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Models for obtaining the daily direct, diffuse and global solar radiations

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A B S T R A C T

Solar radiation models are desirable for designing solar-energy systems, for good evaluations of thermal environments and for several solar systems in buildings. The purpose of this work is to evaluate four empirical models developed in literature such as Ghouard, Perrin Brichambaut, Bird and Hulstrom and Capderou models. These models can be used to predict the daily direct, diffuse and global solar radiation intensities for clear skies at a given Earth's position, in our case, Tetuan city in northern of Morocco (35.57361 latitude, −5.37528 longitude). The statistical analysis was performed by combining simulations through computed values with provided data from local energetic laboratory station. Results obtained show several accuracy levels which indicate that the studied models can be successfully used to predict the daily solar radiation data by days of the year.

Contents

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Nomenclature

G global solar radiation flux on horizontal surface (W/m^2)
I direct solar radiation flux on horizontal surface (W/m^2)
D diffuse solar radiation flux on horizontal surface (W/m^2)
I_0 solar constant (W/m^2)
C_t correction of the Earth–Sun distance (dimensionless)
h solar elevation (degrees)
θ_z zenith angle (degrees)
χ true solar time (h)
ψ solar azimuth (degrees)
δ solar declination (degrees)
ω hour angle (degrees)
φ latitude (degrees)
λ longitude (degrees)
z altitude (m)
S_e sunshine duration (h)
S_j day length (h)
T_L Linke turbidity factor (dimensionless)
τ_r, τ_o, τ_g, τ_w, τ_a (dimensionless) are the Rayleigh, ozone, gas, water and aerosols scattering transmittances, respectively

1. Introduction

The Earth daily receives a large solar energy flux. The power of this radiation is based on several criteria such as weather conditions, atmospheric diffusion (dispersion, reflection and absorption phenomenons). Knowledge of solar radiation is essential to calculate various performance levels related to solar energy systems, such as solar water heaters, photovoltaic systems, solar concentration, building constructions with a view to a better thermal insulation adapted to local climate and also for heating houses and rooms by solar energy. The usage examples are only increasing over time. However, the development of these sectors can not be achieved without a thorough knowledge of solar radiation [1–6].

Values of direct, diffuse and global solar radiations for individual hours are essential for research and engineering applications. Hourly diffuse and global radiations on horizontal surfaces are available for many stations, but relatively few stations measure the hourly direct radiation [7,8].

The original idea for writing this paper came after a number of review papers which were published in literature on solar radiation intensity prediction, where the purpose is to determine the prediction accuracy of several models developed to estimate different solar radiation components at an Earth's position [9–13], in order to develop a new model of high prediction accuracy. In addition, we intend to show how the solar radiation varies at ground level in function of latitude, season, day length and weather conditions. It also outlines the measures taken by the weather station of Laboratory Energy of the Faculty of Sciences of Tetuan city to compare it with the computed values by some models prediction. For this, we present here an integral study of solar radiation, its intensity variations and its accuracy prediction by using four empirical models from literature of the Ghouard, Perrin and Brichambaut, Bird and Hulstrom and Capderou models.

2. Solar Gisement

In this party, by using several solar radiation references [1–14], we present all astronomical parameters related to Sun motions for an observatory at an Earth's position.

2.1. Earth–Sun distance

The Earth trajectory around the Sun is an ellipse with the Sun being one of its foci. The mean of Earth–Sun distance varies from 144 (21 December) to 154 million km (21 June).

The correction of the Earth–Sun distance (dimensionless) can be calculated as follows:

$$C_t = 1 + 0.034\cos(j-2) \tag{1}$$

where j is the day number of the year, ranging from 1 on 1 January to 365 on 31 December.

2.2. Solar declination

The solar declination δ (degrees) is the angle between the Sun direction with the equatorial plane of the Earth. It varies from $-23°27'$ in winter solstice to $+23\,°27'$ in summer solstice, while at equinoxes it is null.

The solar declination can be calculated by the given equation by Copeer (1969) [15]:

$$\delta = 23.45\sin(0.986(j+284)) \tag{2}$$

2.3. Hour angle

The hour angle ω (degrees) is the angle between the meridian plane passing through the Sun center and the vertical plane of place (meridian) and it defines the true solar time T_{sv} (h).

The hour angle can be calculated by the next equation:

$$\omega = 15(12 - T_{sv}) \tag{3}$$

where T_{sv} (h) is the true solar time at a given position and it is determined by the following relationship:

$$T_{sv} = T_l - DT_l + (D_{hg} + E/60)/60 \tag{4}$$

- T_l: local time (h).
- DT_l: difference between local and standard time (h).
- D_{hg}: time difference (advance of 4 min per degree).
- E: equation of time, which is calculated by the equation (s):

$$E = 450.8\sin(2\pi j/365 - 0.026903) + 595.4\sin(4\pi j/365 + 0.352835) \tag{5}$$

2.4. Geographical coordinates

The geographical coordinates of a study location are represented by the latitude φ (degrees), longitude λ (degrees) and altitude z (m), where the latitude is the angle between the study position with the equator and longitude is the angle between the meridian of the study position with the meridian.

2.5. Sun elevation

The Sun elevation h (degrees) is the angle between the horizontal plane with the Sun direction. The value $h = 0$ is at sunrise and sunset, it varies between 90° (zenith) and $-90°$ (nadir) and it