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Evaluation of transposition models of solar irradiance over Egypt

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ABSTRACT

The main objective in this paper is to carry out evaluation of statistical comparison of the monthly hourly and the daily data of global, beam and diffuse solar radiation incident on a horizontal and inclined surfaces for Cairo, Egypt during the period time from 1984 to 2014. The maximum and minimum values of correlation coefficient (R^2) are 0.994 and 0.968 according to Eqs. (13) and (15) respectively. The comparison between the measured ($G_{d,m}$) and calculated ($G_{d,c}$) values of the diffuse solar radiation along with the values of mean base error (MBE), root mean square error (RMSE), mean percentage error (MPE), and *t*-Test statics are summarized. The values of MBE results show that the isotropic, Perez's, Hay's and Klucher's models are substantially under predicts the irradiance incident on an inclined surface, and the Tamps and Coulson model considerably over predicts irradiance incident on an inclined surface on an overall basis, and the RMSE results indicate that the anisotropic models (Hay, Klucher and Perez) show similar performance on an overall basis, but isotropic model and Tamps and Coulson exhibit much larger error. In general we confirm that, the observation of the Perez's and Klucher models describe the irradiance on inclined plane more accurately than anther models. These results in the present work are good agreement with other work in [9,12,129,130] (Khalil and Shaffie, 2013a; Khalil and Shaffie, 2013b; Khalil and Shaffie, 2014; Khalil and Shaffie, 2016). The statistical results of the models for south facing and west facing surface in the present study are analyzed.

Contents

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1. Introduction

Solar radiation is essential to life on earth. Solar radiation affects the earth's weather processes which determine the natural environment. Its presence at the earth's surface is necessary for the provision of food for mankind. Thus it is important to be able to understand the physics of solar radiation and knowledge of the local solar-radiation is essential for the proper design of building energy systems, solar energy systems and a good evaluation of thermal environment within buildings [1–3], the best database would be the long-term measured data at the site of the proposed solar system, however, the limited coverage of radiation measuring networks dictates the need for developing solar radiation models. Since the beam component (direct irradiance) is important in designing systems employing solar energy, such as high-temperature heat engines and high-intensity solar cells, emphasis is often put on modeling the beam component [4–7]. And the total solar radiation is essential in the prediction, study and design of the economic viability of systems which use solar energy. Information on total solar radiation received at any site (preferably gained over a long period) should be useful not only to the locality where the radiation data is collected but also for the wider world community, the total solar radiation study of the world distribution of total solar radiation requires knowledge of the radiation data in various countries and for the purpose of worldwide marketing, the designers and manufacturers of solar equipment will need to know the average total solar radiation available in different and specific regions. Obviously, measured data is the best form of this knowledge. Unfortunately, there are very few meteorological stations that measure total solar radiation, especially in developing countries. In places where no measured values are available, a common application has been to determine this parameter by appropriate correlations which are empirically established using the measured data [8,9].

Solar irradiation is measured at many locations around the globe. Unfortunately, these locations are mainly concentrated in developed countries, and are scarce within the developing world, solar irradiation data are fundamental inputs for solar energy applications such as photovoltaics, solar thermal systems, and passive solar design. Daily data on horizontal and tilted surface are required for day-to-day performance monitoring in applications such as solar gains from vertical glazing, day lighting and agricultural processes, these data are also useful to engineers are designing of various solar energy conversion devices, accurate modeling of the impact of solar gains through glazing is imperative especially when simulating the thermal behavior of these buildings. Empirical validations of solar gain models are therefore an important and necessary endeavor to provide confidence to developers and modelers that their respective algorithms simulate reality [10–12].

The measured solar energy values can be used for developing solar energy models which describes the mathematical relations between the solar energy and the meteorological variables such as ambient temperature, humidity and sunshine ratio [9,13]. These models can be later used to predict the direct and diffuse solar energy using historical metrological data at sites where there is no solar energy measuring device installed. Solar energy of daylight utilization for any site is dependent upon the quality of the available flux. Obviously, the flux impinging upon any arbitrary surface undergoes monthly as well as diurnal variations. The measurements of solar energy received from the sun, on horizontal as well as sloped surface, is an expensive affair. As such, few locations in the world have reliable, long-term measured irradiation data sets [14]. Daylight records are even scarcer. Most radiation data are given as the energy received on a horizontal surface. Since only very few applications use this configuration, there is a genuine need for insolation estimation to be carried out for sloped surface of any given aspect, the accuracy of these models varies from 40% to 50% for abbreviated techniques to limits set out by the accuracy of the measuring equipment for modern sophisticated models [9,13,14]. The total solar radiation on a horizontal surface is called global irradiance and is the sum of incident diffuse radiation plus the direct normal irradiance projected onto the horizontal surface. If the surface is tilted with respect to the horizontal, the total irradiance is the incident diffuse radiation plus the direct normal irradiance projected onto the tilted surface plus ground reflected irradiance that is incident on the tilted surface [15–18].

In the last two decades, some of the empirical correlations models have been used to predict the solar radiation by using meteorological, geographical and climatological parameters [19–35]. Among various correlations, has been widely used to estimate the global solar irradiation on horizontal surface [36–44].

Many solar energy models have been presented in the literature using mathematical linear [45–53] and nonlinear functions [54–60], artificial neural network [61–71] and fuzzy logic [72–74]. An important aspect in modeling solar energy is the accuracy of the developed model which is evaluated using statistical errors such as the mean absolute percentage error (MAPE), mean bias error (MBE) and root mean square error (RMSE). The MAPE is an indicator of accuracy in which it expresses the difference between real and predicted values to the real value. The calculated MAPE is summed for every fitted or forecasted point in time and divided again by the number of fitted points; n. MBE is an indicator for the average deviation of the predicted values from the measured data. A positive MBE value indicates the amount of overestimation in the predicted total solar energy and vice versa. On the other hand, RMSE provides information on the short-term performance of the model and is a measure of the variation of the predicted values around the measured data. RMSE also shows the efficiency of the developed model in predicting future individual values [9,12,71]. A large positive RMSE implies a big deviation in the predicted value from the measured value. Part of this study was used before to evaluate the statistical comparison models of solar energy on horizontal and inclined surface [12].

In most of the solar energy applications, inclined surfaces at different angles are widely employed. The solar irradiance on a horizontal surface has been measured in many meteorological stations around the world, but there are only a few stations that measure the solar component on inclined surfaces [75–77]. There are a number of models available to estimate solar irradiation on inclined surface from corresponding horizontal data. This requires, in general, the availability of detailed information on the magnitude of diffuse and direct horizontal irradiance. A number of diffuse fraction models are available as documented in [77–81]. These models are usually expressed in terms of polynomial functions relating the diffuse fraction to the clearness index. An inclined surface solar irradiation model developed by Olmo et al. [82] requires only the horizontal surface solar irradiation, with incidence and solar zenith angles as input parameters. In the present study, the evaluation of statistical comparison of monthly hourly and daily, global, beam and diffuse solar irradiation models on horizontal and inclined surfaces for the selected site are presented, and using the empirical models were selected to predicted the solar radiation on horizontal and inclined surfaces.

2. Instrumentations of observations used

In the present work, the global, beam and diffuse solar radiation incident on a horizontal surface at Cairo, Egypt (lat. 30° 05′ N and Long. 31° 15′ E), during the period time from January 1984 to December 2014 are used. The radiation data of the corresponding periods are obtained from the Egyptian Meteorological Authority. The data sets used consist of monthly hourly and daily values of global, beam and diffuse solar irradiations on a horizontal plane. Total solar radiation was measured using Eppley high-precision