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The Application of Empirical Models to Compute the Solar Radiation Energy in Shahrekord

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ABSTRACT

Solar energy is one of the most significant sources of energy on the globe. One of the most outstanding factors in predicting, studying and designing solar energy systems in each site is to have the exact information and statistics regarding the degree of solar radiation on that site, to the extent that it is necessary to estimate the amount of solar energy in each area before measurement and scheduling for its use. Taking previous programming to use solar energy in Shahrekord, the amount of the above energy has been assessed moderately. Therefore, considering available information of the climate condition and meteorological information, a number of suitable models have been selected and used in order to assess the amount of solar energy reached to the surface of the city of Shahrekord. The results prove that the degree of solar radiation in this city is between 10 (MJ m^{-2} day^{-1}) in cold and 32 (MJ m^{-2} day^{-1}) in warm season. This amount of energy, if any suitable instrument is provided for its collecting and saving up, can play a significant role in consumptive energy.
KEYWORDS: Solar, Energy, Designing, Globe, Radiation.

1. INTRODUCTION

Knowing about the sources and equipments in each area requires investigating about the situation, limitations, quality and quantity of the sources and their types. One of the basic sources in each place is the degree of solar radiation within a year. One of the important factors in predicting, studying and designing the solar energy systems in each place is to know the exact information and statistics regarding the degree of solar radiation at that place. There are several factors which affect the degree of solar radiation in each place. Among them, geographical factors such as longitude and latitude, altitude from the sea level and the degree of pollution and dust of the place and also meteorological factors such as changes in daily temperature, changes in the relative humidity, the amount of rainfall, the bulk of the clouds in the sky and the number of the sunshine hours can be mentioned. The rendered models to predict the amount of solar radiation, in the same way, have been founded on this information. In addition to weather conditions, there are other conditions such as economical and political situation of launching those solar systems which are effective as well. Therefore, prior to carrying out these solar energy exploitation projects, it seems vital to estimate it in case of all the parameters [1].

In most of the developing countries and Iran, as well, the real measured amounts of solar radiation are not available in different areas. So, it is extremely important to use empirical models to assess the solar energy at different areas under various weather conditions, especially the places whereof the possibility of empirical data availability is low. Considering previous schedules to use solar energy in Shahrekord, in the present study the amount of this energy has been assessed moderate. To get to the results, regarding available information from climate condition and meteorological information, some appropriate empirical models have been selected and applied in order to predict the amount of solar energy reached to the surface of Shahrekord city.

Applicable models to predict the amount of solar radiation in Shahrekord

As pointed out in the previous section, there are several models to predict the amount of solar radiation. Each of the above models is a function of different parameters such as the number of sunshine hours, latitude, and altitude from the sea level, changes in the temperature and the bulk of clouds, etc. Regarding available information, some models have been selected from present models in order to predict the amount of solar radiation in Shahrekord. The definition for each of the models and their mathematical relationships will be briefly offered in the next sections.

Daneshyar model

The above model has been offered by Daneshyar (1978) based on empirical relationships to assess the degree of solar radiation in 34 cities in Iran. According to this model, the direct and diffuse solar radiation is estimated for a horizontal surface through following relations [2]:

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1) $I_{dir}(\theta_z, CF) = 3.42286[1 - \exp(-0.075(90 - \theta_z))](1 - CF)\cos\theta_z$

2) $I_{dif}(\theta_z, CF) = 0.00515 + 0.00758(90 - \theta_z) + 0.43677CF$

In equations 1 and 2 the degree of solar direct radiation (I_{dir}) and diffuse radiation (I_{dif}) will be achieved in (MJ m^{-2} h^{-1}). In these relations CF is the cloud fraction the average amount of which has been rendered in 34 cities in the study done by Daneshyar [2]. The amount of CF in different months of the year has been reported in Table 1 for Shahrekord.

Table 1: the monthly mean cloud fraction in Shahrekord

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CF	0.464	0.393	0.392	0.441	0.282	0.208	0.243	0.191	0.151	0.173	0.319	0.356

In the above relations θ_z is the angle of the sun vertex which is given by below relation.

3) $\cos\theta_z = \sin\delta \sin\varphi + \cos\delta \cos\varphi \cos\omega$

That φ latitude of the place, δ deviation angle and ω is the angle of sunshine hour which is measured through following relation:

4) $\delta = 23.45 \sin\left(\frac{360}{365}(284 + DN)\right)$

5) $\omega = 15(12 - t)$

In relations 4 and 5, DN and t, in order, are the day, year (from the first month of lunar year) and the time in hour, from the solar noon.

By summing up the direct and diffuse radiation and integrating from them within the day, the amount of total solar radiation energy is estimated in (MJ m^{-2} day^{-1}).

6) $R_{est} = (1 - CF)\int_{sunrise}^{sunset}[3.42286[1 - \exp(-0.075(90 - \theta_z))]\cos\theta_z]dt$
$+ \int_{sunrise}^{sunset}[0.00515 + 0.00758(90 - \theta_z) + 0.43677CF]dt$

Modified Daneshyar model

Sabziparvar (2008) modified Daneshyar model while taking into account altitude modification factor for solar direct ($K_{alt-dir}$) and diffuse($K_{alt-dif}$) radiation concomitant with the modification of earth-sun distance. The modified Daneshyar model to estimate the degree of solar radiation is as the followings [3]:

7) $R_{est} = (1.01)(K_{\varepsilon})\{((3.42286)(1 - CF)(K_{alt-dir})) \times \int_{sunrise}^{sunset} [1 - \exp(-0.075(90 - \theta_z))]\cos\theta_z dt] +$
$(K_{alt-dif}) \times \int_{sunrise}^{sunset} [0.00515 + 0.00758(90 - \theta_z) + 0.43677CF]dt] \}$

8) $K_{\varepsilon} = 1 + 0.033\cos\left(\frac{2\pi(DN - 0.5)}{365}\right)$

9) $K_{alt-dir} = [1 + 0.07(h - h_{ref})]$

10) $K_{alt-dif} = [1 - 0.1(h - h_{ref})]$

In the above relations, h is the height from the sea level in Kilometers and h_{ref} the reference height, equals to 0.265 kilometers.

Sabbagh model

This model which is based on Reddy model [4] would give the total amount of solar radiation as a function of meteorological information like maximum of the daily temperature, the amount of relative humidity and geographical data such as latitude. Below relation renders the amount of solar radiation according to this model [5]:

11) $R_{est} = 0.06407(K_g)\exp\left[L\left(\frac{n}{12} - \frac{RH^{0.333}}{100} - \frac{1}{T_{max}}\right)\right]$

In equation number 11, L is the latitude in radian, n the mean sunshine hours, RH relative humidity, T_{max} the maximum temperature and K_g which is measured through following relations [4]:

12) $K_g = 100(\lambda N + \psi_{i,j} \cos\varphi)$

13) $\lambda = \frac{0.2}{1 + 0.1\varphi}$

14) $N = \frac{2}{15}\cos^{-1}(-\tan\varphi \tan\delta)$

In equations 12 and 13 the latitude is in degrees, N the mean day length and $\psi_{i,j}$ is the multiple of the season. i=1, 2 in which i=1 is applied for the stations located in natural areas and i=2 for those near the sea. j=1, 2… 12 which is used for different months of the year and the amounts dealing with $\psi_{i,j}$ have been reported in Table 2.

Table 2: the amounts related to $\psi_{i,j}$ for different months of the year

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ψ_1	1.28	1.38	1.54	1.77	2.05	2.3	2.48	2.41	2.36	1.73	1.38	**1.17**
ψ_2	1.46	1.77	2.05	2.15	2.05	2.05	2.1	2.17	2.14	1.96	4.6	**1.43**

Modified Sabbagh model

Sabziparvar offered modified Sabbagh model in order to estimate the degree of solar radiation [3].

15) $$R_{est} = 0.06407(K_s)(K_{alt-glob})(K_g)\exp\left[L\left(\frac{n}{N} - \frac{RH^{0.333}}{100} - \frac{1}{T_{max}}\right) - 0.011NDD\right]$$

In equation 15, R_{est} is the mean total solar radiation in (MJ m^{-2} day^{-1}) on a horizontal surface. K_g can be calculated through equations 12, 13 and 14. K_s, $K_{alt-glob}$ and NDD are, in order, modifying the earth-sun distance factor (equation 8), modifying altitude factor and the number of dusty days.

16) $$K_{alt-glob} = [1 + 0.02(h - h_{ref})]$$

Hottel model

Hottel model was suggested for clear weather with visibility of 5 to 25 kilometers in which the amount of total solar radiation in w/m^2 is given through following relations [6].

17) $$I_{dir} = \tau_{dir} G_{on} \cos\theta_z$$

18) $$I_{dif} = \tau_{dif} G_{on} \cos\theta_z$$

19) $$I_{tot} = I_{dir} + I_{dif}$$

In the above relations θ_z is the right angle of the sun vertex which is calculated by relations 3 and 5, G_{on} is the degree of intensity in solar radiation above the atmosphere.

20) $$\tau_{dir} = a_0 + a_1 \exp\left(-\frac{k}{\cos\theta_z}\right)$$

21) $$\tau_{dif} = 0.271 + 0.2939\tau_{dir}$$

22) $$G_{on} = G_{sc}\left(1 + 0.033\cos\left(\frac{360\,DN}{365}\right)\right)$$

In the equation 22, G_{sc} is the solar constant which has been considered equal to 1367 w/m^2 [7]. The constants a_0, a_0 and k are measured by the following relations in standard atmosphere conditions.

23) $$a_0 - r_0[0.4237 - 0.0082(6.0 - A)^2]$$

24) $$a_1 = r_1[0.5055 + 0.00595(6.5 - A)^2]$$

25) $$k = r_k[0.271 + 0.01855(2.5 - A)^2]$$

In the above relations A is the altitude of the place in kilometers and r_0, r_1 and r_k, in order, are considered 0.97, 0.99, and 1.02 [8].

Cloudy sky model

Taking into account the studies carried out in Shiraz, the above model has been given. In this model the amount of total solar radiation is estimated through the following relation [8]:

26) $$I_{tot} = [(1 + \alpha_1)(1 - CF) + 0.55CF]I_{dir}$$

In equation 26, $\alpha_1 = 0.16$ and I_{dir} is calculated from equation 17 as well.

Clear sky model

This mode, like cloudy sky model, is achieved via studies done in Shiraz. The amount of total solar radiation for the days with clear sky is measured through the following relation [8].

27) $$I_{tot} = (1 + \alpha_2)I_{dir}$$

In equation 27, $\alpha_2 = 0.08$ and I_{dir} , too, is calculated by equation 17.

Rietveld model

Rietveld (1978) reported a model to predict the amount of solar radiation based on collected data from 42 world stations located in Yugoslavia, Sweden, Belgium, and the United States. The base of its function is the one rendered by Angstrom [9] in which the amount of solar radiation is a function of the amount of solar radiation above the atmosphere and sunshine hours. Riveted offered the following equation to compute the amount of solar radiation that can be applied in all over the world [10].

28) $$\frac{\bar{H}}{\bar{H}_0} = 0.18 + 0.62\ \frac{n}{N}$$

In equation 28, $\bar{H}_0$ is the amount of solar radiation above the atmosphere and $\frac{n}{N}$ the average number of sunshine hours divided by the day length.

29) $$\bar{H}_0 = \frac{24 \times 3600 G_{sc}}{\pi}\left[1 + 0.033 \cos\left(\frac{360\,DN}{365}\right)\right] \times \left[\cos\varphi \cos\delta \sin\omega_s + \frac{2\pi\omega_s}{360} \sin\varphi \sin\delta\right]$$

In equation 29, ω_s is the angle of sunshine hours at sunrise and sunset which is measured through following relation:

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

In equation 28 the amount of solar radiation is given in (J m^{-2} day^{-1}).

Glover model

Glover model, like Rietveld model, has been founded on Angstrom model. He made the amount of solar radiation as a function of latitude in addition to radiation above the atmosphere and sunshine hours. According to this model the amount of solar radiation is estimated by the following relation in semiarid areas [11].

28) $$\frac{\bar{H}}{\bar{H}_0} = 0.27\cos\varphi + 0.54\ \frac{n}{N}$$

In equation 28, $\frac{n}{N}$ is the mean sunshine hour divided by the day length, φ latitude of the place and $\bar{H}_0$ the average amount of radiation above the atmosphere (equation 29).

Ya'ghoubi & Jafarpour model

This model, like clear sky and cloudy sky models, is also achieved regarding studies carried out in Shiraz. According to this model which is, likewise, founded based on Angstrom and is mostly applicable in Shiraz, the amount of solar radiation is achieved through following relation [8]:

29) $$\frac{\bar{H}}{\bar{H}_0} = 0.23 + 0.54\ \frac{n}{N}$$

RESULTS

Due to achieved information from meteorology annuals from 2001 to 2010, the average of meteorological data was computed; afterwards, a mean day has been selected for each month according to reference [12] and related calculations in case of that mean day has been supplied. The reported results have been given in Table 3.

Considering the relations and rendered models in previous sections, the amount of total daily solar radiation for different months of the year has been estimated. Table 4 shows the amount of predicted solar radiation energy based on various models in Shahrekord. Due to the fact that the number of dusty days was not accessible in meteorological information; in Sabbagh modified model, the number of dusty days have been considered zero.

As it was proposed in models sections, some of them are able to render the amount of direct, diffuse or total radiation in each specific moment. Graphs 1, 2 and 3 describe the comparison between direct, diffuse and total of radiation energy in Daneshyar and modified Daneshyar models in the first days of April, July and September. It can be observed that in these graphs, modified Daneshyar model would predict the degree of diffuse radiation at all times less than Daneshyar model, whereas the degree of direct and total receivable radiation does predict it more than that.

Direct, diffuse and total radiation energy for Hottel model in the first days of April, July and September have been shown in Graphs 4, 5 and 6.

Table 3: Averaged meteorological information from the measured information in ten years (2001-2010)
Latitude: 32° 17' longitude: 50° 50' altitude from the sea level: 2050 meters

Month	number of days of the month	mean day of the month	maximum temperature (°C)	minimum temperature (°C)	mean temperature (°C)	mean relative humidity
Jan	31	17	4.82	-10.07	-2.62	66.90
Feb	28	16	90.01	-0.4.50	2.25	58.30
Mar	31	16	15.16	-1.63	6.76	44.81
Apr	30	15	18.77	2.72	1.074	48.08
May	31	15	24.54	5.60	15.07	40.30
Jun	30	11	30.79	8.96	19.87	30.51
Jul	31	17	33.84	12.82	33.23	28.47
Aug	31	16	32.75	11.08	21.91	27.46
Sep	30	15	29.07	6.45	17.76	30.64
Oct	31	15	23.24	2.66	12.95	37.42
Nov	30	14	14.41	-1.74	6.33	52.63
Dec	31	10	7.91	-6.66	0.625	64.66

Continuation of Table 3: Averaged meteorological information from the measured information in ten years (2001-2010)
Latitude: 32° 17' longitude: 50° 50' altitude from the sea level: 2050 meters

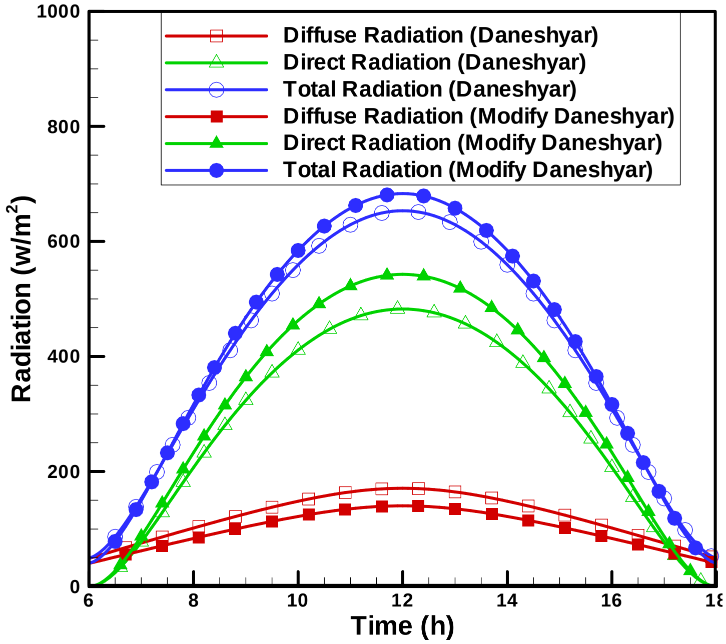
Month	total sunshine hours (h)	mean sunshine hours (h)	day length (h)	Sunshine hours divided by the day length	mean of the cloud fraction
January	195.50	6.30	10.14	0.621	0.464
February	206.00	7.35	10.89	0.675	0.393
March	247.76	7.99	11.79	0.677	0.392
April	233.26	7.77	12.79	0.607	0.441
May	307.28	9.91	13.64	0.726	0.282
June	344.55	11.48	14.07	0.816	0.208
July	335.94	10.83	13.88	.0780	0.243
August	328.44	10.91	13.15	0.830	0.191
September	313.50	10.45	12.18	0.857	0.151
October	276.06	8.9	11.18	0.796	0.173
November	214.62	7.15	10.34	0.691	0.391
December	188.06	6.06	9.93	0.610	0.356

Table 4: predicted solar radiation energy through the application of various models for Shahrekord

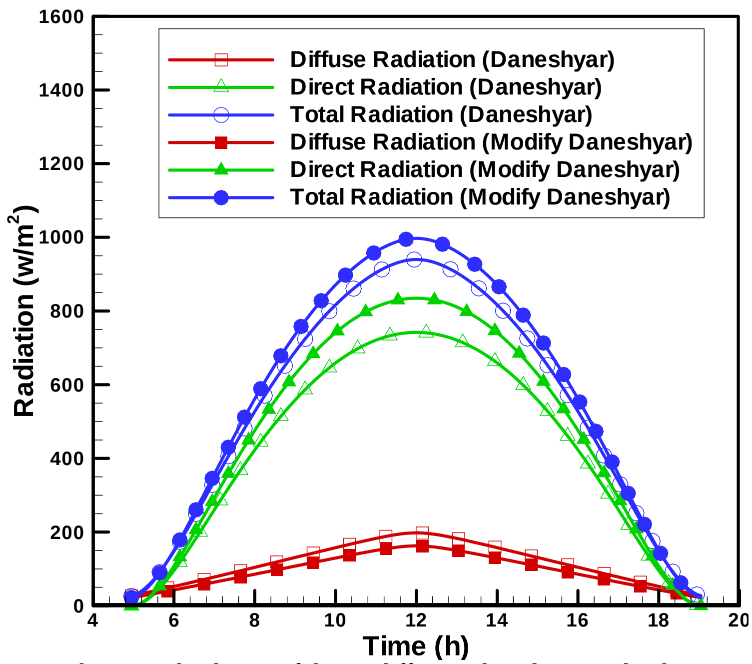
Model / Month	Daneshyar	Modify Daneshyar	Sabbagh	Modify Sabbagh	Hottel
Jan	10.13	10.52	11.82	13.33	14.07
Feb	13.45	14.16	14.13	15.51	18.03
Mar	17.04	17.80	16.54	17.40	22.90
Apr	19.80	20.20	18.63	18.72	27.58
May	25.57	26.31	23.50	22.50	30.53
Jun	28.35	29.16	27.92	25.90	31.59
Jul	27.07	27.79	28.63	26.80	31.00
Aug	25.81	26.81	27.75	26.84	28.66
Sep	22.43	23.75	26.18	26.66	24.56
Oct	17.20	18.45	18.75	20.17	19.43
Nov	11.94	12.67	14.12	15.77	14.98
Dec	10.10	10.69	11.43	12.94	12.96

Continuation of Table 4: predicted solar radiation energy through the application of various models for Shahrekord (MJ m^{-2} day^{-1})

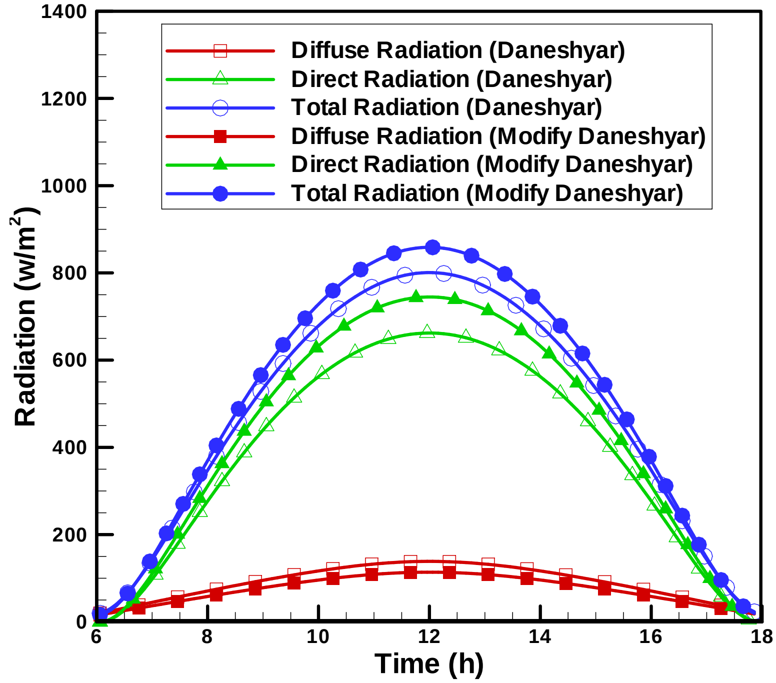
Model / Month	Cloudy Sky	Clear Sky	Rietveld	Glover	Y.J
Jan	10.86	13.38	11.29	11.27	11.30
Feb	14.87	17.45	14.87	14.74	14.77
Mar	19.18	22.50	18.45	18.28	18.32
Apr	22.57	27.36	20.27	20.27	20.32
May	27.81	30.41	25.22	24.84	24.90
Jun	30.13	31.50	28.36	27.67	27.73
Jul	28.93	30.89	26.94	26.38	26.43
Aug	27.53	28.50	26.20	25.53	25.58
Sep	23.97	24.24	23.29	22.64	22.68
Oct	18.48	18.92	17.87	17.47	17.51
Nov	12.80	14.32	12. 83	12.69	12.72
Dec	10.69	12.25	10.38	10.37	10.40



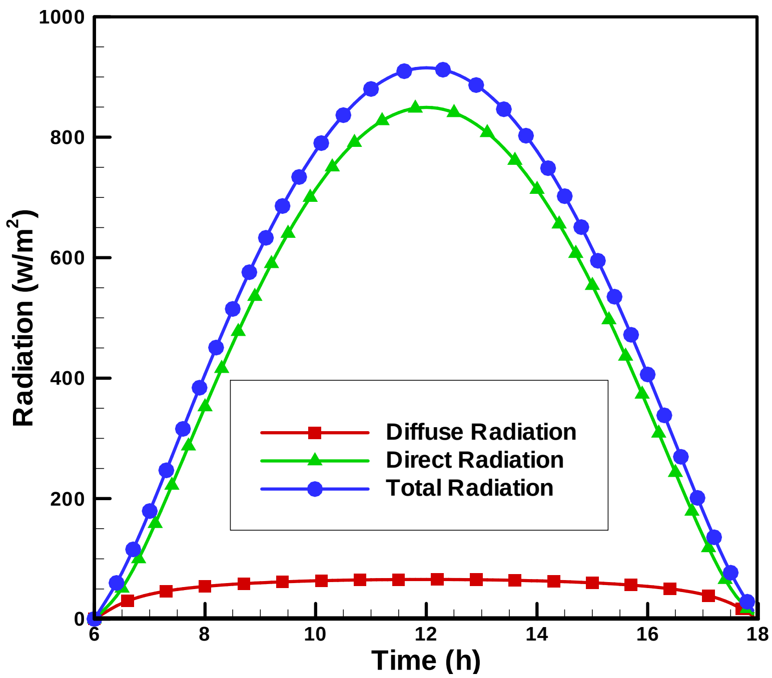
Graph 1: the comparison between the degree of direct, diffuse and total received radiation in the first day of April in Daneshyar and modified Daneshyar models



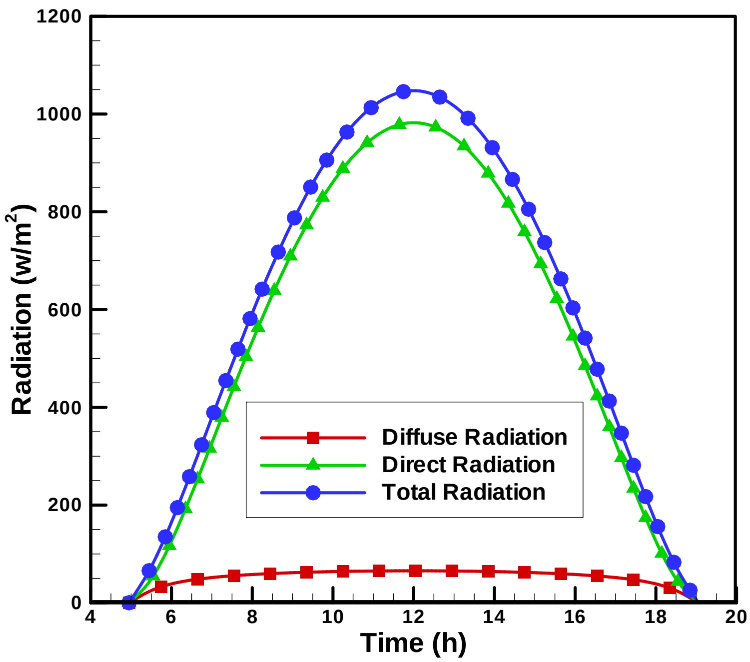
Graph 2: the comparison between the degree of direct, diffuse and total received radiation in the first day of July in Daneshyar and modified Daneshyar models



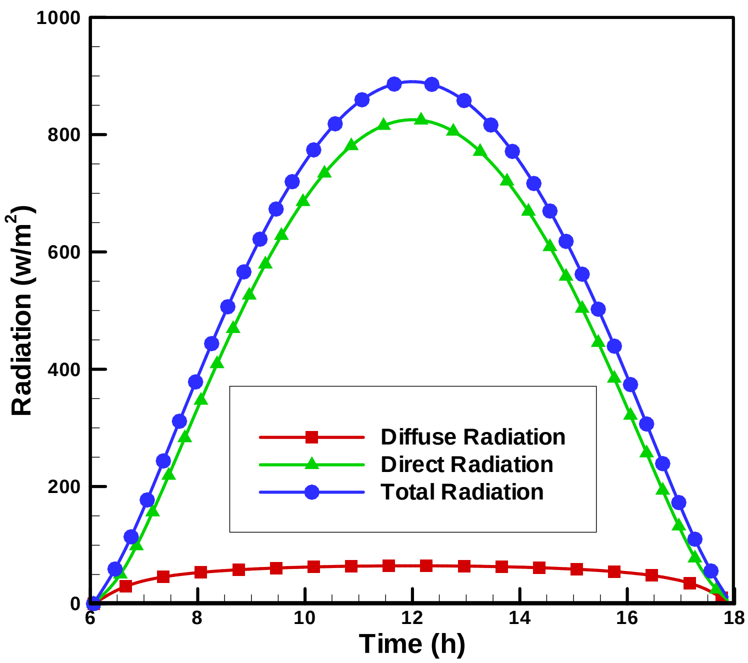
Graph 3: the comparison between the degree of direct, diffuse and total received radiation in the first day of September in Daneshyar and modified Daneshyar models



Graph 4: the degree of direct, diffuse and total received radiation in the first day of April in Hottel model

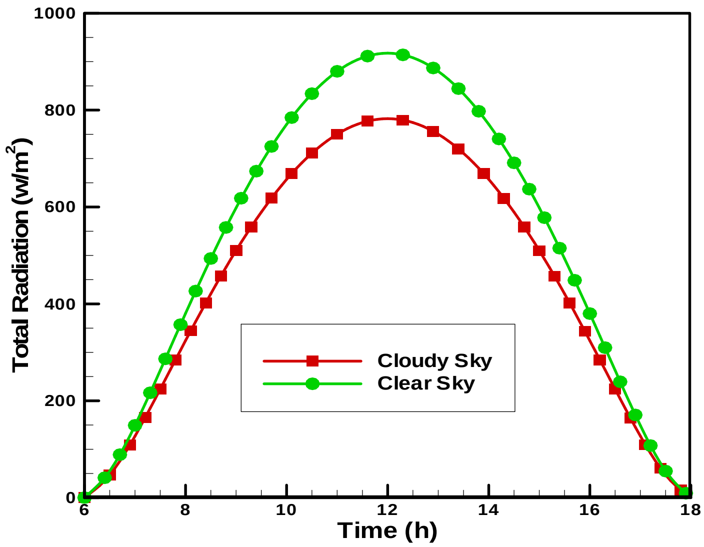


Graph 5: the degree of direct, diffuse and total received radiation in the first day of July in Hottel model

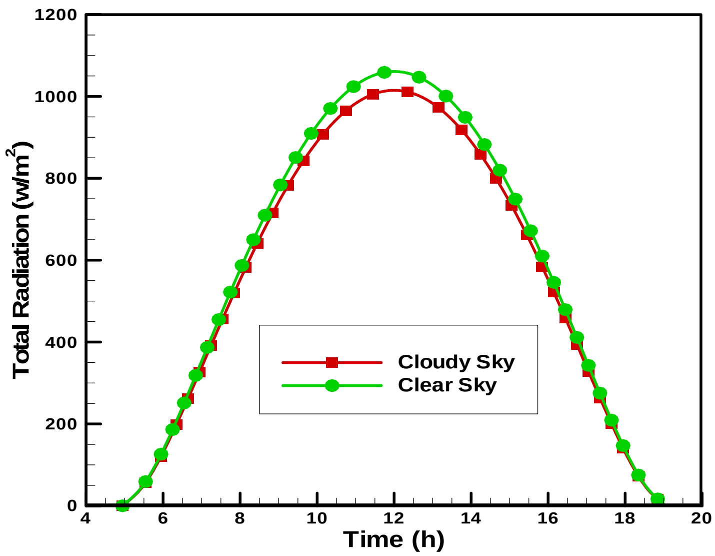


Graph 6: the degree of direct, diffuse and total received radiation in the first day of September in Hottel model

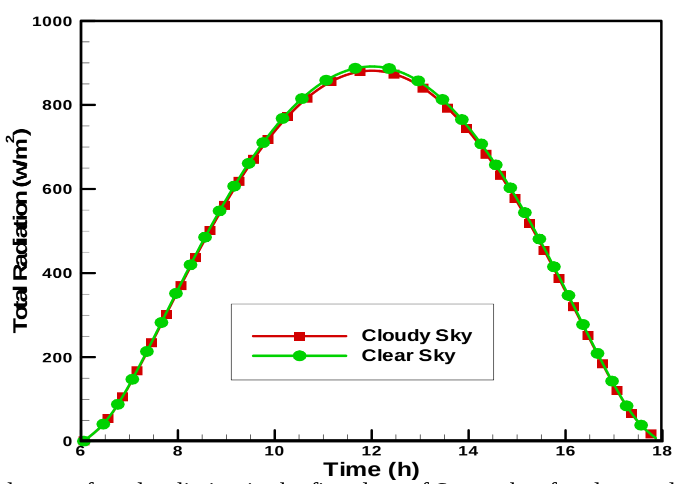
The changes in the degree of total received radiation in the first days of April, July and September for clear and cloudy sky models have been compared in graphs 7, 8 and 9. As it can be seen in graph 7, for the first days of April, clear sky model predicts the degree of received radiation in all the hours' more than cloudy sky model. However, in graph 8 the difference of the amount of predicted radiation energy in the first days of July is less by both models. In graph 9, both models predict the degree of received radiation almost the same in the first days of September; because the cloud fraction in the first days of April, July and September are, in order, 0.392, 0.208 and 0.151; and as the cloud fraction decreases, the average results of both models become extremely close to each other.



Graph 7: changes in the degree of total radiation in the first days of April for clear and cloudy sky models

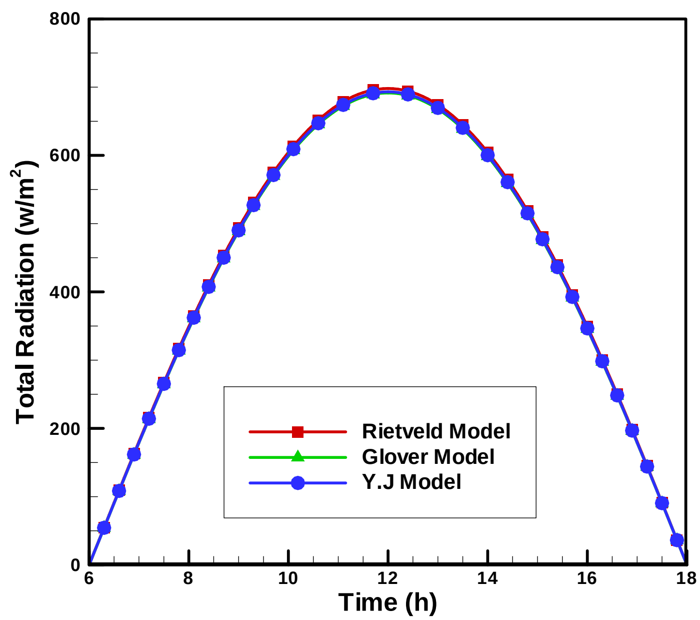


Graph 8: changes in the degree of total radiation in the first days of July for clear and cloudy sky models

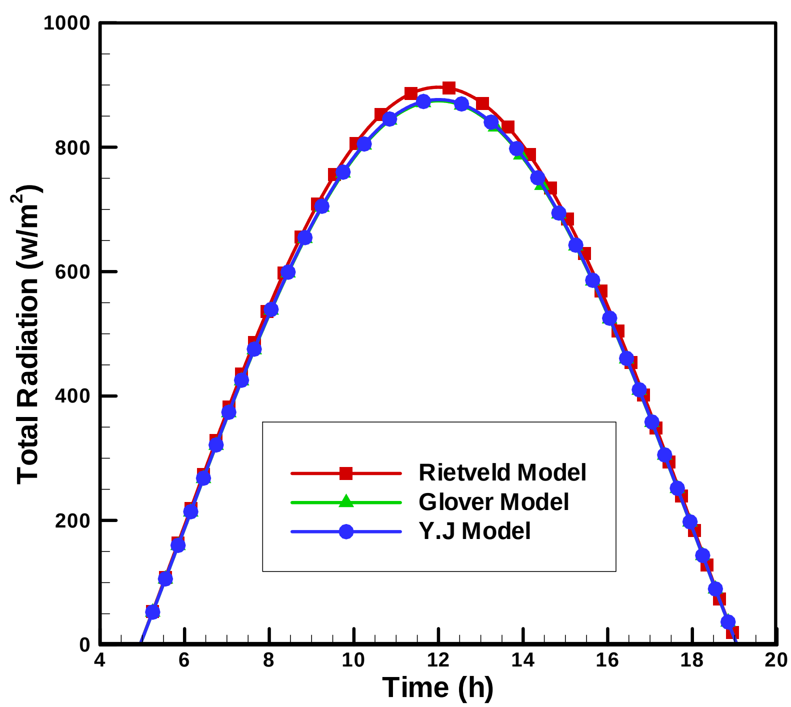


Graph 9: changes in the degree of total radiation in the first days of September for clear and cloudy sky models

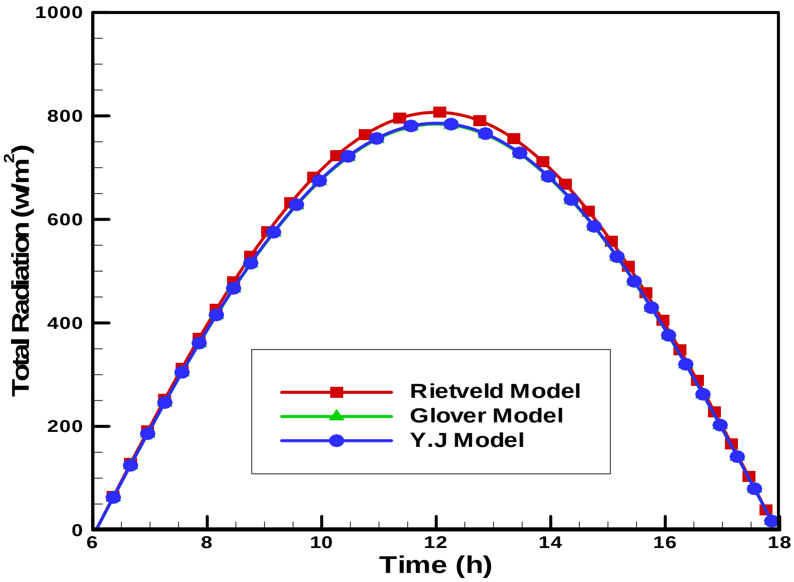
The comparison between the degree of total received radiation in the first days of April, July and September for Rietveld, Glover and Ya'ghoubi & Jafarpour are shown in graphs 10, 11 and 12. Considering the fact that all these models are founded on Angstrom model, there is a slight difference between the results of these models and all these models would predict almost the same results. Referring to graphs 11 and 12 it is observed that Rietveld model predicts the degree of received radiation at the hours near the solar noon slightly more than Glover and Ya'ghoubi & Jafarpour models in the first days of July and September.



Graph 10: changes in the degree of total radiation in the first day of April in Rietveld, Glover and Ya'ghoubi & Jafarpour models



Graph 11: changes in the degree of total radiation in the first day of April in Rietveld, Glover and Ya'ghoubi & Jafarpour models



Graph 12: changes in the degree of total radiation in the first day of September in Rietveld, Glover and Ya'ghoubi & Jafarpour models

Conclusion

In the present study the degree of solar radiation has been estimated via different models in Shahrekord city. In order to select or render a completely exact model to predict the amount of solar radiation in Shahrekord, there needs to have empirical and measured data which have to be measured for some years. The results report that the degree of solar radiation in mentioned city was between 10 (MJ m^{-2} day^{-1}) in cold to 32 (MJ m^{-2} day^{-1}) in warm season. This degree of energy can play an important role in consumptive energy if there is any suitable instrument for its collecting and saving up. The comparison of the results proves the fact that the modified Daneshyar model would predict the degree of diffuse radiation less at all times, and the direct and total received radiation more than Daneshyar model. Through investigating various models it can be concluded that the application of solar energy for Shahrekord in different fields have the potential to be examined and estimated.

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