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Availability of Solar Energy in Hashemite University

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Abstract

The purpose of this work is to give the potential of solar energy in Hashemite University HU. The solar radiation in HU for March 2009 was obtained from Pyranometer which measures the global radiation over horizontal surfaces. Solar data in several different forms, over period of 5 minutes, hour-by-hour, daily and monthly data radiation have been presented. Beam and diffuse radiation have been estimated from total data. Moreover, the radiation on tilted surface has been calculated from available solar data on the horizontal surface.

Keywords: Solar Energy; Hashemite University; Global Radiation

1. Introduction

Jordan lies between Latitude 28°4'-33°30' N and between Longitude 35 ° -39 ° E. The total area of Jordan is about 89,206 Square Kms, around 90% of which is desert and rural areas. The population of Jordan was about 5.723 million in 2007 with growth rate of about 3.4%. Almost 90 per cent of the population lives in the north-west of Jordan, situated in areas which together constitute about 10% of the county's total land area. Jordan like other developing countries in general has to meet the energy challenges for achieving the requirements of the government strategy for a comprehensive and sustainable social and economic development. The lack of commercial energy resources in Jordan and dependence on crude oil and oil products imports, high population growth rate, an expected continuous high energy consumption growth rate of about (3% / year) and (6%) for the electricity consumption, all these yearly costs make the energy bill a big burden on the national economy. Part of the solution to this problem to utilize Jordan's renewable energy resources like solar energy. According to the energy sector's strategy of Jordan, it is planned that the renewable energy contribution will reach 3% of the overall energy mixture until the year 2015 [1].

Several studies have been showed that the solar energy are promising in Jordan [2, 3, 4]. Jordan is one of the sun belt countries according to the international classification since the average annual solar radiation per day is (3.8) Kwh/ square meter in winter to more than (8) Kwh/square meter in summer. The yearly global solar radiation in Jordan ranges from (1700) kWh/m² in Jordan Valley to more than (2250) kWh/m² for Hill area which facilitates building investment projects utilizing solar energy for the generation of electricity[5,6].

The Hashemite University HU lies at latitude of 32 5' N and longitude of 36 7' E with elevation of 555 m. Unfortunately, there are no solar data available in Zarqa governate despite of 50% of industrial facilities lie within its zone in addition to energy-producing facilities such as the Jordan petroleum refinery and Al-Hussein thermal station.

Mapping of solar energy along the year is essential for the utilization solar energy applications. This includes photovoltaic applications, thermal- solar systems, solar desalination and passive solar architecture. Moreover, the availability of solar data may be encoure the existing energy units to seek alternatives such as combined solar-thermal energy or hybrid system.

The main objective of this current paper is to make the solar energy data in HU available for people interested in this area and to measure and assess the characteristics of the solar radiation in Hashemite University HU (Zarqa-Jordan)

2.Data Collection

The solar radiation in HU for March 2009 was measured using Pyranometer which measures the global radiation on horizontal surfaces. It is mounted on the roof of the engineering college. It contains carefully calibrated thermoelectric elements fitted under a glass cover, which is open to the whole vault of the sky. A voltage proportional to the total incident light energy is produced and then recorded electronically. Pyranometer measurements are recorded simply as total energy incident on the horizontal surface (beam plus diffuse). The data have been taken over the March; 2009 period. Data are recorded every 5 min and then averaged on hourly, daily, and monthly basis. The sensor is photodiode detector, the spectral response from 0.4 to 1.1 microns, the sensivity is 100 mV/1000 W/m^2, and the accuracy is ±5%.

3.Results and Discussion

The objective of present measurement is to introduce four types of solar radiation data in HU. These are irradiance G (W/ m^2), hourly radiation I (MJ/ m^2), daily radiation H (MJ/ m^2), and monthly average daily radiation $\overline{H}$ (MJ/ m^2). As an example, the irradiance G data were recorded as shown in Fig. 1 for March 11;2009. Values for G were recorded by integrated over period of 5 minutes. Exact values of G for an hour 11:00-12:00 AM (standard time) are given in Table 1.

Fig.2 shows hourly radiation I on a horizontal surface versus 24 hours for March 11; 2009. The hourly radiation I at a specific an hour is calculated by averaging the irradiance values for that hour as shown in Table 1. Exact values of I for March 11 are shown in Table 2.

Daily total radiation H on a horizontal surface vs 31 days for March; 2009 are shown in Fig.3 and Table 3. The data are recorded by summing the total hourly radiation over the day. It can also be found the monthly average daily radiation $\overline{H}$ of 18.5 MJ/ m^2 for March 2009. This is done by averaging the daily total radiation for 31 days.

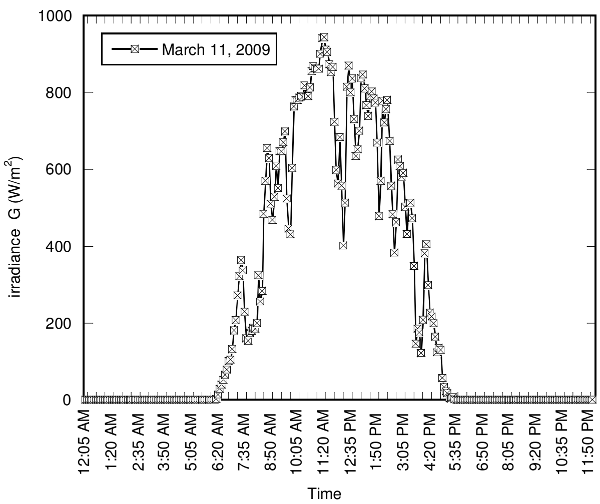

Fig. 1: Total irradiance on a horizontal surface vs time for March 11, 2009

Table 1: Irradiance data G for an hour 11:00-12:00 AM for March 11, 2009

(standard time)	Irradiance G (W/m^2)
11:00 AM	862.44
11:05 AM	901
11:10 AM	942.31
11:15 AM	944.56
11:20 AM	911.12
11:25 AM	905.69
11:30 AM	873.06
11:35 AM	854.25
11:40 AM	866.06
11:45 AM	724.56
11:50 AM	599.12
11:55 AM	563.38
Hourly Radiation, I	828.96 W/m^2=2.98MJ/m^2

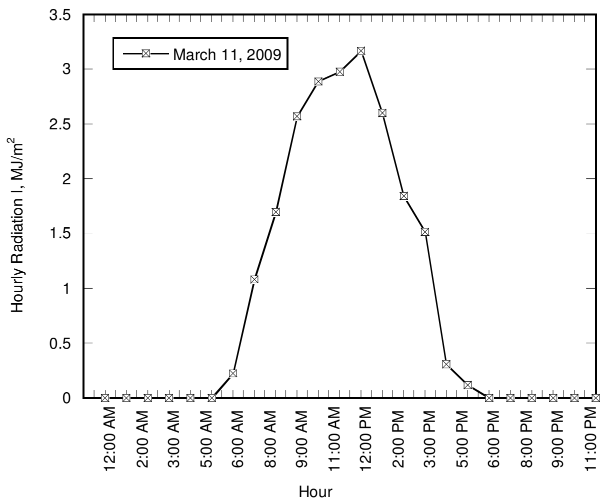

Fig.2: Hourly total radiation on a horizontal surface vs 24 hours for March 11; 2009

Table 2: Hourly radiation for March 11; 2009

standard time	Hourly radiation I, MJ/m^2
12:00 AM	0
1:00 AM	0
2:00 AM	0
3:00 AM	0
4:00 AM	0
5:00 AM	0
6:00 AM	0.186948
7:00 AM	0.832176
8:00 AM	1.53012888
9:00 AM	2.2120164
10:00 AM	2.94129288
11:00 AM	2.984256
12:00 PM	2.45932776
1:00 PM	2.66204376
2:00 PM	2.2233384
3:00 PM	1.264293
4:00 PM	0.7136928
5:00 PM	0.01780776
6:00 PM	0
7:00 PM	0
8:00 PM	0
9:00 PM	0
10:00 PM	0
11:00 PM	0
Daily Radiation, H	20.0273 MJ/m^2

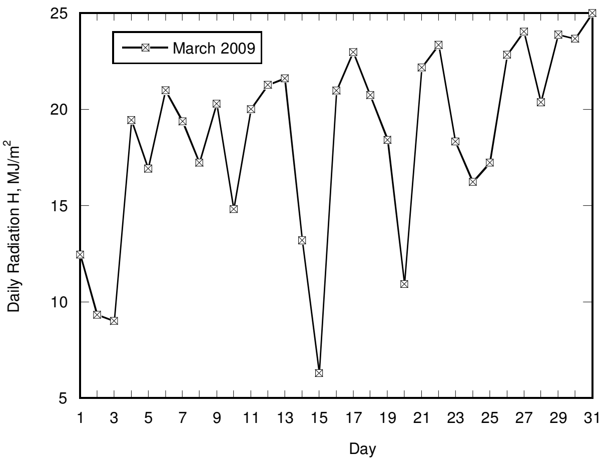

Fig.3: Daily total radiation on a horizontal surface vs 31 days for March; 2009

Table 3: Main daily radiation for March; 2009

Day's of March 2009	Mean daily radiation H, MJ/m^2
1	12.456
2	9.323892
3	8.99656
4	19.453
5	16.9191
6	21.00638
7	19.37706
8	17.20837
9	20.31079
10	14.80400
11	20.02732
12	21.26547
13	21.61253
14	13.20208
15	6.2865
16	20.97
17	22.976
18	20.7276
19	18.436
20	10.92
21	22.175
22	23.3584
23	18.3266
24	16.2235
25	17.2185
26	22.849
27	24.0404
28	20.3688
29	23.88
30	23.686
31	24.997
Monthly average daily radiation $\overline{H}$	18.49 MJ/m^2

Since the measurements of total radiation (beam plus diffuse) were done on a horizontal surface, then measurements are required for direct and diffuse radiation. In addition, measurements of solar radiation on inclined planes are important in determining the input to solar collectors, PV cells, and passive heating and cooling systems. Beam and diffuse radiation and data for inclined surfaces can be deduced from the available data on a horizontal surface. The following part illustrates the two cases. We should refer here that March 2009 was selected for calculations that concern monthly average daily radiation, day 30 of March was selected for daily radiation and an hour 11:19-12:19 solar time (which is equivalent to 11:00-12:00 standard time) from day 30 was selected for calculations concern the irradiance and hourly radiation. Moreover, the slope $\beta=45^0$ for tilted surface was selected and faced south with surface azimuth angle $\gamma=0^0$.

We should refer that the following equations are taken from Duffie and Beckman [7]. The declination can be found from:

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

(1)

where n is day of the year counted from 1st January, in the present case March 30; 2009 was selcted to be n =89. The hour angle ω was calculated as:

$$\omega = [solar\,time - 12:00](in\,hrs)\times 15^o$$

(2)

The solar time is defined as:

$$solar\,time - s\tan dard\;\; time = -4(L_{st} - L_{loc}) + E$$

(3)

where L_{st} is the standard meridian for the local time zone (for Jordan L_{st} =30^0 E), and L_{loc} is the longitude of the location (for HU, L_{loc}=36^{0}E).

The surface azimuth angle γ can be estimated according to the following formula,

$$\gamma_s = C_1C_2\gamma_s^/ + C_3(\frac{1-C_1C_2}{2})180$$

(4)

In present case C_1=C_2=1, and C_3=-1. Where $\gamma_s^/$ is apseudo sloar azimuth angle and given by

$$\sin\gamma_s^/ = \frac{\sin\omega\cos\delta}{\sin\theta_z}$$

(5)

where θz is the zenith angle and defined as:

$$\cos\theta_z = \cos\phi\cos\delta\cos\omega + \sin\phi\sin\delta$$

(6)

where ϕ is the latitude, for HU ϕ=32^0. The angle of incident θ is calculated by:

$$\begin{aligned}\cos\theta = &\sin\delta\sin\phi\cos\beta \\ &-\sin\delta\cos\phi\sin\beta\cos\gamma \\ &+\cos\delta\cos\phi\cos\beta\cos\omega \\ &+\cos\delta\sin\phi\sin\beta\cos\gamma\cos\omega \\ &+\cos\delta\sin\beta\sin\gamma\sin\omega\end{aligned}$$

(7)

The sunset hour angle ω_s is estimated by

$$\cos\omega_s = -\tan\phi\tan\delta$$

(8)

Extraterrstrial radiation (G_0) on a horizontal surface at any time:

$$G_o = G_{sc}(1+0.033\cos\frac{360n}{365})\cos\theta_z$$

(9)

where G_{sc} is the solar constant and equal to 1367 W/m^2.

It is also interest to calculate the extraterrstrial radiation (I_0) on a horizantal surface for an hour for period between two hours angle ω_1, ω_2

$$I_o = \frac{12\times3600}{\pi}G_{sc}(1+0.033\cos\frac{360n}{365})\times [\cos\phi\cos\delta\{\sin\omega_2 - \sin\omega_1\} + \frac{\pi(\omega_2-\omega_1)}{180}\sin\phi\sin\delta]$$

(10)

The daily extraterrstrial radiation (H0)on a horizontal surface:

$$H_o = \frac{24\times3600}{\pi}G_{sc}(1+0.033\cos\frac{360n}{365})\times (\cos\phi\cos\delta\sin\omega_s + \frac{\pi\omega_s}{180}\sin\phi\sin\delta$$

(11)

Beam and diffuse components of hourly radiation can be estimated as:

$$\frac{I_d}{I} = \begin{cases} 1-0.09k_T & for\; k_T \le 0.22 \\ 0.9511 - 0.1604k_T + 4.388k_T^2 & for\; 0.22 < k_T \le 0.8 \\ -16.638k_T^3 + 12.336k_T^4 & \\ 0.165 & for\; k_T > 0.8 \end{cases}$$

(12)

where kT is an hourly clearness index:

$$k_T = \frac{I}{I_o}$$

(13)

The day's total radiation on a horizontal surface in HU for March are measured , so the fraction and amount of beam and diffuse radiations can ce calculated:

$$\frac{H_d}{H} = 1 + 0.2832K_T - 2.5557K_T^2 + 0.8448K_T^3$$

$$for\ K_T < 0.722,\ \omega_s > 81.4^\circ$$

(14)

where K_T is a daily clearness index which is the ratio of particular day's radiation to the extraterstrial radiation for that day:

$$K_T = \frac{H}{H_0}$$

(15)

Beam and diffuse components of monthly average daily radiation can be calculated:

$$\frac{\overline{H}_d}{\overline{H}} = \begin{cases} 1.391 - 3.56\overline{K}_T + 4.189\overline{K}_T^2 - 2.137\overline{K}_T^3 & for\ \omega_s \le 81.4^\circ \\ 1.311 - 3.022\overline{K}_T + 3.427\overline{K}_T^2 - 1.821\overline{K}_T^3 & for\ \omega_s > 81.4^\circ \end{cases}$$

(16)

where $\overline{K}_T$ is the monthly average clearness index:

$$\overline{K}_T = \frac{\overline{H}}{\overline{H}_o}$$

(17)

It is necessary to know the solar radiation incident on tilted surfaces such as solar collectors, PV cells, windows, or other passive system receivers. The incident solar radiation is the sum of beam, diffuse, and reflected Radiation. The diffuse radiation is assumed to be isotropic (uniformly distributed over the sky). The hourly solar radiation on an unshaded tilted surface, if the diffuse and ground radiation are each assumed to be isentropic, can be written as:

$$I_T = I_b R_b + I_d\left(\frac{1+\cos\beta}{2}\right) + I\rho_g\left(\frac{1-\cos\beta}{2}\right)$$

(18)

where, $(1+\cos\beta)/2$ is the view factor to the sky, $(1-\cos\beta)/2$ is the view factor to the ground, ρ_g is the reflectance of the ground, and R_b is the geometric factor. The geomertic factor R_b is the ratio of beam radiation on the tilted surface to that on a horizantal surface at any time, can be calculate as:

$$R_b = \frac{G_{b,T}}{G_b} = \frac{I_{b,T}}{I_b} = \frac{\cos\theta}{\cos\theta_z}$$

(19)

The ratio of hourly total radiation on the tilted surface to that on the horizontal surface can be defined as:

$$R = \frac{I_T}{I} = \frac{I_b}{I}R_b + \frac{I_d}{I}\left(\frac{1+\cos\beta}{2}\right) + \rho_g\left(\frac{1-\cos\beta}{2}\right)$$

(20)

The monthly mean solar radiation on an unshaded tilted surface, if the diffuse and ground radiation are each assumed to be isentropic, can be expressed as:

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

(21)

The ratio of monthly average daily radiation on the tilted surface to that on the horizontal surface can be defined as:

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

(22)

where $\overline{R}_b$ is the ratio of the average daily beam radiation on the tilted surface to that on the horizontal surface for the month:

$$\overline{R}_b = \frac{\overline{H}_{bT}}{\overline{H}_b} = \frac{\cos(\phi-\beta)\cos\delta\sin\omega_s' \sin(\phi-\beta)\sin\delta}{\cos\phi\cos\delta\sin\omega_s + (\pi/180)\omega_s\sin\phi\sin\delta}$$

(23)

where ω_s' is the sunset hour angle for the tilted surface for the mean day of the month which is given by

$$\omega_s' = \min\begin{bmatrix} \cos^{-1}(-\tan\phi\tan\delta) \\ \cos^{-1}(-\tan(\phi-\beta)\tan\delta \end{bmatrix}$$

(24)

The angles which have been used in the present calculations are given in Table 4. Hourly data radiation (11:00-12:00 AM) are shown in Table 5 where total, extraterrestrial, beam, diffuse and tilted radition values are obtained. Daily data radiation for March 30; 2009 are presented in Table 6 where total, extraterrestrial, beam, and diffuse radition values are obtained. Monthly average daily radiation of March; 2009 are shown in Table 7 where total, extraterrestrial, beam, diffuse and tilted radition values are obtained.

Table 4: Angles that have been used

ϕ^0	β^0	δ^0	ω^0	ω_s^0	γ^0	γ_s^0	θ^0	θ_z^0
32	45	3.22	-2.75	92	0.0	-5.7	16.45	28.9

Table 5: Hourly data radiation (11:00-12:00 AM)

I MJ/m^2	I_o MJ/m^2	I_b, MJ/m^2	I_d MJ/m^2	I_T MJ/m^2	k_T	R_b	R
3.446	4.29	2.877	0.568	3.834	0.803	1.095	1.113

Table 6: Daily data radiation (March 30, 2009)

H, MJ/m^2	H_o,MJ/m^2	H_b,MJ/m^2	H_d,MJ/m^2	K_T
23.686	33.6	18.35	5.34	0.705

Table 7: Monthly average daily radiation (March 2009)

$\overline{H}$ MJ/m^2	$\overline{H}_o$, MJ/m^2	$\overline{H}_b$, MJ/m^2	$\overline{H}_d$ MJ/m^2	$\overline{H}_T$ MJ/m^2	$\overline{K}_T$	$\overline{R}_b$	$\overline{R}$
18.49	30.74	12.24	6.25	21.26	0.6	1.215	1.15

4.Conclusions

We have presented useful solar data in Hashemite University in several different forms, hour-by-hour, daily and monthly data radiation. Methods for the estimation of solar radiation information in the desired format from the data that are available have been shown. Beam and diffuse radiation have been estimated from total data. Moreover, the radiation on tilted surface has been calculated from available solar data on the horizontal surface.

5.Future Work

Long term collection of solar data will continue in the future. This data will be documented, analyzed and published which will be very beneficial for researchers, engineers and designers working in the development of solar energy in this region.

Nomenclature

G irradiance (W/ m^2)
G_{sc} solar constant =1367 W/m^2
H irradiation for a day (kJ/ m^2)
$\overline{H}$ a monthly average daily radiation (kJ/ m^2)
I irradiation for an hour (kJ/m^2)

Greek Symbols

ϕ: Latitude
δ: Declination
γ: surface azimuth angle
γ_s: solar azimuth angle
α_s:solar altitude angle
β: slope
θ: angle of incident
θ_z: zenith angle
ω: hour angle
ω_s : sunset hour angle

Subscripts

b beam radiation
d diffuse radiation
n refer to radiation on a plane normal to the direction of propagation. If neither T and n appear, the radiation is on a horizontal plane.
o refers to radiation above the earth's atmosphere (extraterrestrial radiation)
T refer to radiation on a tilted plane

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