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Beam and Diffuse Solar Energy in Zarqa City

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***Abstract*—**Beam and diffuse radiation data are extracted analytically from previous measured data on a horizontal surface in Zarqa city. Moreover, radiation data on a tilted surfaces with different slopes have been derived and analyzed. These data are consisting of of beam contribution, diffuse contribution, and ground-reflected contribution radiation. Hourly radiation data for horizontal surface possess the highest radiation values on June, and then the values decay as the slope increases and the sharp decreasing happened for vertical surface. The beam radiation on a horizontal surface owns the highest values comparing to diffuse radiation for all days of June. The total daily radiation on the tilted surface decreases with slopes. The beam radiation data also decays with slopes especially for vertical surface. Diffuse radiation slightly decreases with slopes with sharp decreases for vertical surface. The ground-reflected radiation grows with slopes especially for vertical surface. It's clear that in June the highest harvesting of solar energy occurred for horizontal surface, then the harvesting decreases as the slope increases.

***Keywords*—**Beam and Diffuse Radiation, Zarqa City

I. Introduction

DUE to sharp increase in conventional energy prices and environmental effects, solar energy is being seriously considered for satisfying part of the energy demand in Jordan. 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 is 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]. Zarqa is a city in Jordan located to the north-east of Amman. It is the capital of Zarqa Governorate**.** Zarqa city lies at latitude of 32 5' N and longitude of 36 7' E with elevation of 555 m. Zarqa can be described as having a desert climate.

Several studies have been showed that the solar energy are promising in Jordan [2]-[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/m^2 in winter to more than (8) Kwh/m^2 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]. Fine contribution to study the visibility of some applications that driven by solar energy in Jordan had been done by [7]-[9].

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The availability of solar data (beam, diffuse, and ground reflected radiation) either on a horizontal or tilted surfaces may be encouraging the existing energy units to seek alternatives such as combined solar-thermal energy or hybrid system.

Since the measurements of total radiation (beam plus diffuse) were done on a horizontal surface as explained in previous work by Jawarneh and AL-Shyyab [10], then beam and diffuse radiation data for a horizontal surfaces can be deduced separately from the available data on the horizontal surfaces. Moreover, beam contribution, diffuse contribution, and ground-reflected contribution radiation data can also be extracted for the tilted surfaces. Measurements of solar radiation on inclined planes are important in determining the input to solar collectors, PV cells, and passive heating and cooling systems.

The main objective of this current paper is to introduce a solar radiation data in Zarqa city and assess the characteristics of the solar radiation that will include the beam, and diffuse radiation on a horizontal surface. In addition, the beam, diffuse and ground–reflected contribution on the tilted surface will be introduced and assessed.

II. Data Collection

The solar radiation data on June 2009 was measured using Pyranometer which measures the global radiation on horizontal surfaces. It is mounted on the roof of the engineering college in Hashemite University. 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). 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%.

III. Methods of Analysis

(a) Horizontal Surfaces

We should refer that the following equations are taken from Duffie and Beckman [11]. The declination can be found from:

$$\delta = 23.45 \sin(360 \frac{284+n}{365}) \quad (1)$$

where n is day of the year counted from 1st January. The hour angle ω was calculated as:

$$\omega = [solar\ time - 12:00](in\ hrs) \times 15^o \quad (2)$$

The solar time is defined as:

$$solar\ time - s\tan dard\ time = -4(L_{st} - L_{loc}) + E \quad (3)$$

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 Zarqa city, L_{loc} =36^0 E).

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

$$\gamma_s = \text{sign}(\omega)\left|\cos^{-1}\left(\frac{\cos\theta_z \sin\phi - \sin\delta}{\sin\theta_z \cos\phi}\right)\right| \quad (4)$$

The sign function is equal to +1 if ω is positive and is equal to -1 if ω is negative.
where θ_z is the zenith angle and defined as:

$$\cos\theta_z = \cos\phi\cos\delta\cos\omega + \sin\phi\sin\delta \quad (5)$$

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

$$\begin{aligned}\cos\theta = {} & \sin\delta\sin\phi\cos\beta \\ & - \sin\delta\cos\phi\sin\beta\cos\gamma \\ & + \cos\delta\cos\phi\cos\beta\cos\omega \\ & + \cos\delta\sin\phi\sin\beta\cos\gamma\cos\omega \\ & + \cos\delta\sin\beta\sin\gamma\sin\omega\end{aligned} \quad (6)$$

The sunset hour angle ω_s is estimated by

$$\cos\omega_s = -\tan\phi\tan\delta \quad (7)$$

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

$$G_o = G_{sc}(1 + 0.033\cos\frac{360n}{365})\cos\theta_z \quad (8)$$

where G_{sc} is the solar constant and equal to 1367 W/m^2.
Extraterrstrial radiation (I_0) on a horizantal surface for an hour for period between two hours angle ω_1, ω_2 can be calculated by

$$I_o = \frac{12\times 3600}{\pi} G_{sc}(1 + 0.033\cos\frac{360n}{365}) \times [\cos\phi\cos\delta\{\sin\omega_2 - \sin\omega_1\} + \frac{\pi(\omega_2 - \omega_1)}{180}\sin\phi\sin\delta] \quad (9)$$

The daily extraterrstrial radiation (H_0) on a horizontal surface is given by:

$$H_o = \frac{24\times 3600}{\pi} G_{sc}(1 + 0.033\cos\frac{360n}{365}) \times (\cos\phi\cos\delta\sin\omega_s + \frac{\pi\omega_s}{180}\sin\phi\sin\delta \quad (10)$$

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

$$\frac{I_d}{I} = \begin{cases} 1 - 0.09k_T & \text{for } k_T \le 0.22 \\ 0.9511 - 0.1604k_T + 4.388k_T^2 \\ -16.638k_T^3 + 12.336k_T^4 & \text{for } 0.22 < k_T \le 0.8 \\ 0.165 & \text{for } k_T > 0.8 \end{cases} \quad (11)$$

where k_T is an hourly clearness index and is given by:

$$k_T = \frac{I}{I_o} \quad (12)$$

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

for $\omega_s \le 81.4^o$

$$\frac{H_d}{H} = \begin{cases} 1 - 0.2727K_T + 2.4495K_T^2 - 11.9514K_T^3 + \\ 9.3879K_T^4 \quad \text{for } K_T < 0.715 \\ 0.143 \quad \text{for } K_T \ge 0.715 \end{cases} \quad (13)$$

for $\omega_s > 81.4^o$

$$\frac{H_d}{H} = \begin{cases} 1 + 0.2832K_T - 2.5557K_T^2 + \\ 0.8448K_T^3 \quad \text{for } K_T < 0.715 \\ 0.175 \quad \text{for } K_T \ge 0.715 \end{cases} \quad (14)$$

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

$$K_T = \frac{H}{H_0} \quad (15)$$

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

$$\frac{\overline{H}_d}{\overline{H}} = \begin{cases} 1.391 - 3.56\overline{K}_T + 4.189\overline{K}_T^2 - 2.137\overline{K}_T^3 & \text{for } \omega_s \le 81.4^\circ \\ 1.311 - 3.022\overline{K}_T + 3.427\overline{K}_T^2 - 1.821\overline{K}_T^3 & \text{for } \omega_s > 81.4^\circ \end{cases} \quad (16)$$

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

$$\overline{K}_T = \frac{\overline{H}}{\overline{H}_o} \quad (17)$$

(b) Inclined Surfaces

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 hourly diffuse radiation is assumed to be anisotropic. It can be written from the anisotropic sky model as:

$$I_T = (I_b + I_d A_i)R_b + I_d(1 - A_i)(\frac{1+\cos\beta}{2})[1 + f\sin^3(\frac{\beta}{2})] + I\rho_g(\frac{1-\cos\beta}{2}) \quad (18)$$

where, (1+cosβ)/2 is the view factor to the sky, (1-cosβ)/2 is the view factor to the ground, ρ_g is the reflectance of the ground and it is assumed to be 0.3 due to desert climate. The first term in previous equation represens the beam contribution, the second term represents the diffuse contribution, and the last term represent the ground-reflected contribution. An anisotropy index A_i which is a function of the transmittance of the atmosphere for beam radiation,$A_i = I_b/I_o$, and f is given by f=sqrt(I_b/I).

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:

$$R_b = \frac{G_{b,T}}{G_b} = \frac{I_{b,T}}{I_b} = \frac{\cos\theta}{\cos\theta_z} \quad (19)$$

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

$$H_T = H(1-\frac{H_d}{H})R_b + H_d(\frac{1+\cos\beta}{2}) + H\rho_g(\frac{1-\cos\beta}{2}) \quad (20)$$

where R_b is the ratio of the daily beam radiation on the tilted surface to that on the horizontal surface:

$$R_b = \frac{H_{bT}}{H_b} = \frac{\cos(\phi-\beta)\cos\delta\sin\omega_s^{'}\sin(\phi-\beta)\sin\delta}{\cos\phi\cos\delta\sin\omega_s + (\pi/180)\omega_s\sin\phi\sin\delta} \quad (21)$$

where ω'$_s$ is the sunset hour angle for the tilted surface for the particular day is given by

$$\omega_s^{'} = \min\begin{bmatrix}\cos^{-1}(-\tan\phi\tan\delta) \\ \cos^{-1}(-\tan(\phi-\beta)\tan\delta\end{bmatrix} \quad (22)$$

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

$$\overline{H}_T = \overline{H}(1-\frac{\overline{H}_d}{\overline{H}})\overline{R}_b + \overline{H}_d(\frac{1+\cos\beta}{2}) + \overline{H}\rho_g(\frac{1-\cos\beta}{2}) \quad (23)$$

Where R_b is the ratio of the average daily beam radiation on the tilted surface to that on the horizontal surface for the month:

$$\overline{R}_b = \frac{\overline{H}_{bT}}{\overline{H}_b} = \frac{\cos(\phi-\beta)\cos\delta\sin\omega_s^{'}\sin(\phi-\beta)\sin\delta}{\cos\phi\cos\delta\sin\omega_s + (\pi/180)\omega_s\sin\phi\sin\delta} \quad (24)$$

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

$$\omega_s^{'} = \min\begin{bmatrix}\cos^{-1}(-\tan\phi\tan\delta) \\ \cos^{-1}(-\tan(\phi-\beta)\tan\delta\end{bmatrix} \quad (25)$$

IV. Results and Discussion

The objective of previous work by Jawarneh [10] was to introduce four types of solar radiation data on a horizontal surface. Those are irradiance G (W/ m^2), hourly radiation I (MJ/ m^2), daily radiation H (MJ/ m^2), and monthly average daily radiation H' (MJ/ m^2). In extension to previous work we will extracte the beam and diffuse radiation from the total radiation on a horizontal surface(β=0^o), then we will introduce the radiation data on a tilted surfaces with different slopes. These data will consist of of beam, diffuse, and ground-reflected radiation.

We should refer here that June 2009 was selected for present calculations. June 11 is selected that concern monthly average daily radiation. Moreover, the slopes of β=20^0, 32^0, 45^0, and 90^0 for tilted surface were selected and faced south with surface azimuth angle γ=0^0 also was selected.

Hourly radiation data for horizontal surface I and tilted surfaces I_T for June 11 are given in Fig.1. The comparison is made for different slopes (β=0^0,20^0, 32^0, 45^0, and 90^0). Slope with β=0^0 is referring to a horizontal surface and it's possess the highest values. The values then decay as the slope increases and the sharp decreasing happened for vertical surface (β=90^0).

Hourly radiation components on a horizontal surface I (β=0^0) with it's components (beam, I_b and diffuse, I_d) and hourly radiation components on a tilted surface I_T with it's components (beam contribution, $(I_b+I_dA_i)R_b$, diffuse contribution, $I_d(1-A_i)(1+\cos\beta)/2[1+f\sin^3(\beta/2)]$, and ground-reflected contribution, $I\rho_g(1-\cos\beta)/2$ on a tilted Surface with a slope of β=20 ^{0} for June 11 is given in Fig.2.

Daily total radiation H with it's components of it's beam H_b and it's diffuse H_d radiation on a Horizontal Surface for June is shown in Fig. 3. The beam radiation owns the highest values comparing to diffuse radiation for all days of June.

Fig.4 to Fig.7 show daily total radiation on a tilted surface H_T with It's components of beam contribution $H(1-H_d/H)R_b$, diffuse contribution $H_d(1+\cos\beta)/2$ and ground-reflected contribution $H\rho_g(1-\cos\beta)/2$ for different slopes starting from slope of β=0^o to slope of β=90^o. The total daily radiation on the tilted surface H_T decreases with slopes. The beam radiation data also decays with slopes especially for vertical surface β=90^o. Diffuse radiation slightly decreases with slopes with sharp decreases for vertical surface. The ground-reflected radiation grows with slopes especially for vertical surface where the total radiation is coming mainly from the ground-reflected radiation.

Fig.8 compared the daily total radiation between the horizontal surface (β=0^o) and inclined surfaces (β=0^0,20^0, 32^0, 45^0, and 90^0). It's clear that in June the highest harvesting of solar energy occurred for horizontal surface (β=0^o), then the harvesting decreases as the slope increases.

Table I shows the monthly average daily total radiation on a horizontal surface H' and on inclined surfaces H'$_T$. June 11 is the monthly average day. The beam and diffuse contribution decrease with slopes while the ground-reflected contribution grows up with slopes.

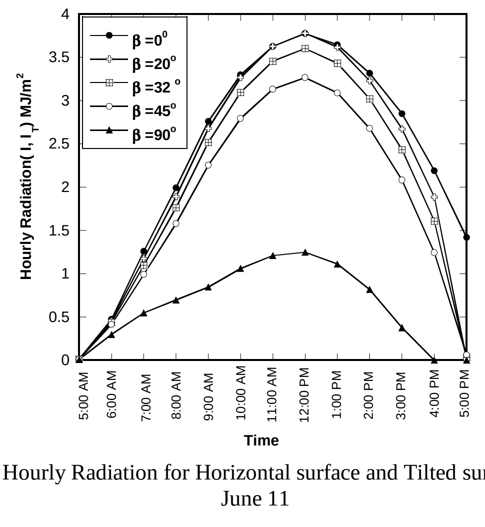

Fig. 1 Hourly Radiation for Horizontal surface and Tilted surfaces for June 11

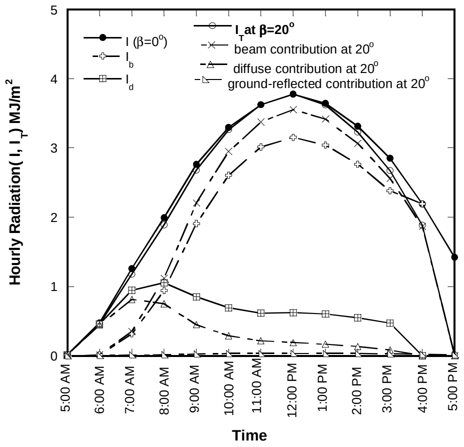

Fig. 2 Hourly Radiation: Beam, Diffuse and Ground-Reflected Contribution on a Tilted Surface with a slope of β=20 ^{0} for June 11

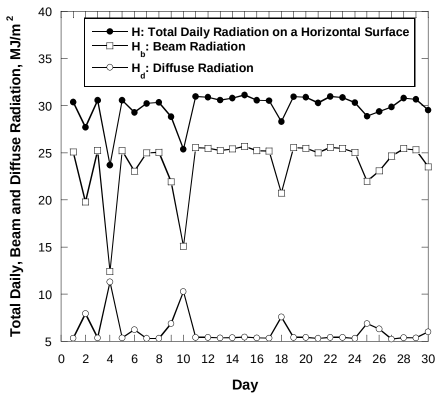

Fig. 3 Daily Total Radiation, Beam and Diffuse on a Horizontal Surface for June

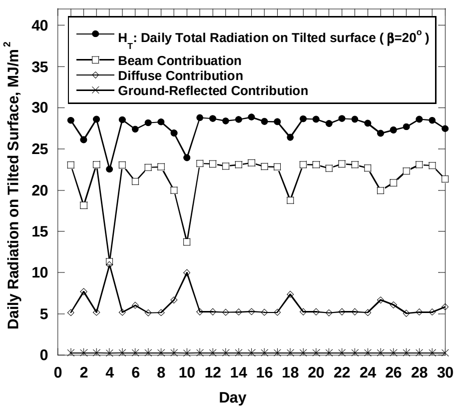

Fig. 4 Daily Total Radiation, Beam Contribution, Diffuse Contribution and Ground-Reflected Contribution on a Tilted Surface with a slope of β=20 ^{0} for June

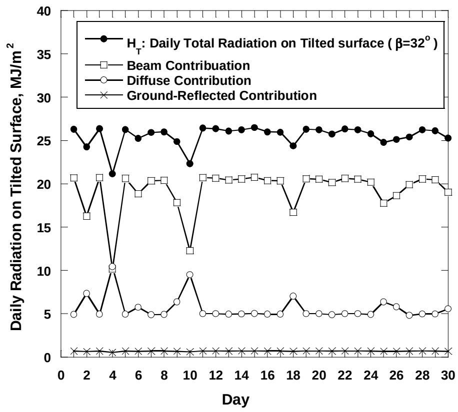

Fig. 5 Daily Total Radiation, Beam Contribution, Diffuse Contribution and Ground-Reflected Contribution on a Tilted Surface with a slope of β=32 ^{0} for June

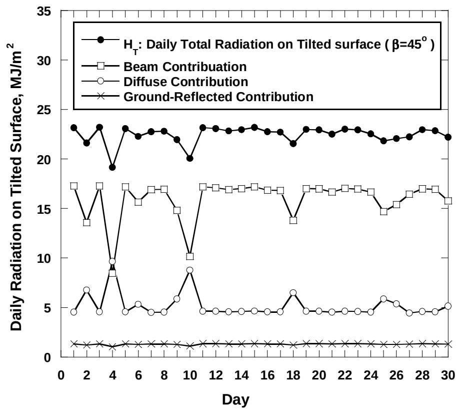

Fig. 6 Daily Total Radiation, Beam Contribution, Diffuse Contribution and Ground-Reflected Contribution on a Tilted Surface with a slope of β=45 ^{0} for June

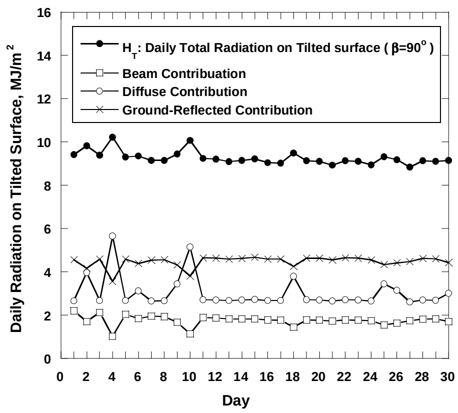

Fig. 7 Daily Total Radiation, Beam Contribution, Diffuse Contribution and Ground-Reflected Contribution on a Tilted Surface with a slope of β=90 ^{0} for June

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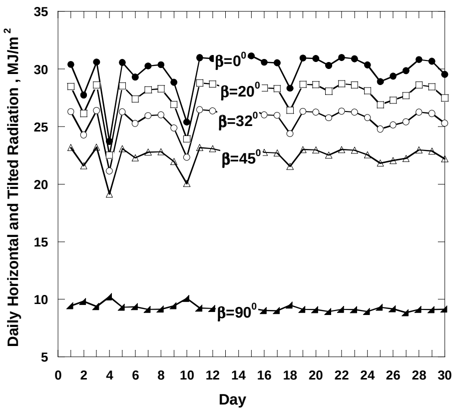

Fig. 8 Comparison of Daily Total Radiation between the horizontal and inclined surfaces

TABLE I
MONTHLY AVERAGE DAILY RADIATION AT AN AVERAGE DAY OF 11 OF JUNE

β	$\overline{H}(1-\frac{\overline{H}_d}{\overline{H}})\overline{R}_b$	$\overline{H}_d(\frac{1+\cos\beta}{2})$	$\overline{H}\rho_g(\frac{1-\cos\beta}{2})$	$\overline{H}_T$	$\overline{H}_b$	$\overline{H}_d$	$\overline{H}$
0^0	-	-	-	-	**24.65**	**6.33**	**30.98**
20^0	**22.42**	**6.14**	**0.28**	**28.84**	-	-	-
32^0	**20**	**5.85**	**0.71**	**26.55**	-	-	-
45^0	**16.57**	**5.4**	**1.36**	**23.33**	-	-	-
90^0	**1.82**	**3.16**	**4.65**	**9.63**	-	-	-

V. CONCLUSIONS

Beam, diffuse and ground-reflected radiation data is extracted analytically and analyzed from previous measured data on a horizontal surface. In June the highest harvesting of solar energy occurred for horizontal surface, then the harvesting decreases as the slope increases. The ground-reflected radiation grows with slopes especially for vertical surface.

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