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The assessment of different models to predict the global solar radiation on a surface tilted to the south

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Abstract

Global and diffuse solar radiation intensities are, in general, measured on horizontal surfaces, whereas stationary solar conversion systems (both flat plate solar collector and PV) are tilted towards the sun in order to maximize the amount of solar radiation incident on the collector surface. Consequently, the solar radiation incident on a tilted surface must be determined by converting the solar radiation intensities measured on a horizontal surface to that incident on the tilted surface of interest. There exist a large number of models designed to perform such a conversion. 11 such models have been tested utilizing data measured in Beer Sheva, Israel. The data consist of hourly global and diffuse solar radiation on a horizontal surface, normal incidence beam and global radiation on a south-oriented surface tilted at 40°. The horizontal diffuse radiation measured using a shadow ring was corrected using four different correction models. This resulted in 44 model permutations. The individual model performance is assessed by an inter-comparison between the calculated and measured solar global radiation on the south-oriented surface tilted at 40° using both graphical and statistical methods. The relative performance of the different models under different sky conditions has been studied. Different grading systems have been applied in an attempt to score the relative performance of the models.

Keywords: Solar radiation; Tilted surface; Diffuse models; Grading of models

1. Introduction

Meteorological stations that measure global and diffuse solar radiation intensities do so, in general, on horizontal surfaces. Stationary solar conversion systems (both for production of thermal and electrical energy, i.e., flat plate solar collectors and PV cells) are tilted towards the sun in order to maximize the amount of solar radiation incident on the collector/cell surface. Consequently, the solar radiation incident on a tilted surface must be determined by converting the solar radiation intensities measured on a horizontal surface to that incident on the tilted surface of interest in order to design the system size and estimate its productivity.

The measured normal incident beam is converted to beam radiation on a tilted surface by the relatively simple geometrical relationship between the two surfaces. This is not the case regarding the diffuse component, since the diffuse radiation comes from all points of the sky except the sun. There exist a relatively large number of models that attempt to correlate the diffuse radiation on a tilted surface to that measured on a horizontal surface. The abundance of such models attests to the complexity of the task of converting diffuse solar radiation measured on a horizontal to that on a tilted surface.

Kudish and Ianetz (1991) have evaluated the relative ability of three models, an isotropic (Liu and Jordan, 1961) and two anisotropic (Hay, 1979; Klucher, 1979)

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Nomenclature

I_g, I_b, I_d	horizontal global, beam and diffuse solar radiation (W m^{-2})
$I_{b,n}$	normal incidence beam solar radiation (W m^{-2})
I_r	reflected solar radiation (W m^{-2})
I_0	extraterrestrial horizontal radiation (W m^{-2})
G_{SC}	solar constant = 1367 W m^{-2}
k_t	hourly sky clearness index
n	number of data values
n_0	Julian day number

Greek symbols

α	solar altitude angle (deg)
β	surface tilt angle (deg)
δ	declination angle (deg)
θ	incidence angle on inclined surface (deg)
θ_z	zenith angle (deg)
ρ	albedo (ground reflectance)

Subscripts

m	mean
o	observed
p	predicted
β	tilted surface

models, to predict the global solar radiation on a tilted surface in Beer Sheva, Israel. They found that the relative ability of the models to predict the global solar radiation on a tilted surface varied with time of year and site climatic conditions.

Kambezidis et al. (1997) compared the relative ability of several models to predict the global solar radiation on surfaces of various tilts and azimuths against those measured in Athens, Greece. Olmo et al. (1999) developed a model to determine the global radiation on inclined surfaces using a database consisting of only horizontal global solar radiation measured in Granada, Spain. This model depends on local atmospheric conditions, based upon the clearness index k_t, and avoids partitioning the global solar radiation into beam and diffuse components.

Nijmeh and Mamlook (2000) reported on the testing of two models, isotropic (Liu and Jordan, 1961) and anisotropic (Hay, 1979), using a database consisting of horizontal global and diffuse solar radiation, to predict the global solar radiation on a south-facing surface tilted at 45° in Amman, Jordan. They compared the predicted global solar radiation to that measured by a pyranometer on a 45° tilted surface. They found that the performance of the models was a function of time of the year, namely, season.

Bilbao et al. (2003) tested the performance of five models for predicting the hourly diffuse solar radiation on tilted surfaces using horizontal global and diffuse solar radiation data measured at six Spanish meteorological stations. Diez-Mediavilla et al. (2005) studied the relative performance of 10 different models to predict the diffuse radiation on a south-facing surface tilted at 42°on both an hourly and a daily basis for a site located about 35 km from Valladolid, Spain. They used a database consisting of horizontal global and diffuse solar radiation measurements and compared the calculated diffuse radiation to that measured by a second pyranometer with a shadow ring on a south-facing surface tilted at 42°.

Kamali et al. (2006) have tested eight models to predict the global solar radiation on 45° south-facing and 40° west-facing surfaces in Karaj, Iran. The input database for the models consisted of only horizontal global radiation and the daily beam and diffuse radiation was estimated using the de Miguel et al. (2001) model.

Notton et al. (2006a) tested the relative ability of 15 models to predict the global solar radiation on south-facing surfaces tilted at 45° and 60° for the French Mediterranean site of Ajaccio. Their database consisted of global radiation measured on a horizontal, 45° and 60° tilted surfaces and normal incidence beam radiation. They had previously tested seven models that correlate diffuse to global solar radiation on a horizontal surface, cf., Notton et al. (2004). More recently, Notton et al. (2006b) have combined their two previous studies and compared it to the Olmo et al. (1999) model, transforming global solar radiation directly onto tilted from horizontal surfaces.

Loutzenhiser et al. (2007) have tested the performance of seven models to compute the global solar radiation incident on a south-west façade. Two of the three measured components of global solar radiation, viz., horizontal global, normal incidence beam and horizontal diffuse, were used as inputs for calculating the global radiation on a south-west façade. The calculated radiation intensities were compared to that measured by a pyranometer on the façade plane (29° W of S).

The simplest model, Liu and Jordan (1961) assumes that diffuse solar radiation is isotropic, whereas the other, more complex models insert different parameters that account for the inherent anisotropic characteristics of the diffuse radiation. These more complex models insert parameters that attempt to account for some or all of the inherent anisotropic factors such as circumsolar radiation, sky conditions and horizon brightening. In addition, these models differ in the type of data required to calculate the diffuse radiation on a tilted surface. There are models that require only horizontal global solar radiation data and utilize empirical methods to transform the horizontal global radiation to its beam and diffuse radiation components. These models were developed for sites that measure horizontal radiation only. Most of the models require two of the three measured components of global solar radiation, viz., hori-