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A simplified model exploration research of new anisotropic diffuse radiation model

Wanxiang Yao [a,b,*], Zhengrong Li [c], Xiao Wang [d], Qun Zhao [e], Zhigang Zhang [a], Lin Lin [a]

[a] School of Energy and Safety Engineering, Tianjin Chengjian University, Tianjin 300384, China
[b] State Key Laboratory of Building Safety and Built Environment, Beijing 100013, China
[c] College of Mechanical Engineering, Tongji University, Shanghai 200092, China
[d] School of Economics and Management, Tianjin Chengjian University, Tianjin 300384, China
[e] College of Architecture and Urban Planning, Tongji University, Shanghai 200092, China

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ABSTRACT

More accurate new anisotropic diffuse radiation model (NADR model) has been proposed, but the parameters and calculation process of NADR model used in the process are complex. So it is difficult to widely used in the simulation software and engineering calculation. Based on analysis of the diffuse radiation model and measured diffuse radiation data, this paper put forward three hypotheses: (1) diffuse radiation from sky horizontal region is concentrated in a very thin layer which is close to the line source; (2) diffuse radiation from circumsolar region is concentrated in the point of the sun; (3) diffuse radiation from orthogonal region is concentrated in the point located at 90 degree angles with the Sun. Based on these hypotheses, NADR model is simplified to a new simplified anisotropic diffuse radiation model (NSADR model). Then the accuracy of NADR model and its simplified model (NSADR model) are compared with existing models based on the measured values, and the result shows that Perez model and its simplified model are relatively accurate among existing models. However, the accuracy of these two models is lower than the NADR model and NSADR model due to neglect the influence of the orthogonal diffuse radiation. The accuracy of the NSADR model is higher than that of the existing models, meanwhile, another advantage is that the NSADR model simplifies the process of solution parameters and calculation. Therefore it is more suitable for calculating the diffuse radiation of the inclined plane.

1. Introduction

Accurate solar radiation data is essential for design, simulation, performance evaluation of solar energy system [1,2]. Which is also affect the building cooling load and air-conditioning equipment selection, meanwhile, diffuse radiation is also the key problem in calculating solar radiation [3,4]. The diffuse radiation on the inclined plane is very significant for solar thermal use and photovoltaic power generation; however, meteorological station cannot provide these data [5–8]. Therefore it is urgent to develop a theoretical model to calculate diffuse radiation on an inclined surface through diffuse radiation on a horizontal surface.

The research of the diffuse radiation models can be divided into three generations [9]. The first generation models are isotropic diffuse radiation models, represented by the Liu and Jordan model [10]. These diffuse radiation models are only suitable for cloudy days, which cannot be applied to partially cloudy days and clear days.

The second generation models are generally based on modification of the first generation models, which are suitable for partially cloudy and sunny weather. The typical models include Temps and Coulson model [11], Klucher model [12], Hay model [13], Skartveit and Olseth model [14] and Reindl model [15]. The second generation models have relatively simple forms and better practical values, but they do not have clear physical meaning and are lower accuracy because they are only adjusted based on isotropic models.

The third generation are anisotropic diffuse radiation models which are obtained by building the diffuse radiation integral equation, and the typical models are Perez model [16] and Muneer model [9,17]. Muneer model [9,17] is developed from Steven and Unsworth model [18] which is gained by integrating Moon and Spencer model [19]. The radiation distribution index is a core indicator of these models, which has a significant impact on accuracy of diffuse radiation calculation. Perez model [16] is strictly set up

* Corresponding author at: School of Energy and Safety Engineering, Tianjin Chengjian University, Tianjin, China.
E-mail address: yaowanxiang@126.com (W. Yao).

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Nomenclature

A, B, C intermediate variables (dimensionless)
a solid angle of the circumsolar region on a tilted surface, $a = 2(1 - \cos\alpha)\chi_c(\theta)$ (sr)
a' intermediate variable used in simplified Perez model (dimensionless)
b solid angle of the orthogonal region on a tilted surface, $b = 2(1 - \cos\zeta)\chi_c(\frac{\pi}{2} - \theta)$ (sr)
c solid angle of the sky horizontal region on a tilted surface, $c = \begin{cases} 0.5(\cos\beta - \cos 2\xi), \beta \leqslant \xi \\ -\frac{1}{2}\cos 2\xi + \frac{1}{2\pi}(1 + \cos 2\xi)\arccos(\tan\xi\cot\beta) \\ +\frac{1}{\pi}\arcsin(\sin\xi\csc\beta)\cos\beta, \beta > \xi \end{cases}$ (sr)
c_i is the ith calculated value, (W/m^2 in this paper)
d solid angle of the circumsolar region on a horizontal surface, $d = 2(1 - \cos\alpha)\chi_h(\theta_z)$ (sr)
d' intermediate variable used in simplified Perez model (dimensionless)
e solid angle of the orthogonal region on a horizontal surface, $e = 2(1 - \cos\zeta)\chi_h(\frac{\pi}{2} - \theta_z)$ (sr)
f solid angle of the sky horizontal region on a horizontal surface, $f = 0.5(1 - \cos 2\xi)$ (sr)
F_1 circumsolar diffuse radiation coefficient (dimensionless)
F_2 orthogonal diffuse radiation coefficient (dimensionless)
F_3 horizontal diffuse radiation coefficient (dimensionless)
F_1' circumsolar diffuse radiation adjustment coefficient (dimensionless)
F_2' orthogonal diffuse radiation adjustment coefficient (dimensionless)
F_3' horizontal diffuse radiation adjustment coefficient (dimensionless)
F_1'' circumsolar diffuse radiation adjustment coefficient used in simplified Perez model (dimensionless)
F_2'' horizontal diffuse radiation adjustment coefficient used in simplified Perez model (dimensionless)
$F_{11}, F_{12}, F_{13}, F_{21}, F_{22}, F_{23}, F_{31}, F_{32}, F_{33}$ the intermediate variables (dimensionless)
$F_{11}', F_{12}', F_{13}', F_{21}', F_{22}', F_{23}', F_{31}', F_{32}', F_{33}'$ the intermediate variables (dimensionless)
h solar altitude (°)
h' the intermediate variable, $h' = 0.01h$ (°)
k_d diffuse ratio, $k_d = I_{h,d}/I_h$ (dimensionless)
k_t clearness index, $k_t = I_h/I_{h,0}$ (dimensionless)
I direct normal incidence irradiance (W/m^2)
I_0 normal incidence extraterrestrial radiation (W/m^2)
I_s diffuse radiation from the sky dome (W/m^2)
$I_{h,0}$ extraterrestrial radiation on a horizontal surface (W/m^2)
I_h global solar radiation on a horizontal surface (W/m^2)
$I_{h,d}$ diffuse solar radiation on a horizontal surface (W/m^2)
$I_{h,b}$ beam solar radiation on a horizontal surface (W/m^2)
$I_{h,d1}$ diffuse radiation on a horizontal surface from circumsolar region (W/m^2)
$I_{h,d2}$ diffuse radiation on a horizontal surface from orthogonal region (W/m^2)
$I_{h,d3}$ diffuse radiation on a horizontal surface from the sky horizontal region (W/m^2)
$I_{h,d4}$ diffuse radiation on a horizontal surface from the sky dome (W/m^2)
$I_{h,d4}'$ diffuse radiation on a horizontal surface from hemispherical (W/m^2)
$I_{t,d}$ diffuse radiation on a tilted surface (W/m^2)
$I_{t,d1}$ diffuse radiation on a tilted surface from circumsolar region (W/m^2)
$I_{t,d2}$ diffuse radiation on a tilted surface from orthogonal region (W/m^2)
$I_{t,d3}$ diffuse radiation on a tilted surface from the sky horizontal region (W/m^2)
$I_{t,d4}$ diffuse radiation on a tilted surface from the sky dome (W/m^2)
$I_{t,d4}'$ diffuse radiation on a horizontal surface from hemispherical (W/m^2)
m relative air mass (dimensionless)
m_a is the average value of measured value (W/m^2 in this paper)
m_i is the ith measured value (W/m^2 in this paper)
n is the number of calculated values or measured values (dimensionless)
$u(m_a)$ uncertainty of the test values (W/m^2 in this paper)
$u_a(m_a)$ relative uncertainty of the test values (dimensionless)
α the half angle of the circumsolar region (°)
β tilt angle (°)
γ solar azimuth angle (°)
δ solar declination (°)
φ latitude (°)
ω hour angle (°)
θ the incident angle of the tilted surface (°)
θ_z solar zenith angle (°)
ζ half vertex angle of orthogonal spherical cap (°)
ξ the angular thickness of the horizon band (°)
ε sky clearness parameter, $\varepsilon = (I_{h,d} + I)/I_{h,d}$ (dimensionless)
Δ new sky brightness parameter, $\Delta = I_{h,d} \cdot m/I_0$ (dimensionless)
$\chi_h(\theta_z)$ the fraction of the circumsolar region which is seen by horizontal (dimensionless), $\chi_h(\theta_z) = \begin{cases} \psi_h \cos\theta_z, \ 0 \leqslant \theta_z < \frac{\pi}{2} - \alpha \\ \psi_h \sin(\psi_h\alpha), \ \frac{\pi}{2} - \alpha \leqslant \theta_z \leqslant \frac{\pi}{2} \end{cases}$
ψ_h the fraction of the circumsolar region which is not shadowed (dimensionless), $\psi_h = \begin{cases} 1, 0 \leqslant \theta_z < \frac{\pi}{2} - \alpha \\ \frac{\pi/2 - \theta_z + \alpha}{2\alpha}, \frac{\pi}{2} - \alpha \leqslant \theta_z \leqslant \frac{\pi}{2} \end{cases}$
$\chi_h(\frac{\pi}{2} - \theta_z)$ the fraction of the orthogonal region which is seen by horizontal (dimensionless), $\chi_h(\frac{\pi}{2} - \theta_z) = \begin{cases} \psi_h' \sin(\psi_h'\zeta), 0 \leqslant \theta_z < \zeta \\ \psi_h' \sin\theta_z, \zeta \leqslant \theta_z \leqslant \frac{\pi}{2} \end{cases}$
ψ_h' the fraction of the orthogonal region which is not shadowed (dimensionless), $\psi_h' = \begin{cases} \frac{\theta_z + \zeta}{2\zeta}, \ 0 \leqslant \theta_z < \zeta \\ 1, \ \zeta \leqslant \theta_z \leqslant \frac{\pi}{2} \end{cases}$
$\chi_c(\theta)$ the fraction of the circumsolar region which is seen by tilt (dimensionless), $\chi_c(\theta) = \begin{cases} \psi_h \cos\theta, 0 \leqslant \theta < \frac{\pi}{2} - \alpha \\ \psi_h \frac{\pi/2 - \theta + \alpha}{2\alpha} \sin\left(\frac{\pi/2 - \theta + \alpha}{2}\right), \frac{\pi}{2} - \alpha \leqslant \theta \leqslant \frac{\pi}{2} + \alpha \\ 0, \frac{\pi}{2} + \alpha < \theta \leqslant \pi \end{cases}$
$\chi_c(\frac{\pi}{2} - \theta)$ the fraction of the orthogonal region which is seen by tilt (dimensionless), $\chi_c(\frac{\pi}{2} - \theta) = \begin{cases} \psi_h' \frac{\theta + \zeta}{2\zeta} \sin\left(\frac{\theta + \zeta}{2}\right), 0 \leqslant \theta < \zeta \\ \psi_h' \sin\theta, \zeta \leqslant \theta < \frac{\pi}{2} \\ \psi_h' \sin(\pi - \theta), \frac{\pi}{2} \leqslant \theta < \pi - \zeta \\ \psi_h' \frac{\pi - \theta + \zeta}{2\zeta} \sin\left(\frac{\pi - \theta + \zeta}{2}\right), \pi - \zeta \leqslant \theta \leqslant \pi \end{cases}$