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RESEARCH ARTICLE

AN ESTIMATION OF SOLAR RADIATION COMPONENTS ON HORIZONTAL SURFACES IN PALESTINE

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ABSTRACT

In the applications of solar energy, the solar radiation components data in a site must be known for the design of a system. However, for many developing countries solar radiation data are only available for site stations due to the cost of the measurement equipment and techniques involved. The present work proposes a simple model to estimate the direct, diffuse, and total solar radiation on horizontal surfaces. Calculations of this model were made for solar solstices and equinox for the purpose of testing. Results showed that the model provides an acceptable estimation of the direct, diffuse, and total components of solar radiation components. This simple model can be used at any location in the northern hemisphere.

INTRODUCTION

Palestine is blessed with an abundance of solar radiation and has the opportunity to use this bounty of natural energy effectively, promoting a clean environment and developing renewable energy technologies in the region. Renewable energy is considered as a key source for the future, this is primarily due to the fact that renewable energy resources have some advantages if compared to fossil fuels. Solar radiation is the major energy source on earth and solar energy can play an important role in meeting the ultimate goal of replacing fossil fuels (Alsamamra, 2013). An accurate knowledge of solar radiation distribution at a particular geographical location is of vital importance for the development of many solar energy devices and for estimates of their performances. Therefore, a solar system may exhibit a high performance in some areas but low performance in others. Before making an investment decision, it is essential to investigate the solar energy characteristics of the particular location at which the solar energy system is to be used (Alsamamra, 2013). Unfortunately, for many developing countries solar radiation measurements are only available for site stations due to the cost of the measurement equipment. Therefore, it is rather important to develop mathematical methodologies to estimate the solar radiation on the basis of sun position geometry and more readily meteorological data (Iqbal, 1983).

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In the literature, many mathematical and statistical models have been proposed to predict the amount of solar radiation using climatological and meteorological parameters (Iqbal, 1983; Canada, 1988; Canada, 1992; Ibrahim, 1985; Supit, and Van Kappel, 1998; Husain Alsamamra *et al.,* 2009). Some works used the sunshine duration data (Alsamamra, 2013; Iqbal, 1983; Canada, 1988), others used the mean daytime cloud cover or relative humidity and maximum and minimum temperatures (Canada, 1992; Ibrahim, 1985; Supit and Van Kappel, 1998), while others used the number of rainy days, sunshine hours, slope, aspect, and a factor that depends on latitude and altitude (Husain Alsamamra *et al.,* 2009; Ododo, 1997). The literature contains more complex models for the solar irradiance, for example see (Iqbal, 1983; Psiloglou and Kambezidis, 2007; Miroslav *et al.,* 2007). In many developing countries meteorological stations do not cover rural areas, therefore solar radiation models that do not involve meteorological data is employed. This work aims to develop a solar radiation model to predict hourly direct, diffuse, and global solar radiation on horizontal surfaces in Palestine.

The proposed model

Direct beam irradiance

A combination of Beers and Lamberts laws gives the direct beam irradiance on a horizontal surface (S_b) as (Davies *et al.,* 1984):

$$S_b \approx S_p \tau^m sin\varphi \quad (1)$$

where, S_p is the solar constant (~1360 Wm^{-2}), τ is the atmospheric transmission coefficient (~0.7) with values between 0.55 and 0.8 being commonly used and φ is the solar altitude.

If the atmospheric refraction index is neglected then the optical airmass (m) is given by (Iqbal, 1983):

$$m = \frac{1}{sin\varphi} \quad (2)$$

Diffuse beam irradiance

Campbell (1981) (Mahmoud and Ibrik, 2003) has developed an empirical formula based on list (1971) (List, 1971) for estimating the diffuse beam of the solar radiation when global solar radiation (S_t) measurements are available:

$$S_d \approx \frac{\alpha(\beta S_p sin\varphi - S_t)}{(1-\alpha)} \quad (3)$$

where $\alpha = 0.5$ and $\beta = 0.91$ (Davies *et al.,* 1984). β refers to the absorption coefficient of the solar beam by atmospheric water, ozone, and other constituents.

If the global solar radiation is not available, then by substituting S_b from equation (1) it is possible to estimate S_d under cloudless skies using an empirical formula (Davies *et al.,* 1984):

$$S_d = \alpha(\beta sin\varphi - S_b) \quad (4)$$

Total beam irradiance

Total beam irradiance on a horizontal surfaces is obtained by summing the direct beam irradiance from equation (1) and the diffuse beam irradiance from either equation (3) or (4). The solar altitude can be calculated by the following expression (Iqbal, 1983):

$$sin\alpha = sin\varphi sin\delta + cos\varphi cos\delta cos\omega \quad (5)$$

where φ is the altitude of the site, ω is the hour angle of the sun, and δ is the solar declination which can be approximated by (Iqbal, 1983):

$$\delta = 0.006918 - 0.399912\cos(\Gamma) + 0.070257sin(\Gamma) - 0.006758cos(2\Gamma) + 0.000907sin(2\Gamma) - 0.002697cos(3\Gamma) + 0.00148sin(3\Gamma) \quad (6)$$

where Γ is the day angle and can be calculated from (Iqbal, 1983):

$$\Gamma = \frac{2\pi(J-1)}{365} \quad (7)$$

where J is the day of the year (january 1^{st}=1).

The hour angle can be calculated by using the following equation (Iqbal, 1983):

$$\omega = \frac{360}{24}(12 - T) \quad (8)$$

where T is the solar time (in hour), T can be calculated from local time by using the following relation (Alsamamra, 2013):

$$T = t + \frac{E_t}{60} + \frac{4(L_{st} - L)}{60} \quad (9)$$

where t is the local time (in hour), L_{st} is the local standard longitude (35° E for Palestine) and L is location longitude. The equation time E_t (in minutes) is given by (Iqbal, 1983):

$$E_t = 229.18(0.000075 + 0.001868\cos(\Gamma) - 0.032077sin(\Gamma) - 0.01465cos(2\Gamma) - 0.04089sin(2\Gamma) \quad (10)$$

RESULTS AND DISCUSSION

The formulations of the simple model discussed in the previous section were programmed using Python scientific language. The program only requires the geographical location (Latitude, Longitude and Zone) and day of the year (e.g. 311 2009 for the 31^{st} day of January 2009). The program then returns a result of a table of hours of the day and the hourly solar radiation along with the daily total of these solar radiation components. As an example, Table (1) shows the output of the program for 21 of June 2012 at Hebron city (Latitude 31.31° N and longitude 35.8° E).

Table 1. A sample of the output model

Hour	Diffuse	Direct	Total
6.0	27.71	135.71	163.42
7.0	151.40	194.78	346.18
8.0	319.46	222.69	542.16
9.0	484.12	235.72	719.84
10.0	617.02	241.54	858.56
11.0	700.90	243.85	944.75
12.0	726.26	244.39	970.65
13.0	690.40	243.61	934.01
14.0	597.17	240.86	838.03
15.0	457.29	234.13	691.43
16.0	289.62	219.24	508.86
17.0	125.08	187.44	312.53
18.0	15.80	120.45	136.25
19.0	0.00	7.44	7.44

Daily Diffuse Solar Radiation= 5202.23 W/M2
Daily Direct Solar Radiation= 2771.86 W/M2
Daily Total Solar Radiation= 7974.09 W/M2

To test the model, the diffuse, direct, and total beam components of the solar radiation were calculated for Hebron city. Four cases were considered; spring equinox, summer solstice, autumn equinox, and winter solstice. The results are provided by Figures (1) to (4) respectively. It is seen that, and as expected, the direct beam component starts to increase from morning hours and reaching a peak value at noon and then gradually decreases towards sunset time. As seen in the figures, the direct component is much greater than the diffuse component except during early and late times of the day. This is because during these hours the solar altitude is very low, i.e longer path of the solar ray, and much of the solar radiation is depleted by atmospheric components through scattering and absorption processes.

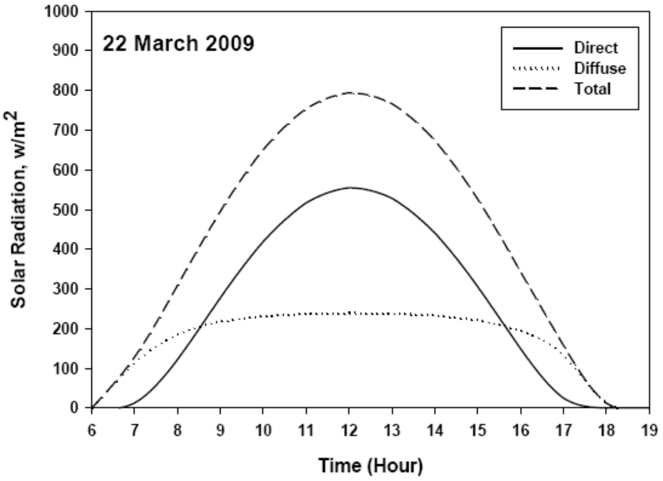

Figure 1. Direct, diffuse, and total solar radiation components during spring equinox for Hebron city

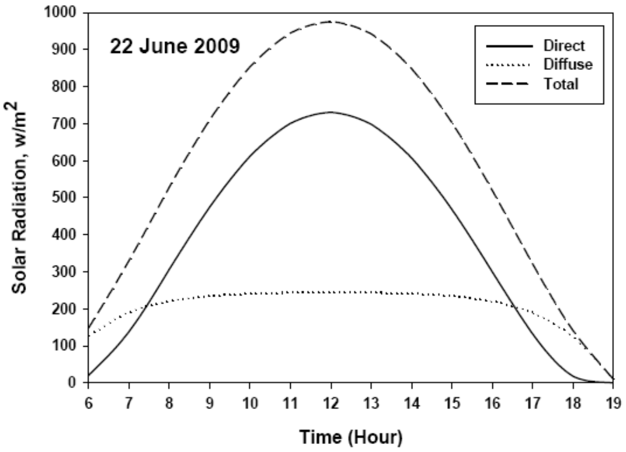

Figure 2. Direct, diffuse, and total solar radiation components during summer solstice for Hebron city

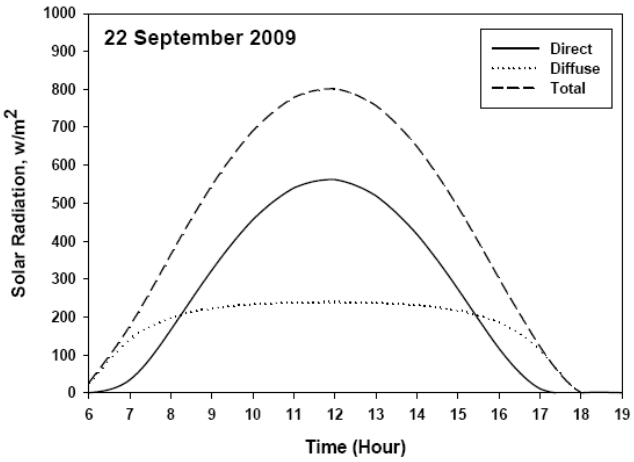

Figure 3. Direct, diffuse, and total solar radiation components during autumn equinox for Hebron city

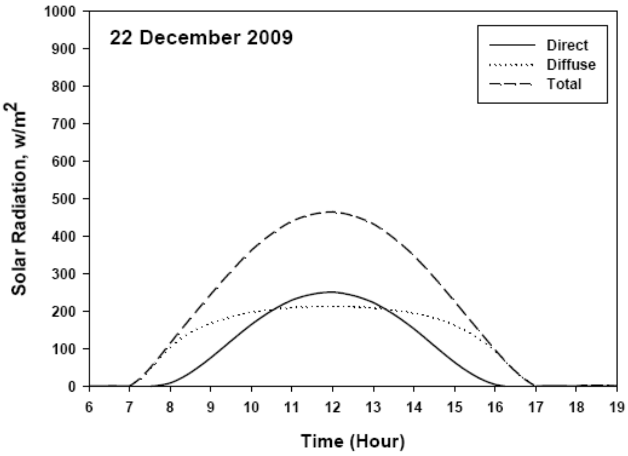

Figure 4. Direct, diffuse, and total solar radiation components during winter solstice for Hebron city

The results also showed that the maximum value of solar radiation components reaching the earth surface occurs during mid day, i.e. very close to noon time. The highest values of the total solar radiation occur during summer solstice while lower values occur winter solstice. The results obtained by the model suggest that the model yields a good estimation of solar radiation components. Further research work is needed to validate the model through comparisons with actual measured data.

Conclusion

The present work has the aim to help engineers and designers in evaluating solar radiation components. A simple model was developed for the calculations of hourly direct, diffuse and total solar radiation for any location. Results provided by the model showed that the model produces acceptable estimates for of these components. Further work is needed to refining the model in order to ensure more accurate results. Future research work will be focused on comparing site measured data with the model output.

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