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# Accuracy Assessment of Models Estimating Total Irradiance on Inclined Planes in Loughborough

J. Zhu\*, T.R. Betts, R. Gottschalg

Centre for Renewable Energy Systems Technology (CREST), Department of Electronic and Electrical Engineering, Loughborough University, Loughborough, Leicestershire, LE11 3TU, UK

\* Corresponding Author: Tel.: +44(0)1509 635313, Fax: +44(0)1509 635301, Email: [J.Zhu@lboro.ac.uk](mailto:J.Zhu@lboro.ac.uk)

## Abstract

The accuracy of estimating total in-plane irradiance is investigated for the UK climate. Several models, which differ in essence in an assumed diffuse irradiance distribution at different levels of sky cloudiness, were used to calculate solar irradiance on inclined planes from horizontal irradiance data. The accuracy of this calculation was validated against measured data. It transpires that there is not massive difference between the various methodologies, but on average the Reindl model seems to be slightly better than other methods, followed by Perez et al. model.

## Introduction

The design of photovoltaic systems requires the use of inclined irradiance data. Typically, the system designer will only have horizontal data available. Thus, the accuracy of translation to inclined irradiance is crucial for modelling the energetic performance of a PV module or system. Several models, which differ in essence in an assumed diffuse irradiance distribution at different levels of sky cloudiness, were used to calculate solar irradiance on inclined planes and the accuracy of this translation was evaluated. These models may behave somewhat differently at different locations since the key parameters in the calculation are empirically determined parameters [1]. Climatic changes from site to site may result in variation of the accuracy arising from calculation of the inclined diffuse component.

This paper presents the results for estimating inclined irradiance and comparatively assesses the performance of different models applied to the UK climate, which is much cloudier (i.e. sky condition corresponding to a cloud index larger than 0.6) [2] with large amount of diffuse component throughout the year.

## Methodology

The statistical evaluation is based on the irradiance data taken from measurements conducted by CREST. The set of data is in 1 minute time steps and hourly steps for three periods in 2005 and 2007, which cover the different environmental conditions seen in Loughborough and represent a full year's worth of data.

Since global horizontal irradiance data only is available from the measurements, Erb's model [3] is used to estimate the beam and diffuse components which are used for calculating inclined diffuse irradiance according to different numerical models, such as the models of Liu & Jordan, Temps & Coulson, Perez, and Reindl. Measurements of diffuse components are ongoing and will be used to evaluate the different estimation methods for diffuse irradiance modelling.

The model output is the total inclined irradiance, which were compared to measured values based on a primary standard thermopile detector.

Some selected models, which include two all-sky models, one overcast model and one clear sky model, are used in the evaluation and described below. The  $G_{d,i}$ ,  $G_{d,h}$  represents in-plane and horizontal diffuse irradiance,  $\beta$  is inclination angle,  $\theta_i$  the incidence angle on a tilted surface, and  $\theta_h$  the solar zenith angle.

The Reindl model [4] is an all-sky model including a circumsolar component and a horizon brightening diffuse term as shown in Eq (1).

$$\frac{G_{d,i}}{G_{d,h}} = \frac{1}{2}(1 + \cos\beta)(1 - F_H) \left[ 1 + F_R \sin^3\left(\frac{\beta}{2}\right) \right] + \frac{\cos\theta_i}{\cos\theta_h} F_H \quad \text{Eq (1)}$$

$F_H$  and  $F_R$  are parameters depending on the horizontal beam and diffuse irradiance.

The method by Perez et al. [5] is another all-sky model including horizon and circumsolar brightening as well as an isotropic background.

$$\frac{G_{d,i}}{G_{d,h}} = F_{P1} \frac{\cos\theta_i}{\cos\theta_h} + (1 - F_{P1}) \cos^2\left(\frac{\beta}{2}\right) + F_{P2} \sin\beta \quad \text{Eq (2)}$$

$F_{P1}$  and  $F_{P2}$  are two empirical factors depending on the sky clearness, the sky brightness and a set of coefficients based on the local climate condition.

The Liu & Jordan model [6] which is in essence valid for a totally overcast sky is given as Eq (3).

$$\frac{G_{d,i}}{G_{d,h}} = \frac{1}{2}(1 + \cos\beta) \quad \text{Eq (3)}$$

Another approach by Temps & Coulson [7] is a clear sky model as shown in Eq (4).

$$\frac{G_{d,i}}{G_{d,h}} = \cos^2\left(\frac{\beta}{2}\right) F_{T,1} F_{T,2} \quad \text{Eq (4)}$$

$F_{T,1}$  and  $F_{T,2}$  are factors determined by the inclination angle  $\beta$ , the incidence angle on a tilted surface  $\theta_i$ , and the solar zenith angle  $\theta_h$ .

## Results and Discussion

Figure 1 to Figure 4 show results of the comparative assessment of different models in which the simulation was implemented in 1 minute time steps. They are plotted as measured in-plane irradiance versus modelled irradiance in the case of a 45° inclined surface.

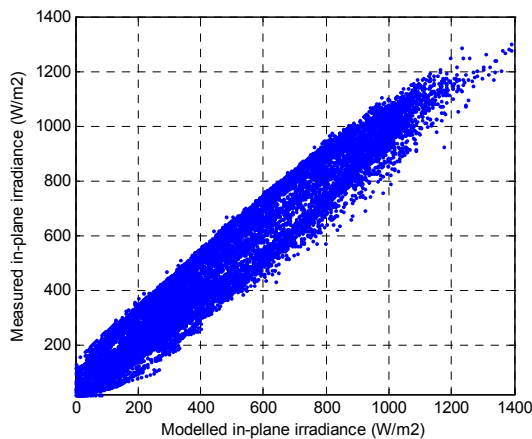


Figure 1: Reindl model

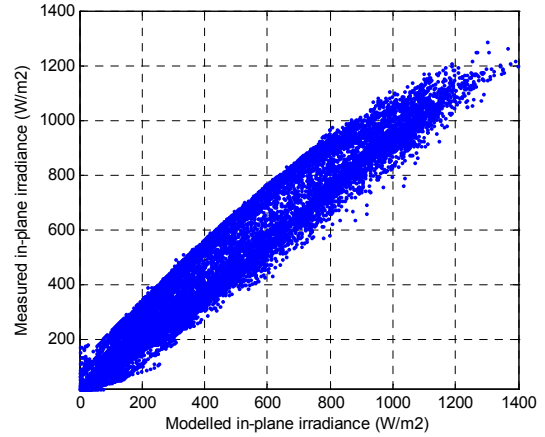


Figure 2: Perez et al. model

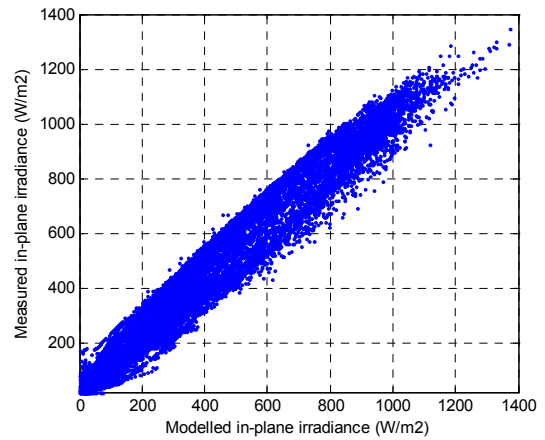


Figure 3: Liu & Jordan model

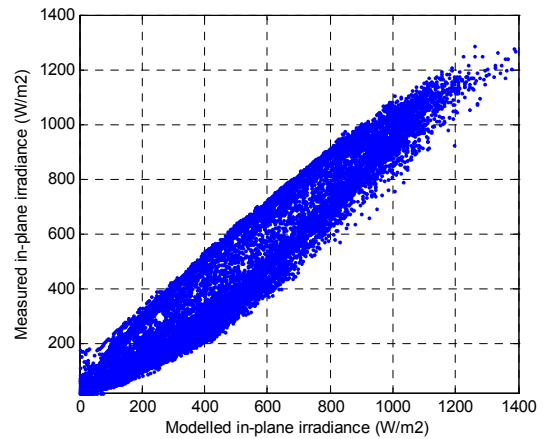


Figure 4: Temps & Coulson model

There are only minor differences between the various models and one could conclude that the difference may be found in the measurement arrangement rather than in the translation procedure as things like clouds and slight inhomogeneities affect the different instruments slightly differently. Visually, one would think that the Reindl model is slightly better for all the irradiance conditions seen by the device. A

further comparison was carried out by using hourly data for the above four models and the results are shown in Figure 5.

Under the UK climate condition, it seems that the all-sky model of Reindl gives better results, followed by the Perez model.

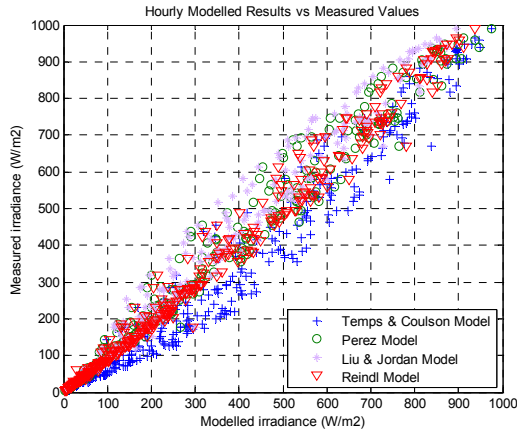


Figure 5: Comparison of measured and modelled irradiance values

The hourly data reveal that the Liu & Jordan model has a tendency to underestimate the modelled irradiance, and the Temps & Coulson model virtually always over-estimates the modelled irradiance.

The correlation coefficients (CORR), mean standard deviation (M-STD) and weighted mean bias error (W-MBE) between modelled and measured are summarized in Tables 1-3 for all models in this work to validate our simulation. It distinguishes between minutely and hourly data.

CORR	MINUTELY	HOURLY
Reindl	0.9878	0.9909
Perez et al.	0.9857	0.9881
Liu & Jordan	0.9854	0.9886
Temps & Coulson	0.9775	0.9778

Table 1: Correlation coefficients

M-STD (W/M <sup>2</sup> )	MINUTELY	HOURLY
Reindl	21.46	20.26
Perez et al.	22.45	22.19
Liu & Jordan	26.45	28.02
Temps & Coulson	40.78	39.92

Table 2: Mean standard deviation

W-MBE	MINUTELY	HOURLY
Reindl	9.62 %	9.17 %
Perez et al.	10.08 %	10.04 %
Liu & Jordan	11.87 %	12.68 %
Temps & Coulson	17.93 %	17.88 %

Table 3: Weighted mean bias error

The correlation coefficients indicate the Reindl model has a higher value, which means higher strength of relationship between the modelled and measured results. The mean standard deviation of the Reindl model is lower than the other three models, which is around 20 W/m<sup>2</sup> for irradiance range from 0 W/m<sup>2</sup> up to 1000 W/m<sup>2</sup>. The weighted mean bias error is irradiance weighted and demonstrates the weighted average error for different models. The Reindl model has W-MBE around 9%, whereas the Temps & Coulson is over 17%.

## Conclusion

The comparative assessment of models estimating the in-plane irradiance shows that the all-sky models give best modelled results under the conditions of the UK climate, followed by overcast sky models. Whereas, the clear sky models do not appear to achieve accurate model results.

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