An estimation of solar radiation components on horizontal surfaces in Palestine

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Abstract

For many developing countries solar radiation measurements are only available for selected stations due to the cost of the measurement equipment and techniques involved. In this work a simple model was developed to estimate the direct, diffuse, and total solar radiation on horizontal surfaces. Calculations were made for solar solstices and equinox for the purpose of testing the model. Results suggested that the model gives an acceptable estimate of the direct, diffuse, and total components of solar radiation components. The model can be used for any location in the northern hemisphere.

Keywords: *Direct irradiance, Diffuse irradiance, Global irradiance*

1. Introduction

Palestine is blessed with an abundance of solar energy and has the opportunity to utilize 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 [1]. 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 [2]. Unfortunately, for many developing countries solar radiation measurements are only available for selected stations due to the cost of the measurement equipment and techniques involved. Therefore, it is rather important to elaborate mathematical methods to estimate the solar radiation on the basis of sun position geometry and more readily meteorological data [3].

Over the years, many models have been proposed to predict the amount of solar radiation using various parameters [3-8]. Some works used the sunshine duration [2-4], others used mean daytime cloud cover or relative humidity and maximum and minimum temperature [5-7], while others used the number of rainy days, sunshine hours, and a factor that depends on latitude and altitude [8]. The literature contains more complex models for the solar irradiance, for example see [3], [9], [10]. Meteorological stations do not cover rural areas in many developing countries, therefore solar radiation models that do not involve meteorological information is employed. This work aims at developing a solar radiation model to predict hourly direct, diffuse, and global solar radiation on horizontal surfaces in Palestine.

2. The proposed model

1. Direct irradiance

A combination of Beers and Lamberts laws gives the direct irradiance on a horizontal surface (S_b) as [11]:

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

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, φ is the solar altitude.
If the atmospheric refraction is neglected then the optical airmass (m) is given by [1]:

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

2. Diffuse irradiance

Campbell (1981) [12] has developed an empirical formula based on list (1971) [13] for estimating the diffuse components of the solar radiation when total 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 $\beta = 0.91$ [13]. β refers to the absorption of the solar beam by atmospheric water, ozone, and other constituents.
If the total 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 [12]:

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

3. Total irradiance

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

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

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 [1]:

$$\begin{aligned}\delta &= 0.006918 - 0.399912\cos(T) + 0.070257\sin(T) - 0.006758\cos(2T) \\ &+ 0.000907\sin(2T) - 0.002697\cos(3T) + 0.00148\sin(3T)\end{aligned} \quad (6)$$

where T is the day angle and can be calculated from [1]:

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

where J is the day of the year (January 1^{st}=1).
The hour angle can be calculated by using the following equation [1]:

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

where T is the solar time (in hour), T can be calculated from local time by using the following relation [1]:

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

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 [1]:

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

3. Results and discussion

The formulations of the 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 31st day of January 2009). The program then returns a table of hours of the day and the hourly solar radiation along with the daily total of these components. As an example, Table (1) shows an example of 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	547.29	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 = 5,202.23 w/m^2
Daily direct solar radiation = 2,771.86 w/m^2
Daily total solar radiation = 7,974.09 w/m^2

As a test for the model, the diffuse, direct, and total components of solar radiation were calculated for Hebron city. Four cases were considered; spring equinox, summer solstice, autumn equinox, and winter solstice. The results are shown in figures (1) to (4) respectively. It is seen that, as expected, the direct component starts to increase from morning hours reaching a peak value at noon and gradually decreases towards sunset time. The direct component is much greater than the diffuse component except during early and late times of the day. This is due to the fact that 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. The results also indicated that the maximum value of solar radiation reaching the earth surface occurs during mid day, i.e. very close to noon time. The highest values of total solar radiation occur during summer solstice while lower values occur winter solstice. These results suggest that the model yields a good estimate of solar radiation. Further research is needed to refine the model through comparisons with actual measured data.

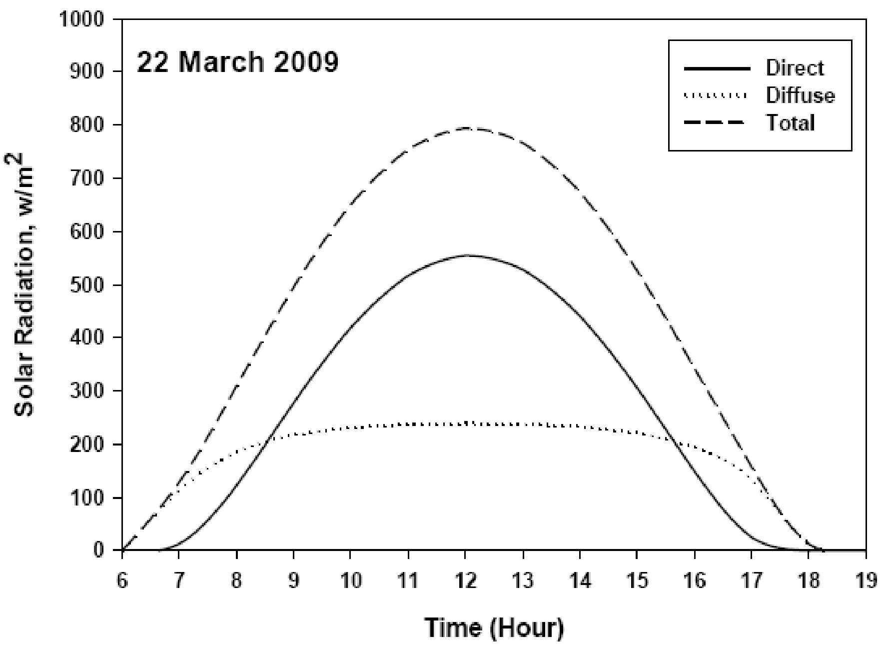

Figure 1. Direct, diffuse, and total solar radiation components during spring equinox for Hebron city.

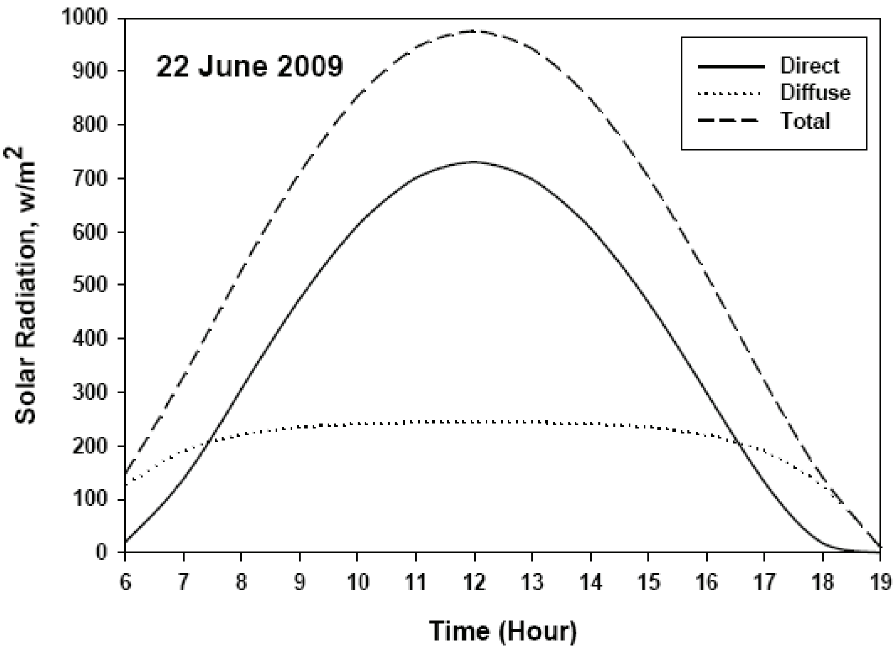

Figure 2. Direct, diffuse, and total solar radiation components during summer solstice for Hebron city.

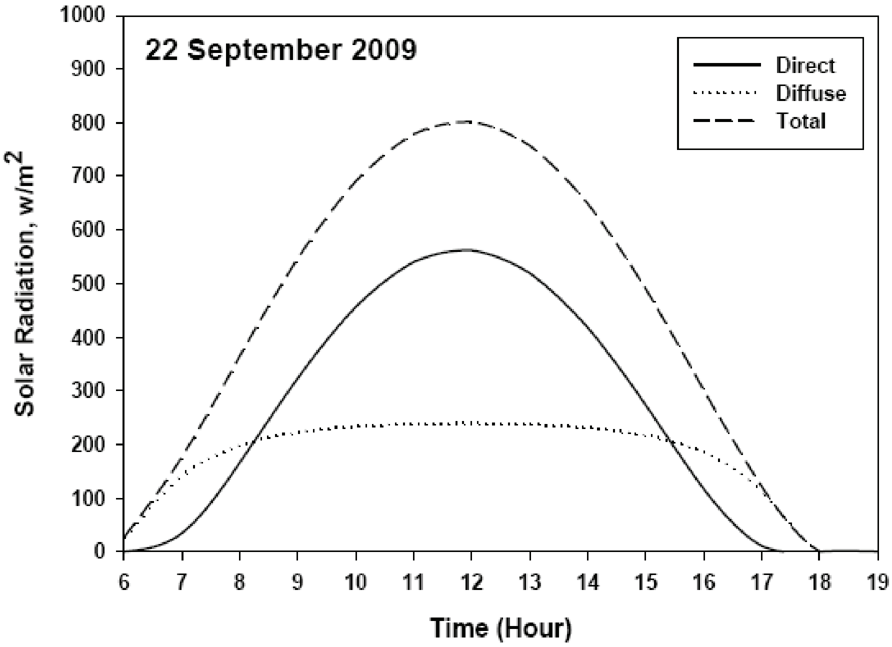

Figure 3. Direct, diffuse, and total solar radiation components during autumn equinox for Hebron city.

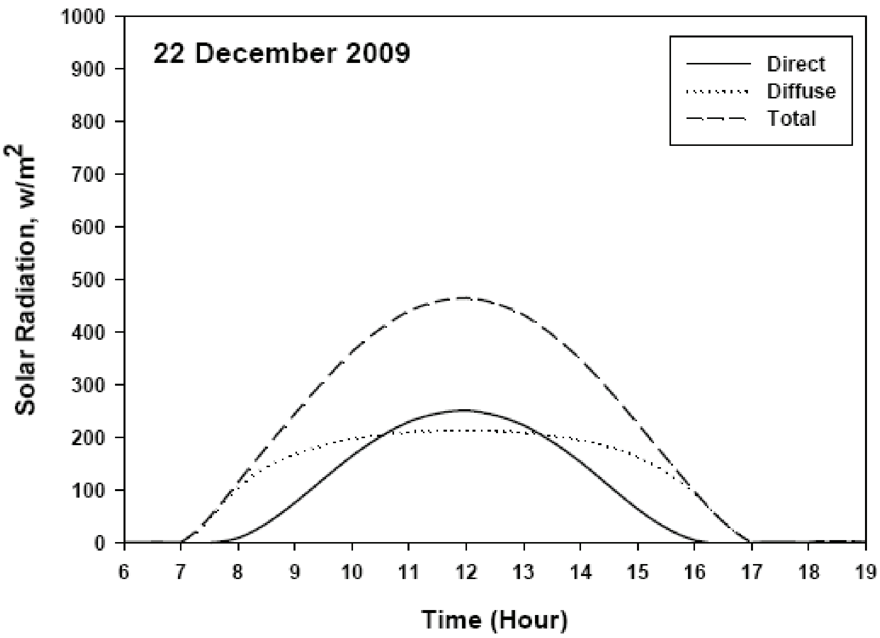

Figure 4. Direct, diffuse, and total solar radiation components during winter solstice for Hebron city.

4. Conclusions

A simple solar radiation model was developed for the calculations of hourly solar radiation components for any location. Results indicated that the model produces acceptable estimates for of these components. Further refining of the model is needed to ensure more accurate results. Future work will be focused on comparing actual measured data with the model output.

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