here. Figs. 4 and 5 illustrate the values of $\beta_{opt(m)}$ for Kerman and Karaj, respectively and the values of $\beta_{opt(d)}$ in these cities are also displayed in Figs. 6 and 7.

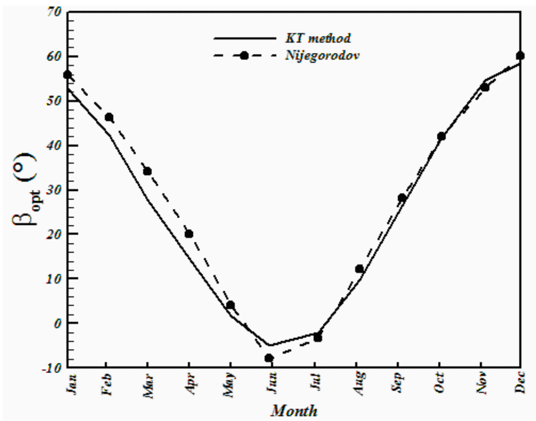

Fig. 4. The mean optimum slope angle at different months of a year employing KT method and Nijegordov equations for Kerman

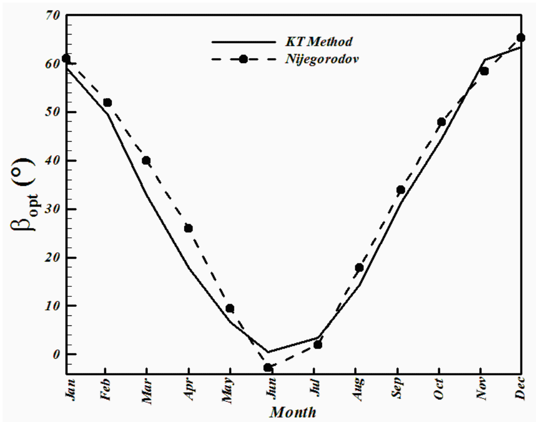

Fig. 5. The mean optimum slope angle at different months of a year employing KT method and Nijegordov equations for Karaj

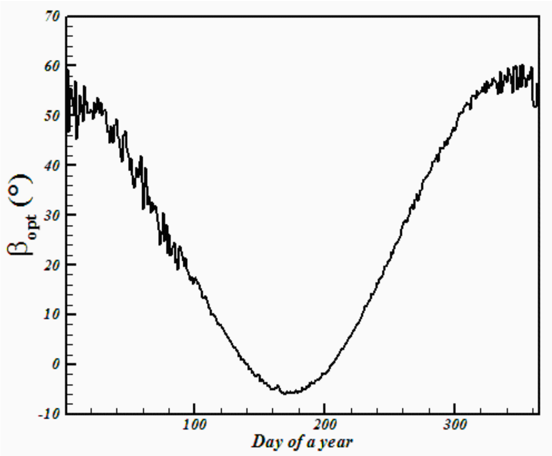

Fig. 6. The daily optimum slope angle at the different days of a year for Kerman

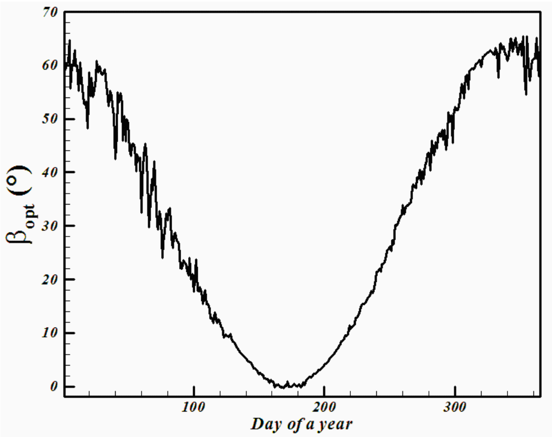

Fig. 7. The daily optimum slope angle at the different days of a year for Karaj

As mentioned before, because of page limitation only the figures regarding the optimum slope angles for these two cities are shown.

In Figs. 8 and 9, the energy received by the collector is displayed with respect to γ at four different slope angles $\phi-10°, \phi, \phi+10°, \phi+20°$ employing the KT method for Kerman for example in January and September, respectively.

It is observed from Figs. 8 and 9 that the maximum received energy occurs in   for both January and September and increasing the azimuth angle in positive or negative direction, the energy is decreased. Furthermore, the optimum slope angle is in January and with decreasing , the received energy is decreased; however, the optimum slope angle is in September and with decreasing , the received energy is increased.

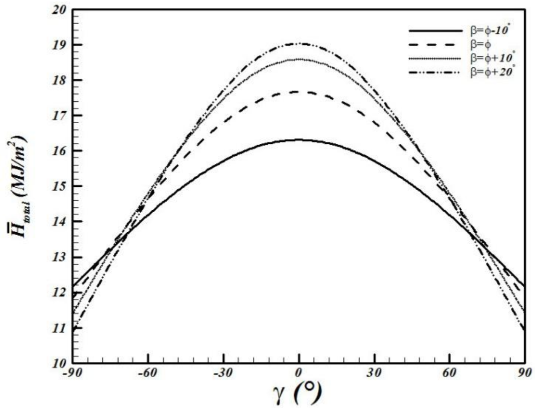

Fig. 8. The monthly mean daily radiation versus γ at different slope angles for Kerman in January

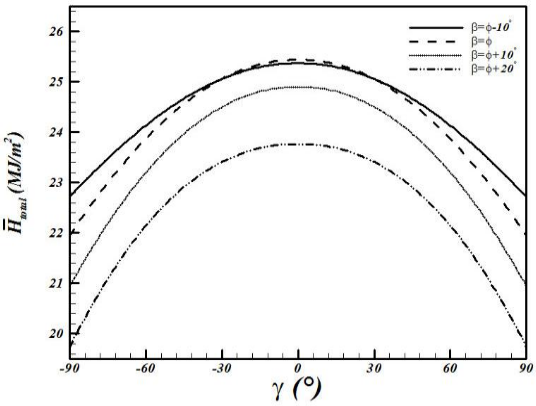

Fig. 9. The monthly mean daily radiation versus γ at different slope angles for Kerman in September

The results of optimum slope angle at different months of a year for receiving maximum solar energy using the KT method are listed in Table 1 for all the above cities. Note that when the sign of the angle varies from positive to the negative, it means that the collector surface direction is changed from the north to the south.

The optimum slope angle for the maximum solar energy is different for different months of the year and also for different cities. The results of $\beta_{opt(s)}$ and $\beta_{opt(y)}$ are listed in Table 2. The values of $\beta_{opt(s)}$ are achieved by averaging the monthly optimum slope angles for that season and the value of $\beta_{opt(y)}$ is achieved by averaging the monthly optimum slope angles in the whole year. It is notable that winter consists of January, February and March, spring consists of April, May and June, summer consists of July, August and September, and autumn consists of October, November and December.

Table 1. The values of slope angle at different months of a year for different cities

City/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bandar Abbas(27.18, 56.27)	47.4	36.4	22.7	10.9	0.2	-4.2	-1.2	6.1	18.8	33.4	47.5	49.4
Bushehr(28.99, 50.82)	45.9	35.4	24.5	12.1	1.0	-5.3	-2.0	8.6	23.9	38.4	51.6	49.1
Zahedan(29.49, 60.86)	54.1	44	30.0	14.7	0.9	-5.2	-2.7	9.0	25.5	40.6	52.7	56.6
Shiraz(29.62, 59.53)	54.6	40.4	26.2	13.3	1.3	-5.2	-2.0	8.7	24.9	39.5	51.0	57.5
Kerman(30.29, 57.07)	52.8	42.3	27.8	14.5	1.7	-4.8	-2.0	9.8	26.6	41.7	54.6	58.6
Yasoj (30.67,51.60)	53.9	43.9	29.1	15.2	2.0	-4.5	-1.7	10.2	27.0	42.9	54.6	58.7
Ahvaz (31.33,48.69)	55.4	45.3	31.0	16.1	2.5	-4.2	-1.2	10.8	27.8	43.6	54.5	58.8
Yazd(31.9, 54.37)	56.7	47.5	32.5	16.6	2.9	-3.9	-0.9	11.3	28.2	44.0	54.7	58.8
Shahrekord (32.33,50.85)	57.2	48.1	32.7	16.9	3.5	-3.6	-0.8	11.7	28.5	44.1	55.0	59.4
Isfahan(32.63, 51.65)	54.1	42.8	29.0	14.8	4.1	-1.3	1.04	10.7	25.6	37.9	49.6	54.9
Birjand(32.87, 59.2)	58.3	47.6	33.2	17.2	3.8	-2.8	-0.1	12.2	28.9	43.6	55.9	60.9
Khoramabad(33.49,48.35)	54.7	45.1	30.2	16.2	3.6	-2.5	0.7	12.1	26.8	39.8	54.1	58.9
Ilam(33.64,46.42)	53.9	44.8	29.3	15.2	4.5	-2.8	1.4	11.9	26.1	36.5	53.9	57.5
Arak (34.09,49.69)	50.5	43.7	27.4	14.9	5.0	-0.3	2.3	11.3	24.4	37.9	50.8	54.3
Kermanshah(34.35, 47.01)	52.6	41.0	26.1	14.2	5.4	0.0	2.6	11.8	25.0	38.2	51.0	56.4
Ghom(34.64,50.88)	56.5	47.2	28.5	15.8	5.5	-0.4	2.7	12.9	27.3	40.2	55.0	57.9
Hamedan(34.87,48.51)	58.3	51.7	33.1	17.1	5.8	-0.7	2.3	13.8	30.9	42.9	57.5	60.1
Sanandaj (35.31,47.00)	58.0	49.5	32.9	17.5	5.1	-1.1	1.5	12.9	29.7	43.6	56.4	60.0
Semnan(35.58,53.39)	57.6	47.8	33.0	17.8	4.6	-1.9	0.8	12.6	28.8	44.3	55.9	60.1
Tehran(35.69, 51.42)	60.7	52.7	38.0	21.0	6.8	-0.8	2.6	15.6	32.4	48.2	60.5	63.3
Karaj(35.8, 50.97)	59.0	49.3	32.8	17.9	6.6	0.5	3.3	14.4	31.2	44.4	60.7	63.3
Qazvin(36.26,50.00)	58.9	47.1	30.1	16.6	6.4	0.8	3.5	14.1	30.7	44.1	58.5	61.2
Mashhad(36.3, 59.6)	58.3	44.7	26.3	15.6	6.7	1.2	3.7	14.2	30.5	43.1	55.8	59.2
Sari (36.56,53.06)	57.7	44.4	27.0	15.2	6.6	1.3	4.1	13.8	29.7	41.1	52.8	57.5
Zanjan(36.68,4848)	56.2	44.0	27.4	15.4	6.9	1.6	4.2	13.6	27.6	39.9	51.3	54.1
Gorgan (36.84,54.44)	58.7	47.8	29.1	16.4	7.3	1.9	4.5	13.7	28.1	40.7	54.1	60.1
Ramsar (37.28,49.59)	58.5	43.5	24.1	13.8	6.5	3.6	4.9	9.7	20.2	34.2	58.5	63.2
Bojnord(37.47, 57.33)	62.2	49.9	31.4	18.5	7.7	2.1	4.7	15.1	30.6	47.4	60.8	64.4
Urmia (37.55,45.08)	59.8	49.1	30.4	17.7	7.9	2.0	4.8	14.5	28.3	40.9	56.9	63.0
Tabriz (37.07,46.28)	35.2	37.0	24.9	14.6	7.7	2.2	5.1	14.8	29.2	41.7	53.1	46.7
Ardabil(38.25,48.30)	34.1	36.2	23.5	13.9	7.5	2.3	5.2	13.9	28.4	40.1	52.0	44.6

Table 2. The values of $\beta_{opt(s)}$ and $\beta_{opt(y)}$ for different cities

City/Month	Winter	Spring	Summer	Autumn	A year
Bandar Abbas(27.18, 56.27)	35.5	2.3	7.9	43.4	22.3
Bushehr(28.99, 50.82)	35.3	2.6	10.2	46.4	23.6
Zahedan(29.49, 60.86)	42.7	3.5	10.6	50.0	26.7
Shiraz(29.62, 59.53)	40.4	3.1	10.5	49.3	25.9
Kerman(30.29, 57.07)	41.0	3.8	11.5	51.6	27.0
Yasoj (30.67,51.60)	42.3	4.2	11.8	52.1	27.6
Ahvaz (31.33,48.69)	43.9	4.8	12.5	52.3	28.4
Yazd(31.9, 54.37)	45.6	5.2	12.9	52.5	29.0
Shahrekord (32.33,50.85)	46.0	5.6	13.1	52.8	29.4
Isfahan(32.63, 51.65)	42.0	5.9	12.4	47.5	26.9
Birjand(32.87, 59.2)	46.4	6.1	13.7	53.5	29.9
Khoramabad(33.49,48.35)	43.3	5.8	13.2	50.9	28.3
Ilam(33.64,46.42)	42.7	5.6	13.1	49.3	27.7
Arak (34.09,49.69)	40.5	6.5	12.7	47.7	26.9
Kermanshah(34.35, 47.01)	39.9	6.5	13.1	48.5	27.0
Ghom(34.64,50.88)	44.1	7.0	14.3	51.0	29.1
Hamedan(34.87,48.51)	47.7	7.4	15.7	53.5	31.1
Sanandaj (35.31,47.00)	46.8	7.2	14.7	53.3	30.5
Semnan(35.58,53.39)	46.1	6.8	14.1	53.4	30.1
Tehran(35.69, 51.42)	50.5	9.0	16.9	57.3	33.4
Karaj(35.8, 50.97)	47.0	8.3	16.3	56.1	32.0
Qazvin(36.26,50.00)	45.4	7.9	16.1	54.6	31.0
Mashhad(36.3, 59.6)	43.1	7.8	16.1	52.7	29.9
Sari (36.56,53.06)	43.0	7.7	15.9	50.5	29.3
Zanjan(36.68,4848)	42.5	8.0	15.1	48.4	28.5
Gorgan (36.84,54.44)	45.2	8.5	15.4	51.6	30.2
Ramsar (37.28,49.59)	42.0	8.0	11.6	52.0	28.4
Bojnord(37.47, 57.33)	47.8	9.4	16.8	57.5	32.9
Urmia (37.55,45.08)	46.4	9.2	15.9	53.6	31.3
Tabriz (37.07,46.28)	32.4	8.2	16.4	47.2	26.0
Ardabil(38.25,48.30)	31.3	7.9	15.8	45.6	25.1

3.2. Outlining a Map for Determining the Yearly Optimum Slope Angle in Iran

In this section, an illustrative map for the yearly optimum slope angle is outlined. This map gives a guide to the optimal slope angle of a fixed collector used for the entire year with a deviation of less than 1° from the actually calculated. As shown in Fig. 10, Iran can be divided into five zones. For the most cities in the southeast of Iran, the optimum slope angle is , because these areas are climatically hot with low rain and almost the same latitude. Some other part in the middle and west of Iran are also having this optimum angle.

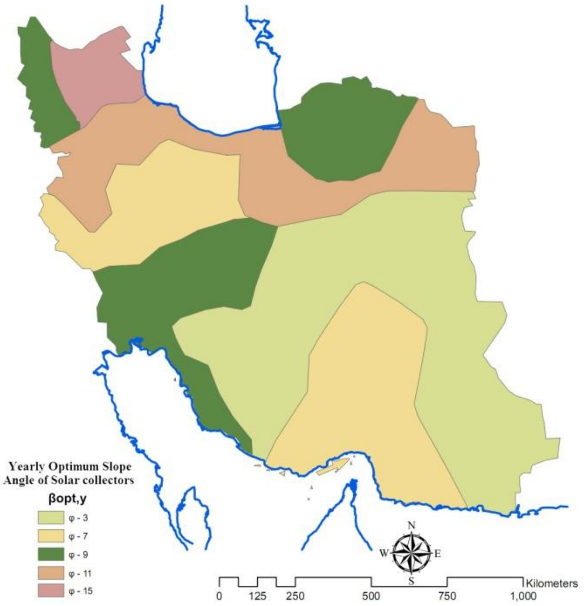

Fig 10. Map of the optimal slope angle of collectors used for the entire year in Iran

Kerman and Bandar Abbas are apart from the southeast area and with Tehran, Karaj and some other areas at the west of Iran have the optimum slope angle of . For Tabriz and Ardebil at the northwest of Iran, the climatic conditions during most of a year are cold with rain and snow; the optimal tilt angle should be taken to be . For the areas from the northeast to the west with the same latitude, the optimum slope angle is and the other areas of Iran with moderate climate have the optimum slope angle of .

3.3. Calculating the Energy Gain of Solar Collectors

As mentioned before, if the collector is perpendicular to the sun's rays, it can receive more energy from the sun. So, it is expected that collector A (mounted at daily optimum slope angle) receives more energy than collector B, collector B (mounted at monthly optimum slope angle) receives more energy than collector C, and collector C (mounted at seasonally optimum slope angle) receives more energy than collector D (mounted at yearly optimum slope angle). Tables 3 and 4 give the energy received by a horizontal collector and collectors A, B, C, D for 2 cities (for example Shiraz and Bushehr) and also gives the energy gain (percent) of collectors A, B, C, and D in comparison with a horizontal collector and gives the energy gain (percent) of collectors A, B, and C in comparison with collector D.

As expected, collector A receives the most energy from the sun. However, the energy received by collector A is only 1% higher than the energy received by collector B. It is evident that changing the slope angles in a daily manner by applying solar trackers is not economical, because of the high cost of trackers. In addition, because of the little difference between the energy gain of collector B and C with respect to D, changing the angles every month has considerable effect on the energy gain. This is more effective when large number of collectors is involved.

Table 3. The energy received on a horizontal surface and on collectors A, B, C, and D in a year and the energy gain on an inclined surface compared with a horizontal surface and collector D in city of Shiraz

Ramsar	a horizontal collector	Collector D	Collector C	Collector B	Collector A
$\sum H\ (MJ/m^2)$	7372	7969	8365	8448	8518
The energy gain compared with a horizontal collector	-	8.10%	13.48%	14.60%	15.55%
The energy gain compared with collector D	-	-	4.97%	6.01%	6.89%

Table 4. The energy received on a horizontal surface and on collectors A, B, C, and D in a year and the energy gain on an inclined surface compared with a horizontal surface and collector D in city of Bushehr

Ramsar	a horizontal collector	Collector D	Collector C	Collector B	Collector A
$\sum H\ (MJ/m^2)$	7372	7969	8365	8448	8518
The energy gain compared with a horizontal collector	-	8.10%	13.48%	14.60%	15.55%
The energy gain compared with collector D	-	-	4.97%	6.01%	6.89%

Fig. 11 displays the energy gain of collector B (mounted at monthly optimum slope angle) in different cities of Iran. As illustrated in this figure, Yazd with the latitude of 31.9 ° and the longitude of 54.36 ° has the most gain of solar energy in Iran and Birjand and Kerman are placed at the next rank. Note that these cities are located in hot areas with low rain all over the world.

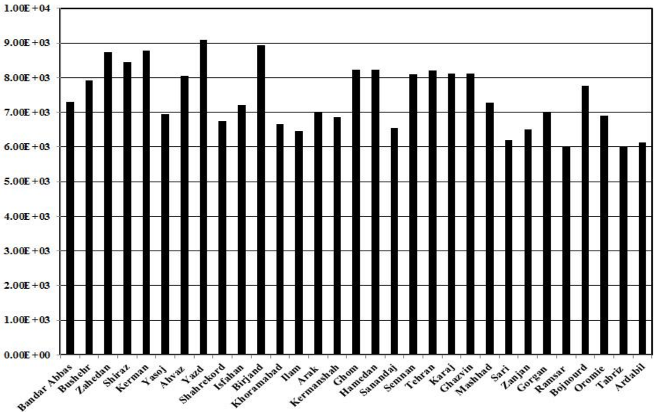

Fig. 11. The energy received on collectors mounted at yearly optimum slope angle in a year

3.4. Outlining a Geographic Atlas for Determining Areas with High Energy Gain in Iran using GIS

In this section, Arc GIS program is used to outline a solar energy atlas for Iran. With this map, the gain of solar energy in each location can be found easily and the best places for constructing solar systems can also be predicted. Fig. 12 shows the contours atlas of solar energy for Iran. As shown in this figure the areas that are shown with pink color have the most gain of energy in Iran. Note that this map is outlines for collectors mounted at monthly optimum slope angle due the mentioned reason in the previous section. It is worth mentioning that only Runsheng Tang et al. [12] outlined a contour map of a yearly optimum slope angle for china, however, they didn't provide of the geographic atlas of solar energy gain.

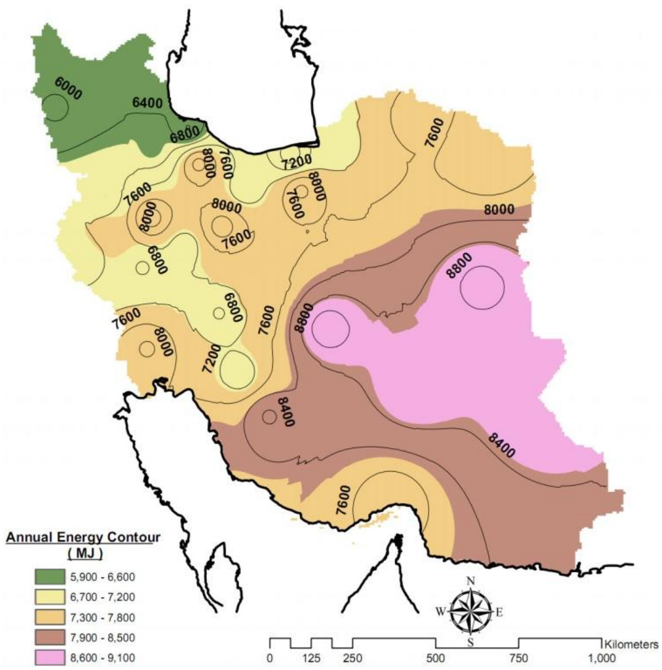

Fig. 12. The contour map of the energy gain of collectors used for the entire year in Iran

4. Conclusion

In this paper, the optimum slope and surface azimuth angles are predicted to determine maximum solar energy gain for solar flat collectors. First, In order to reach this point that using solar trackers are helpful or not, the daily, monthly, seasonally and yearly optimum angles for various areas of Iran are calculated and the gain of solar energy is determined. The results showed that the optimum surface azimuth angle is equal to zero. Furthermore, the energy gain in daily manner is almost the same as monthly manner and consequently, it is not economical to use a solar tracker in order to change the angle each day. Then, due to the high usage of fixed collectors for various reasons, a map for giving the optimal slope angle of a fixed collector used for the entire year is outlined. At last, an atlas is provided to find the best place with high solar energy gain using the monthly optimum slope angle and the results show that the areas of southeast of Iran which have hot climate and low rain with low latitude have the most gain of solar energy in Iran.

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