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Evaluation of hourly solar radiation on inclined surfaces at Seoul by Photographical Method

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Abstract

Generally, a proper solar radiation model considers nothing more than the angle of inclination of a slope, without considering the influence of obstacles and surrounding buildings. In this study, we proposed a Photographical Method, which can increase the prediction accuracy of solar radiation on an inclined surface, with considering the shape of obstacles in the sky view. This paper evaluated twenty cases (5 solar radiation models in each of 4 albedo models), by the new method of the Photographical Method (PM). The following conclusions were drawn: (1) The prediction accuracy of solar radiation on an inclined surface was improved in all twenty cases with the PM. (2) The new method showed a higher degree of improvement of prediction accuracy in the low range of solar radiation (a high proportion of diffuse solar radiation). (3) The prediction accuracy of solar radiation with the PM improves with increasing tilt angle from the horizontal to the vertical. Applying the Photographical Method is more suited to an urban region with a forest of buildings, than a region of wide grasslands and sunny climate.

Keywords: Solar radiation; Inclined surface; Photographical Method; Empirical validation

1. Introduction

The accurate calculation of solar radiation on an inclined surface is very important in many practical applications of solar energy, such as the calculation of the heating and cooling energy use of buildings, the evaluation of photovoltaic plants, BIPV, and so on. Therefore, various prediction models have been proposed to estimate the amount of global and diffuse solar radiation on an inclined surface, for example those of Liu and Jordan (1963), Hay and Davies (1980), Reindl et al. (1990) and Perez et al. (1990), among many others.

Many researchers evaluated several prediction models. Kambezidis et al. (1994) compared the hourly radiation value with twelve sky diffuse models and four albedo models, and found an accurate combined model for Greece (Latitude: 37.98°N, Longitude: 23.75°E). In doing so, he asserts that the Perez model, (which has generally been considered as the most accurate model), is not accurate in every region, and maintains that there exists a most appropriate model for each region.

Vartiainen (2000) combined five solar radiation models and six sky distribution models with twenty-four inclined surfaces for Finland (Latitude: 60°27′N, Longitude: 22°18′E). Cucumo et al. (2007) compared the hourly radiation data calculated by various calculation models of

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Nomenclature

I	global solar radiation on inclined surface, W/m^2
I_{DN}	direct normal solar radiation, W/m^2
I_{dH}	diffuse horizontal solar radiation, W/m^2
I_{GH}	global horizontal solar radiation, W/m^2
I_O	extraterrestrial direct normal solar radiation, W/m^2
SVF	sky view factor, –
GVF	ground view factor, –
K	anisotropic index, –
i	incidence angle of sun's rays on inclined surface, °
H	Gueymard's solar incidence angle on inclined surface, $0.01(90 - i)$ °
a_0, a_1, a_2, a_3	Gueymard's monthly basis coefficients of average ground reflectance, –
A	NKemdirim's coefficient of crop factor, –
B	NKemdirim's coefficient of slope factor, –
f_{bs}	Gueymard's shadow factor for direct solar radiation, –
f_{af}	Gueymard's anisotropy coefficient for forward augmented reflection, –
f_{ab}	Gueymard's anisotropy coefficient for backward augmented reflection, –
a, b	Perez's incidence angle of the sun and surface coefficients, –
F_1	Perez's circumsolar coefficient, –
F_2	Perez's horizon brightening coefficient, –
R	radiance distribution index, –

Greek symbols

ρ	ground reflectance, –
α	solar azimuth angle relative to the inclined surface, °
Ø	latitude angle, °
θ_z	solar zenith angle, °
β	surface tilt angle from horizon, °
ρ_b	ground reflectance for direct solar radiation, –
ρ_d	ground reflectance for diffuse solar radiation, –
ρ_n	ground reflectance for purely isotropic reflection, –

south, west, north and east aspect, measured at Arcavacata di Rende (Latitude: 39°18′N, Longitude: 16°15′E), and found the most accurate model. These studies revealed that even in the same region, solar radiation model accuracy was found to be different, depending on the direction and slope.

Loutzenhiser et al. (2007) compared daily solar radiation at a vertical surface (Latitude: 47°24′N, Longitude: 8°36′E) by seven prediction models that made wide use of building energy simulation codes. He informed and analyzed all solar radiation models in building energy simulation programs, such as ENERGYPLUS, DOE, ESP-r and TRNSYS.

Other studies have been carried out in Saudi Arabia (Latitude: 21°42′N, Longitude: 39°11′E) (el-Sebaii et al., 2010), Spain (Latitude: 41°49′N, Longitude: 4°56′E) (Diez-Mediavilla et al., 2005), and Greece (Latitude: 37°59′N, Longitude: 23°45′E) (Kambezidis et al., 1994). Many studies have been performed in various locations with the changing of variables, such as the ground reflectance model, sky distribution model, and climate, surface direction, and so on.

In this paper, we assumed that the accuracy of the estimated results from the optimal solar radiation model could be affected by the view of the environment, and an obstacle's shape.

Generally, the proper solar radiation model was suggested by using the measured data from a wide field or the top of a mountain, to avoid the shielding effect of obstacles. Therefore, the solar radiation model considers no more than the angle of inclination of the slope, without considering the effect of obstacles and surrounding buildings. It quickly becomes apparent that the predicted radiation from conventional methods cannot give accurate results, due to the difference of the sky view factor caused by obstacles and surrounding buildings.

This study includes the following processes.

1. Predict solar radiation on an inclined surface, by combining five existing solar radiation models, and four ground reflectance models.
2. Evaluate the accuracy of each model on the inclined surface, by comparing the measured data with the predicted data.
3. Predict the solar radiation on the inclined surface, by modified solar radiation models with the Photographical Method.
4. Evaluate the accuracy of modified solar radiation models with the Photographical Method on an inclined surface.
5. Compare the accuracy of the existing solar radiation model with the modified solar radiation model by using the Photographical Method.

2. Solar radiation model

Global solar radiation on a surface can be divided into the following three components: (1) direct component, (2) sky diffuse component, and (3) ground-reflected component.

There are many prediction models that have been developed to predict accurate solar radiation on an inclined surface, according to variables such as latitude, longitude,