A simple Model for Estimating Solar Radiation on Horizontal Surfaces

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(**Received:** 27 / 12 / 2010 ---- **Accepted:** 11 / 5 / 2011)

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 research a simple model was developed to estimate the direct, diffuse, and 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.

Introduction

Solar energy occupies one of the most important places among the various possible alternative energy sources. 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. 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 [1].

Over the years, many models have been proposed to predict the amount of solar radiation using various parameters [2-8]. 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 [1], [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.

The Model

a) Direct Irradiance

A combination of Beer's and Lambert's laws gives the direct irradiance on a horizontal surface (S_b) as [11]:

$$S_b \approx S_p \tau^m \sin\phi \quad \text{.......... (1)}$$

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 solar altitude.

If atmospheric refraction is neglected then the optical airmass (m)is given as [1]

$$m = \frac{1}{\sin\phi} \quad \text{.......... (2)}$$

b) 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:

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

where $\alpha = 0.5$ and $\beta = 0.91$ [13]. β refers to absorption of the solar beam by atmospheric water, ozone, and other constituents. These constants could be change to suit particular conditions.

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]:

$$S_d = \alpha(\beta \sin\phi - S_b) \quad \text{.........(4)}$$

c) Total Irradiance

Total irradiance on a horizontal surface 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]

$$\sin\alpha = \sin\phi \sin\delta + \cos\phi \cos\delta \cos\omega \quad \text{......(5)}$$

where ϕ is the latitude of the site, ω is the hour angle of the sun (solar noon = 0^o), and δ is the solar declination which can be approximated by [1]:

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

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

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

where J is the day of the year (January 1st = 1).

The hour angle can be calculated by using the following equation [1]:

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

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

$T = t + E_t / 60 + 4(L_{st} - L) / 60$ ……. (9)

where t is the local time (in hour), L_{st} is the local standard longitude (45^o for Iraq) and L is location longitude. The equation time E_t (in minutes) is given by [1]:

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

Results and Discussion

The formulations of the model discussed in the previous section were programmed using Fortran programming language. The program only requires the geographical location (Latitude, Longitude and Zone) and day of the year (e.g. 311 2010 for the 31st day of January 2010). 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 2010 at Tikrit city (Latitude 34.55^o N and longitude 43.62^o E).

As a test for the model, the diffuse, direct, and total components of solar radiation were calculated for Tikrit 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.

Conclusions

In this a simple solar radiation model was developed for the calculations of hourly solar radiation components for any location. Results indicated that the model produces an 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.

Table 1: A sample output for the 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

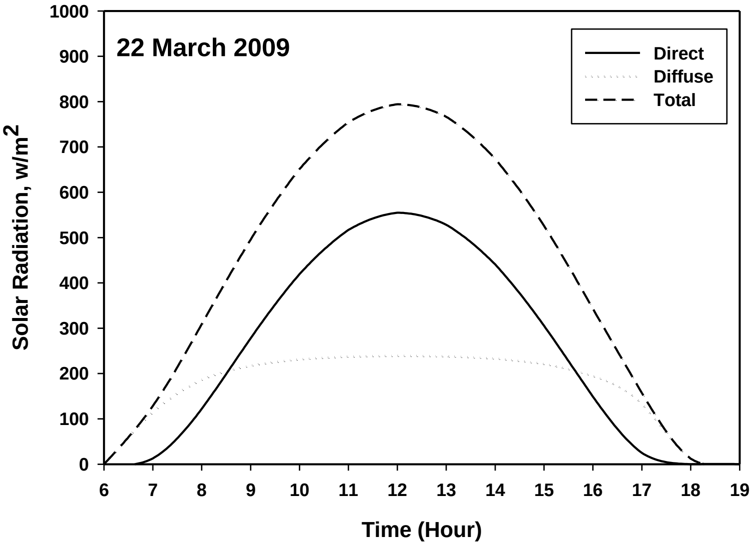

Figure 1: Direct, diffuse, and total solar radiation components during spring equinox for Tikrit city.

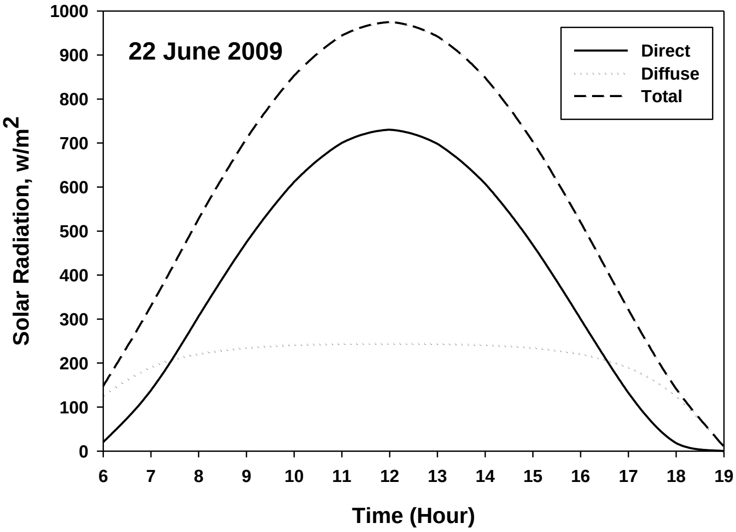

Figure 2: Direct, diffuse, and total solar radiation components during summer solstice for Tikrit city.

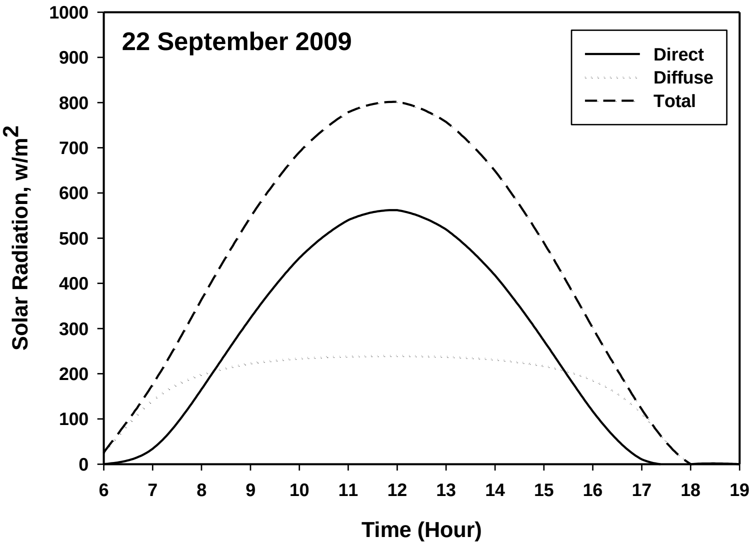

Figure 3: Direct, diffuse, and total solar radiation components during autumn equinox for Tikrit city.

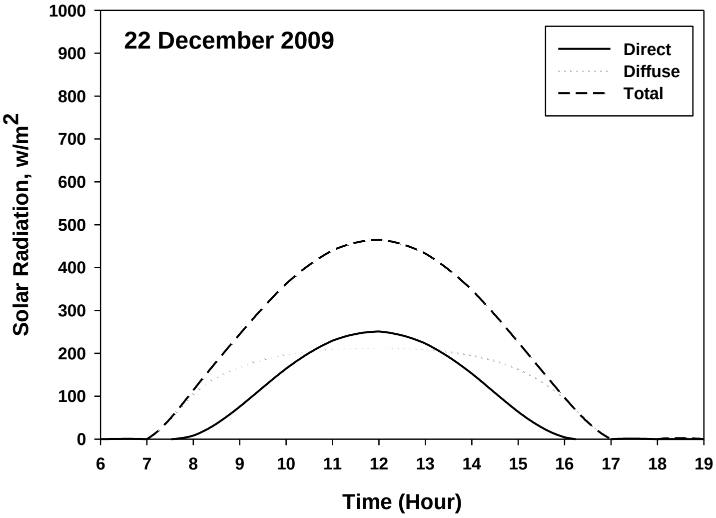

Figure 4: Direct, diffuse, and total solar radiation components during winter solstice for Tikrit city.

References

[1] Iqbal, M., 1983: An Introduction to Solar Radiation, Academic Press, Canada.

[2] Canada, J., 1988: Global solar radiation in Pais Valenciano using sunshine Hours', International Journal of Ambient Energy, 4: 197-201.

[3] Canada, J., 1992: Solar radiation prediction from sunshine in Eastern Spain, Renewable Energy, 3: 219-221.

[4] Ibrahim, S.M.A., 1985: Predicted and measured global solar radiation in Egypt', Solar Energy ; 35: 185-188.

[5] Supit I., and R.R. Van Kappel, 1998: A simple method to estimate global radiation', Solar Energy; 63:147-160.

[6] Ododo, J.C., 1997: Prediction of solar radiation using only maximum temperature and relative humidity', Energy Conversion and Management; 38: 1807- 1814.

[7] Ododo, J. C., et al., 1995: The importance of maximum air temperature in the parametrization of solar radiation in Nigeria', Renewable Energy, 6: 751- 763.

[8] Canada, J., 1988: Global solar radiation in Valencia using Sunshine Hours and meteorological Data', Solar & Wind Technology, 5: 597-599.

[9] Psiloglou, B.E., and H. D. Kambezidis 2007: Performance of the meteorological radiation model during the solar eclipse of 29 March 2006, Atmos. Chem. Phys., 7, 6047–6059.

[10] Miroslav T, , J. Eitzinger , P. Kapler, M. Dubrovsky, D. Semeradova, Z. Zalud and H. Formayerm 2007: Effect of estimated daily global solar radiation data on the results of crop growth models, Sensors , 7, 2330-2362

[11] J. A. Davies, J. A., Abdel-Whahab, M., and McKay, D. C., 1984: estimating solar irradiation on horizontal surfaces, Inter. J. Sol. Energy, 2, 405–424.

[12] Campbell, G. S., 1981: Fundamentals of radiation and temperature relations. In Lange, O. L., P. S. Nobel, C. B. Osmond, and H. Ziegler (Eds.) Physiological Environment, pp. 11-40, Springer-Verlag, Berlin Heidelberg, New York.

[13] List, R. J., 1971: Smithsonian Meteorological Tables, 6th Ed., Smithsonian Institution Press, Washington, DC.

أنموذج مبسط لتقدير الإشعاع الشمسي على السطوح الأفقية

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(تاريخ الاستلام: ٢٧ / ١٢ / ٢٠١٠ ---- تاريخ القبول: ١١ / ٥ / ٢٠١١)

الملخص

في العديد من البلدان النامية تتوفر قياسات الإشعاع الشمسي في محطات مختارة بسبب كلفة أجهزة القياس والتقنيات ذات العلاقة. في هذا البحث تم بناء أنموذج مبسط لتقدير مركبات الشعاع الشمسي المباشر والمنتشر والكلي على السطوح الأفقية. تم إجراء الحسابات للانقلابات والاعتدالات الشمسية لغرض اختبار الأنموذج . وقد دلت النتائج بأن الأنموذج يعطي نتائج مقبولة لتقديرات الإشعاع الشمسي المباشر والمنتشر والكلي. ويمكن استخدام الأنموذج لأي مكان في نصف الكرة الشمالي.