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New Temperature-based Models for Predicting Global Solar Radiation

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HIGHLIGHTS

- New temperature-based models for estimating solar radiation are investigated.
- The models are validated against 20-years measured data of global solar radiation.
- The new temperature-based model shows the best performance for coastal sites.
- The new temperature-based model is more accurate than the sunshine-based models.
- The new model is highly applicable with weather temperature forecast techniques.

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ABSTRACT

This study presents new ambient-temperature-based models for estimating global solar radiation as alternatives to the widely used sunshine-based models owing to the unavailability of sunshine data at all locations around the world. Seventeen new temperature-based models are established, validated and compared with other three models proposed in the literature (the Annandale, Allen and Goodin models) to estimate the monthly average daily global solar radiation on a horizontal surface. These models are developed using a 20-year measured dataset of global solar radiation for the case study location (Lat. 30°51′N and long. 29°34′E), and then, the general formulae of the newly suggested models are examined for ten different locations around Egypt. Moreover, the local formulae for the models are established and validated for two coastal locations where the general formulae give inaccurate predictions. Mostly common statistical errors are utilized to evaluate the performance of these models and identify the most accurate model. The obtained results show that the local formula for the most accurate new model provides good predictions for global solar radiation at different locations, especially at coastal sites. Moreover, the local and general formulas of the most accurate temperature-based model also perform better than the two most accurate sunshine-based models from the literature. The quick and accurate estimations of the global solar radiation using this approach can be employed in the design and evaluation of performance for different solar applications.

1. Introduction

Solar energy is the most promising renewable energy source to supply a significant part of the world's energy demand [1]. Accurate knowledge of solar radiation is considered as the first step in solar energy availability assessment and serves as the primary input for different solar energy applications [2,3]. Because solar radiation measurements are not always available because of the high cost and equipment calibration and maintenance requirements [4,5], different solar radiation models have been developed to estimate solar radiation. Solar radiation models are proposed to predict solar radiation using different techniques based on different types of data including meteorological data, geographical data, geostationary satellite images, neural networks, time series methods, physically radiative transfer models, and stochastic weather methods [6–9]. Many studies have been performed to investigate the applicability of different solar models in estimating solar radiation at several locations. The meteorological data-based models are the most commonly examined and

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widely used models around the world [10]. These models are based on empirical correlations and depends on the most common meteorological parameters including cloud cover, ambient temperature, relative humidity and sunshine duration, which is the most widely used meteorological parameter to estimate solar radiation. The primary sunshine-based model is proposed by Ångström [11], which was modified by Prescott [12] and has become the most widely used model for estimating solar radiation around the world [10,13]. A review and statistical analysis of different global solar radiation sunshine-based models was performed by Despotovic et al. [14]. They attempted to evaluate various solar radiation models on a global scale that might be helpful in the selection of the most appropriate and accurate model based on the sunshine data. Similarly, Al-Mostafa et al. [15] reported the performance of 52 sunshine-based models to estimate the monthly average global solar radiation on horizontal surfaces in Jouf, Saudi Arabia. The results show that some models are totally unsuitable for use in this region (Jouf), and others vary in performance. Mecibah et al. [16] introduced the most accurate model for predicting the monthly average daily global solar radiation on a horizontal surface for six Algerian cities. The obtained results confirmed the results of the previous studies, which demonstrate that the sunshine-based models are generally more accurate than ambient temperature-based models. In addition, the best performance for the six Algerian cities was provided by cubic and quadratic regression models. Robaa [17] modified Barbaro et al.'s [18] model to estimate global solar radiation in Egypt; the predicted values of the Robaa model were compared with the predictions of different models. The results showed that the Robaa model has superior performance in estimating global solar radiation over Egypt. In addition, a study on introducing the best model for estimating the monthly average global solar radiation over six major cities of Iran was carried out by Khorasanizadeh and Mohammadi [19]. The results illustrated that for all cities, the best model is based on either the sunshine duration only or a function of sunshine duration, ambient temperature and relative humidity. Khalil and Shaffe [20] presented a comparative study of direct, diffuse and total solar radiation by using different models on horizontal and inclined surfaces in Cairo, Egypt. They found that three models provided a good estimation of the total solar radiation in the selected location. Ajayi et al. [21] developed a new model for estimating daily global solar radiation over Nigeria, which showed good agreement between model predictions and the measured data. El-Metwally [22] proposed a study of sunshine and global solar radiation estimation at different sites in Egypt and attempted to present a simple nonlinear model for evaluating relative sunshine duration and global solar radiation. The results showed that the proposed model gives the best performance compared with experimental measurements for solar radiation.

For the ambient temperature-based models, Hargreaves and Samani [23] proposed a simple model based only on maximum and minimum temperatures to estimate the solar radiation. Hargreaves and Samani's model was modified by Annandale et al. [24] to calculate the effects of decreased altitude and atmospheric thickness on global solar radiation by suggesting a correction factor. Similarly, Allen [25] presented a self-calibrated model based on Hargreaves and Samani's model to calculate the average monthly global solar radiation. A simple model for estimating daily global solar radiation was proposed by Bristow and Campbell [26], in which the solar radiation is assumed to be an exponential function of temperature difference. Goodin et al. [27] modified Bristow and Campbell's model by adding the extra-terrestrial solar radiation term to behave as a scaling factor, allowing the temperature difference term to adapt the greater range of global solar radiation values. El-Metwally also suggested three simple new models based on minimum and maximum temperature data and cloud cover data for calculating global solar radiation on a horizontal surface in Egypt [28]. Quej et al. [29] evaluated the accuracy and applicability of thirteen empirical models based on temperature and other meteorological parameters for estimating global solar radiation in Yucaton Peninsula, Mexico. Their results showed that the new empirical model, which was developed as a function of ambient temperature and other metrological data, provides the best estimation for solar radiation at all stations. Similarly, Mghouchi et al. [30] examined the performance of three solar radiation models under all sky conditions for estimating different components of solar radiation flux on a horizontal surface in Tetuan, Morocco. The daily global solar radiation spatial distribution from diurnal temperature ranges over the Tibetan Plateau in China was evaluated by Pan et al. [31], and they concluded that the calibrated Bristow–Camp-bell model performs well on the Tibetan Plateau and can give reasonably accurate global solar radiation estimations. Almorox et al. [32] calibrated seven existing solar models and developed one new model for predicting global solar radiation data using temperature data measured at seven stations located in Madrid, Spain. Their results showed that the empirical models based on temperature show good predictions at any location if their coefficients are correctly adjusted. In addition, the newly suggested model gives the best estimation for all stations. Youssef et al. [33] investigated the performance of 31 non-sunshine-based models for estimating the monthly average of daily global solar radiation on a horizontal surface. The best estimations were predicted by Toğrul's [34] and Ertekin's [35], models which are based on extra-terrestrial radiation and solar declination. Besharat et al. [10] reviewed the extensive empirical models available in the literature and evaluated their accuracy and applicability for estimating the monthly average daily global solar radiation on a horizontal surface in Yazd, Iran. Four models by El-Metwally [22], Badescu [36], Hargreaves et al. [23], and Chen et al. [37] were selected from the different categories of sunshine-based models, cloud-based models, temperature-based models and other meteorological-based models, and their performance was compared against the measured data of Yazd. The results show that all proposed correlations achieve good estimations, and El-Metwally's [22] sunshine-based model provides the best prediction with high accuracy.

In general, the sunshine-based models are the most accurate models compared with other meteorological parameter-based models [15]. However, sunshine data are not as widely available compared as ambient temperature data at standard meteorological stations [38], and the ambient temperature is simply measured for most standard meteorological tasks [39]. Thus, the sunshine-based models are difficult to apply at locations where sunshine data are not available [22,40]. Therefore, it is feasible to develop new models based on ambient temperature as alternative models to estimate the solar radiation at different locations around the world.

This study aims to introduce new ambient temperature-based models for estimating global solar radiation on a horizontal surface with high accuracy. For this purpose, 20 different ambient-temperature-based models are proposed for estimating monthly average daily global solar radiation on a horizontal surface; (17 models are introduced in this study as new models, and three models were previously developed in the literature). The performance of the new 17 suggested models is validated and compared with the performance of the selected three models against the measured data of global solar radiation in New Borg El-Arab, Egypt (Lat. 30°51′N and long. 29°34′E). Moreover, the generalization capability of the newly suggested models is examined for all of Egypt as a case study and tested in ten Egyptian cities, namely, Sidi Barrani, New Borg El-Arab, Siwa, El-Arich, Nakhel, Hurghada, Cairo, Asyut, Kharga and Aswan. These cities are distributed over the whole