Renewable Energy 34 (2009) 736–741

Contents lists available at ScienceDirect

Renewable Energy

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

Recommendation on modelling of solar energy incident on a building envelope

Dorota A. Chwieduk

Institute of Fundamental Technological Research, Polish Academy of Sciences, Swietokrzyska 21, Warsaw, Poland

ARTICLE INFO

Article history:
Received 15 April 2008
Accepted 20 April 2008
Available online 1 July 2008

Keywords:
Solar energy availability
Isotropic sky model
Anisotropic sky model
Solar irradiation on building envelope

ABSTRACT

It is important to know how to design a building to meet seasonally varying energy needs. In high latitude countries in winter the demand for space heating is high and a building envelope should receive maximum incident solar energy. On the other hand, in summer, walls and roofs exposed to incident solar radiation usually require shading to avoid too much solar gain. Data on solar energy availability are crucial for good building design. However, it is important how the availability of solar radiation is determined. An important aim of the paper presented is to give some results of a comparative analysis of two basic sky models, isotropic: Hottel–Woertz–Liu–Jordan and anisotropic: the HDKR, Hay–Davies–Klucher–Reindl, to recommend one of these models for determination of solar energy availability on a building envelope and to formulate the energy balance of a building. Differences between results obtained from both models increase with the slope of exposed surfaces. The biggest differences (12–15%) are evident for vertical south surfaces, especially in summer. The simplified isotropic sky model is not recommended for evaluation of solar radiation availability on the building envelope. Underestimation of solar gains can lead to the selection of an unsuitable concept and construction of a building and result in poor indoor thermal comfort, i.e. overheating of rooms in summer.

1. Introduction

Climate, together with the location and orientation of a building and end-users' needs, imposes special limits and requirements on the building, its architecture, construction, materials, energy systems and surroundings. What is vital for modern buildings, which are often classified as low energy buildings, is to focus on non-conventional energy utilisation and conversion, especially using renewable energy. In modern low energy buildings, in order to minimise the energy consumption, we try to use the environment to benefit the indoor living comfort. The application of modern technology, equipment, materials and the structure of a building minimises the energy consumption. Taking into account the local conditions any building can be designed to utilise energy sources from its environment, such as solar energy.

Detailed information about the solar energy incident on a building envelope is very important for the best building concept and design. In winter, solar energy input to energy balance of a building can be significant if the building is designed correctly. The solar energy input can significantly reduce space heating requirements. However, when in summer a building is exposed to too much solar radiation, the danger of overheating can occur. Therefore, it is necessary to protect the interior of a building from excessive solar gains in summer, for example through application of appropriate construction materials, shading devices, shape of a building and location of rooms with different functions.

Analyzing solar energy incident on a building envelope we do not usually consider horizontal surfaces. The main components of active systems, i.e. solar collectors, have to be tilted to the horizontal surface. In a building envelope most surfaces of external walls, windows, sun glass spaces, buffer zones, atria, and roofs are vertical or tilted. For active solar systems it is essential to maximise solar gains. However, for the envelope of a building more careful analysis is needed, which allows the designer to balance the need of high heat gains in winter with necessity of protection against too much solar radiation in summer. To perform an analysis of solar energy incident on a building envelope the appropriate solar radiation data are required.

2. Modelling of solar energy incident on non-horizontal surfaces

Many models calculating solar irradiation on an inclined surface of any particular orientation have been developed. Usually the isotropic diffuse sky model, Hottel–Woertz–Liu–Jordan [1,2], is used. According to this model, solar radiation incident on the tilted surface is considered to include three components: beam, isotropic diffuse and diffusely reflected from the ground. Total solar radiation incident for an hour is described by the following Hottel–Woertz–Liu–Jordan equation:

E-mail address: dchwied@ippt.gov.pl

0960-1481/$ – see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.renene.2008.04.005

Nomenclature

A_i	anisotropy index
f	modulating correction factor of diffuse radiation, include influence of cloudiness
G	irradiance (W/m^2)
I	irradiation [Wh/m^2 (J/m^2)]
n	number of a day in a year
R	correction factor to given radiation, ratio of given radiation on a tilted surface to that on a horizontal
T	temperature (K)
t	time (s)
Greek symbols	
β	slope of a surface (deg)
δ	declination (deg)
γ	azimuth angle of a surface (deg)
θ	angle of incident radiation (deg)
ρ	reflectance
φ	latitude (deg)
ω	hourly angle (deg)
Subscripts	
a	ambient
b	beam (radiation)
d	diffuse
g	ground
o	reflected
s/sc	solar/solar constant
z	zenith

$$I(t) = I_b(t)R_b(t) + I_d(t)R_d + (I_b(t) + I_d(t))\rho_o R_o \quad (1)$$

In Eq. (1) the correction factors of diffuse and reflected radiation are equal to view factors to the sky and are given, respectively, by:

$$R_d = \frac{1+\cos(\beta)}{2} \quad (2)$$

$$R_o = \frac{1-\cos(\beta)}{2} \quad (3)$$

The geometric (correction) factor for beam radiation is the ratio of beam radiation (irradiance) on the tilted surface to that on a horizontal surface as is expressed by the following:

$$R_b(t) = \frac{G_{btil}(t)}{G_b(t)} = \frac{I_b(t)\cos(\theta(t))}{I_b(t)\cos(\theta_z(t))} = \frac{\cos(\theta(t))}{\cos(\theta_z(t))} \quad (4)$$

The angle of incidence of solar radiation to the normal of the surface under consideration (in numerator in Eq. (4)), and the zenith angle (in denominator in Eq. (4)), that is the angle of incidence to the normal of a horizontal surface, are calculated taking into account the position of the sun relative to the surface on the earth at any time as is described by appropriate relationships in terms of several angles [3]. The angles under consideration and some other angles describing position of the sun and the surface considered are shown in Fig. 1.

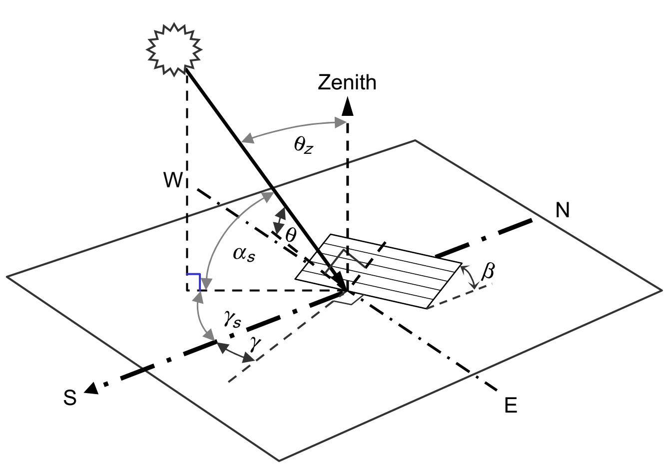

Fig. 1. Geometric relationship between a tilted plane of any orientation relative to the earth and the beam radiation from the sun.

Calculations of solar radiation incident on an inclined surface can be performed using the anisotropic sky model. In this model diffuse radiation is composed of three parts: isotropic, circumsolar diffuse (concentrated in the sky near the sun) and horizon brightening (concentrated in the sky near the horizon). A schematic view of the distribution of all parts of solar radiation on a tilted surface is shown in Fig. 2. There are several anisotropic sky models. The HDKR, Hay–Davies–Klucher–Reindl, model [4] is one of the most popular and is recommended for high latitude countries with dominant share of diffuse part in total radiation [5]. According to the HDKR model the total solar radiation on a tilted surface is as follows:

$$I_s(t) = (I_b(t) + I_d(t)A_i(t))R_b(t) + I_d(t)(1-A_i(t))(R_d) \times \left[1 + f(t)\sin^3\left(\frac{\beta}{2}\right)\right] + (I_b(t) + I_d(t))\rho_g(R_o) \quad (5)$$

The correction factors for isotropic diffuse, reflected and beam radiation have been already described by Eqs. (2)–(4) for isotropic diffuse sky model. New parameters in Eq. (5) are the following:

– the anisotropy index A_i, which is a function of the transmittance of the atmosphere for beam radiation and is expressed as a ratio of beam radiation on a horizontal ground surface to extraterrestrial radiation. The high value of this index enhances the contribution of circumsolar diffuse radiation. The anisotropy index is written as follows:

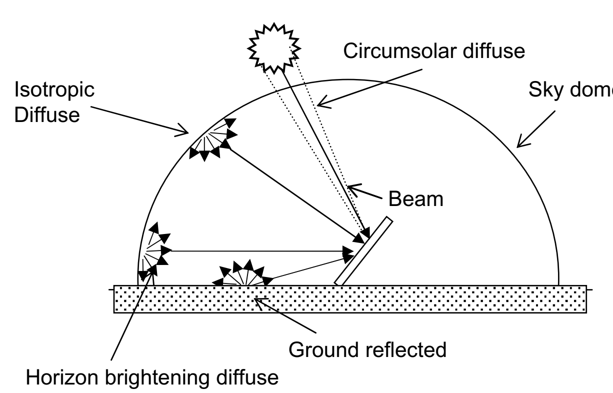

Fig. 2. Schematic view of the distribution of solar radiation on a tilted surface according to anisotropic diffuse sky model.