Renewable Energy 43 (2012) 130–139

Contents lists available at SciVerse ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Comparative study of mathematical models in estimating solar irradiance for Australia

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ARTICLE INFO

Article history:
Received 1 April 2011
Accepted 25 November 2011
Available online 22 December 2011

Keywords:
Radiation
Direct
Diffuse
Global
Modelling

ABSTRACT

Hourly diffuse and direct solar irradiance data are required for weather files used in building energy simulation as well as Photovoltaic and solar thermal calculations. Access to up to date hourly observation data or satellite derived data for these parameters is currently only available for a selection of the Australian Bureau of Meteorology measurement locations. This study aims to investigate the accuracy of the methods used to estimate solar irradiance data from meteorological observations either in the absence of observed irradiance data or when irradiance observations are limited to global irradiance. In particular the focus of this paper is to investigate the accuracy of the process of coupling together global and direct/diffuse models. Five global and four diffuse/direct irradiance models are presented and compared to experimental data for four locations in Australia. In the case where experimental global irradiance data is available, values are used as input into various models to obtain diffuse and direct irradiance. In the absence of experimental irradiance data, the approach taken is to estimate global irradiance with a separate model and then feed these values into the diffuse/direct models. The errors associated with both of these approaches are investigated by comparing the modelled diffuse and direct irradiance values with known experimental data for four Australian locations over a period of a number of years. This study indicates that no single diffuse/direct irradiance model consistently outperformed the other models at estimating diffuse and direct irradiance whilst the Zhang and Huang global irradiance model with coefficients from Seo and Huang achieved the best estimates of global irradiance for the locations investigated. For the approach where global irradiance is estimated from a model, the resulting direct and diffuse data was found to differ significantly from the experimental data. The results indicate that the individual models that achieved the best estimates of global irradiance did not achieve the best estimates of diffuse and direct irradiance when coupled with a diffuse/direct model.

1. Introduction

Solar radiation data such as hourly direct and diffuse irradiance are required for weather files used in building energy simulations as well as Photovoltaic and solar thermal calculations. Particularly, real time solar irradiance data is required to allow comparisons to be made between experimental data from buildings, PV and solar thermal systems to simulated data for the time period under study. The Australian Climatic Data Bank (ACDB) consists of hourly records over numerous years of these climatic variables for a set of locations across Australia, however it only contains data up to 2004 [1]. Up to date data for temperature, humidity and wind speed for the ACDB locations are measured and freely available from the Australian Bureau of Meteorology (BOM). However for most of the ACDB locations irradiance values are not recorded or only global irradiance is inferred from satellite information [2]. To overcome the lack of experimental data a number of mathematical models have been developed to estimate global, direct and diffuse irradiance.

Modelling studies of only global or only diffuse/direct irradiance have been reported for numerous locations across the globe. However only a selection of papers have been reported discussing the accuracies of estimating diffuse and direct irradiance when global irradiance is unknown and needs to be estimated. One study by Thevenard and Brunger [3,4], mentioned that there should be a "very legitimate concern about 'piling up' models as they did" in the production of the International Weather files for Energy Calculations (IWEC). This issue of combining or 'piling up' models has led to the research presented.

Firstly results are discussed with regard to the accuracy of modelling diffuse and direct irradiance when global irradiance is

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doi:10.1016/j.renene.2011.11.050

known. These results will be used to show the increase in modelling uncertainty when global irradiance is unknown and modelled. Based on the work of Ridley et al. [2] and Torres et al. [5], only diffuse models that were able to reproduce a significant proportion of the variance in the diffuse fraction (d_t) and clearness index (k_t) relationship were investigated. The diffuse/direct models of consequence include the works of Ridley et al. [2], Skartveit et al. [6], Watanabe et al. [7] and Zhang [8]. The motivation for the present study is to assess the implementation of the Zhang and Watanabe models for Australian locations in comparison to other models already tested under Australian conditions.

Secondly results are presented regarding the accuracy of modelling global irradiance from meteorological observations. The global models investigated include the works from Zhang et al. [9], Thevenard and Brunger [3,4], Zhang et al. [10] and Moriarty [11]. The Zhang and Huang model is investigated due to its inclusion in the building energy simulation program EnergyPlus [12]. The Seo and Huang 6- and 4-variable variations of the Zhang and Huang model are included to investigate the potential for improved modelling for Australian locations. The Thevenard and Brunger model is included due to its use in the development of the current IWEC weather files. Finally, the Moriarty clear sky model in conjunction with the Kasten and Czeplak cloudy sky model [13] is included as the Moriarty model was developed based on Australian locations. Except for the Moriarty model, a review of the literature found that only the study from Seo and Huang presented model results for an Australian location.

Thirdly this study presents the accuracy of modelling diffuse and direct irradiance when used in combination with estimated values of global irradiance. The review of the literature found that studies focusing on this topic commonly reported only the accuracy of modelling diffuse irradiance and failed to report the level of error associated with modelling direct irradiance.

2. Literature review

The global irradiance models developed by Bird and Hulstrom [14], Kasten and Czeplak [13] and the model used to develop the International Weather files for Energy Calculation (IWEC) [3] were developed using a two step process where the level of irradiance is first calculated under clear sky conditions and then adjusted to take into account the effects of cloud cover. Other models have also been developed which estimate global irradiance based on correlations with meteorological weather parameters like temperature, humidity, wind speed and cloud cover. The most recent is a model developed by Zhang et al. [9]. Similarly, a number of models have been developed to estimate diffuse and direct horizontal irradiance based on known values of global irradiance, the most recent from Ridley et al. [2] and Zhang [8] and the most commonly used from Reindl et al. [15], Maxwell [16] and Perez et al. [17].

In the presentation of their diffuse irradiance model, Ridley et al. [2] undertook a comparative study of the diffuse/direct models from Reindl, Perez, and Skartveit against experimental diffuse data for two Australian locations, Adelaide and Darwin, along with five other locations from across the globe. The authors concluded that their BRL model performed equally well for locations in both hemispheres and outperformed the other models based on the Bayesian Information Criterion (BIC). The data and figures they presented indicated that the Reindl and the Perez models were unable to appropriately model clear sky conditions.

Torres et al. [5] undertook a similar comparative study of seventeen diffuse irradiance models for the location of Pamplona, Spain. The authors recommended the use of the Dirint (Perez model) and the BRL diffuse models as they found they exhibited the highest precision and were able to generate estimated values of diffuse irradiance with distribution functions that were very similar to those of the experimental data. The data and figures presented indicated that the Perez (Dirint) model achieved the highest precision in terms of the coefficient of determination (R^2), the root mean squared error (RMSE) and the BIC.

Zhang et al. [10] undertook an analysis of the Zhang and Huang global irradiance model for several locations throughout the world as well as an analysis of the direct irradiance models of Zhang [8] and Watanabe et al. [7]. Their analysis indicated that only two variables, solar altitude and cloud cover, were required to estimate global irradiance for high latitude locations, whilst dry bulb temperature was required to improve the accuracy of using global irradiance models for tropical locations. The authors also concluded that the Watanabe direct model was found to be suitable for both tropical and non-tropical climates, whilst the Zhang direct model was generally found to provide more accurate results in tropical climates. Darwin was included in the investigation of the Seo and Huang global irradiance models; however no papers could be located discussing the accuracy of using the Zhang and Watanabe models to estimate diffuse and direct irradiance for Australian locations. The RMSE results of the Zhang and Huang global model for the location of Darwin with the coefficients from Seo and Huang ranged between 186 and 194 W/m^2. The RMSE results for estimating direct irradiance for the 7 locations investigated ranged between 86 and 158 W/m^2 for the Watanabe model and between 79 and 150 W/m^2 for the Zhang direct model. This analysis was undertaken assuming values of global irradiance were known and were not estimated.

Zhang et al. [9] presented comparative results for global and diffuse irradiance for two locations in China after combining the Watanabe diffuse model [7] with the results from their global irradiance model. Standard statistical parameters like the root mean squared deviation (RMSD) and the mean bias deviation (MBD) were not presented for either global or diffuse irradiance. The authors however did report the goodness of fit between measured and estimated daily values of global and diffuse irradiance via R^2. Their results indicated that the R^2 values were 0.85 and 0.92 for global irradiance, whilst the values for diffuse irradiance were 0.675 and 0.791. The authors therefore concluded that both their global irradiance model and the Watanabe diffuse/direct model could be used to estimate irradiances for China. However, results for the correlations between estimated direct and experimental direct irradiances were not presented.

Another study conducted by Krarti and Seo [18] investigated two model combinations for the location of Tunisia. This study included the global irradiance models of Kasten and Czeplak [13] and Zhang et al. [9]. The results showed that the average monthly root mean squared error (RMSE) calculated from hourly modelled and experimental values were 174 and 170 W/m^2 for global irradiance and 131 and 110 W/m^2 for diffuse irradiance. Again the results were not presented for the direct component of irradiance.

3. Methodology

This study presents results for five global and four direct/diffuse models against experimental irradiances for the 4 Australian locations of Melbourne, Wagga Wagga, Darwin and Alice Springs. In all cases, presented model coefficients were not re-solved for the locations in this study; all model coefficients used were as presented in their respective publications. For all models the relationship between global, direct and diffuse irradiance is as follows, where α is the solar altitude [19].