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Solar energy — Reference solar spectral irradiance at the ground at different receiving conditions —

Part 1: Direct normal and hemispherical solar irradiance for air mass 1,5

Énergie solaire — Rayonnement solaire spectral de référence au sol sous différentes conditions de réception —

Partie 1: Rayonnement solaire direct normal et hémisphérique pour une masse d'air de 1,5

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Contents

Page

Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee 180, *Solar energy*, Subcommittee SC 1, *Climate – Measurement and data*.

This second edition cancels and replaces the first edition (ISO 9845–1:1992), which has been technically revised.

This main changes are as follows:

— the spectral range has been changed to 280 nm to 4 000 nm;

— the spectral resolution has been improved to 2002 wavelengths, the spectra have nonuniform intervals of 0,5 nanometre (nm) between 280 nm and 400 nm, 1 nm between 400 nm and1 700 nm, 2 nm between 1 700 nm and 1 702 nm, 3 nm between 1 702 nm and 1 705 nm, and 5 nm intervals from 1 705 nm to 4 000 nm;

— the SMARTS (*Simple Model of the Atmospheric Radiative Transfer of Sunshine*) version 2.9.2 (for reference spectra) and 2.9.5 (for subordinate spectra) have been used instead of the BRITE Monte Carlo radiative transfer code. The reference spectra are provided in an .xls file available at https://standards.iso.org/iso/9845/-1/ed-2/en/

— 171 subordinate hemispherical spectral irradiances were added, these subordinate hemispherical tilted irradiance spectra for different atmospheric conditions and receiver orientations are provided in an .xls file available at https://standards.iso.org/iso/9845/-1/ed-2/en/

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Absorptance, reflectance and transmittance of terrestrial solar energy are important factors in solar thermal system performance, photovoltaic system performance, materials studies, biomass studies and solar simulation activities. These optical properties are normally functions of wavelength, which requires that the spectral distribution of the solar flux be known before the solar weighted property can be calculated. In order to compare the performance of competitive products, a reference standard solar spectral irradiance distribution is desirable.

This document greatly expands the original ISO 9845–1:1992, which provides 2 reference solar spectral irradiance and 171 subordinate solar spectral irradiances. The reference solar spectral distributions include direct normal spectral irradiance with a 5,8° field of view centered on the sun and hemispherical solar spectral irradiance on an equator-facing, 37° tilted plane. The subordinate solar spectral distributions include nine atmospheric conditions, 19 tilt angles, and a total of 171 hemispherical irradiance spectra.

Further parts of the standard consider recent improvements in the basic data and modelling techniques leading to better accuracy.

Solar energy — Reference solar spectral irradiance at the ground at different receiving conditions —

Part 1: Direct normal and hemispherical solar irradiance for air mass 1,5

1 Scope

This document provides an appropriate reference spectral irradiance distribution to be used in determining relative performance of solar thermal, photovoltaic, and other systems, components and materials where the direct or hemispherical irradiance component is desired.

This document provides one reference hemispherical irradiance spectrum, one reference direct normal irradiance spectrum and 171 subordinate hemispherical tilted irradiance spectra. The reference spectral irradiance presented in this document defines an air mass 1,5 solar spectral irradiance, for use in solar applications where a reference spectral irradiance is required, for the direct normal radiation 5,8° field-of-view angle and hemispherical radiation on an equator-facing, 37° tilted plane for albedo corresponding to a light sandy soil. The reference spectral irradiance are intended to represent ideal clear sky conditions.

The reference spectra and the subordinate spectral irradiances representing different sky conditions are provided in .xls files available at https://standards.iso.org/iso/9845/-1/ed-2/en/

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
air mass
AM
measure of the length of the path through the atmosphere to sea level traversed by light rays from a celestial body, expressed with reference to the path length along the vertical

3.2
direct solar irradiance
G_b
quotient of the radiant flux on a given plane receiver surface received from a small solid angle centred on the sun's disk to the area of that surface, when the plane is perpendicular to the axis of the solid angle

[SOURCE: ISO 9488:2022, 3.2.28, modified — "when the plane is perpendicular to the axis of the solid angle" was added.]

3.3
hemispherical solar irradiance
G_{hem}
quotient of the radiant flux on a given plane receiver surface received from a solid angle of 2π sr to the area of that surface

Note 1 to entry: The tilt angle and the azimuth of the surface should be specified, e.g. horizontal.

Note 2 to entry: Hemispherical irradiance is expressed in watts per square metre ($W \cdot m^{-2}$).

Note 3 to entry: Examples for hemispherical irradiance are global irradiance and the irradiance received in the plane of solar collector [Plane of Array (POA) irradiance], also called "global tilted irradiance".

[SOURCE: ISO 9488:2022, 3.2.29]

3.4
spectral solar irradiance
E_λ
solar irradiance per unit wavelength interval at a given wavelength

Note 1 to entry: Spectral solar irradiance is expressed in watts per square metre per nanometre ($W \cdot m^{-2} \cdot nm^{-1}$).

[SOURCE: ISO 9488:2022, 3.2.32, modified — The unit "µm" was changed to "nm".]

4 Application of the spectral data for deriving effective solar irradiances and spectrum weighted quantities

4.1 Spectrally modified total solar irradiance

If R_λ is the wavelength-dependent property of a device (such as responsivity, transmittance, reflectance, absorptance) and E_λ represents the solar spectral irradiance, then G_s, the effective total solar irradiance weighted with the spectral property of this device, can be calculated as an integral of the product of E_λ and R_λ as given by Formula (1)

$$G_s = \int_{280\,\text{nm}}^{4\,000\,\text{nm}} R_\lambda E_\lambda \mathrm{d}\lambda \quad (1)$$

4.2 Solar spectrum weighted property

The mean value R_s of the property R_λ, which is effective if the total solar spectrum is applied, can in general be calculated by the following Formula (2):

$$R_S = \frac{\int_{280\ \text{nm}}^{4\,000\ \text{nm}} R_\lambda E_\lambda \mathrm{d}\lambda}{\int_{280\ \text{nm}}^{4\,000\ \text{nm}} E_\lambda \mathrm{d}\lambda} \tag{2}$$

Since the spectral property and the spectral irradiance are usually known as discrete values, the integration shall be performed as summations so that Formulae (1) and (2) become, respectively, Formulae (3) and (4):

$$G_s = \sum_{i=1}^{N} R_{\lambda_i} E_{\lambda_i} \Delta\lambda_i \tag{3}$$

and

$$R_S = \frac{G_s}{\sum_{i=1}^{N} E_{\lambda_i} \Delta\lambda_i} \tag{4}$$

Where λ_i is the wavelength of the i^{th} point out of N for which the spectral data are known. The values represent the practical limits of the summation.

4.3 Integrated irradiance

The integrated irradiance values $G(0 \rightarrow \lambda_i)$, were computed using a modified trapezoidal integration technique. More specifically as given in Formula (5):

$$G(0 \rightarrow \lambda_i) = G(0 \rightarrow \lambda_1) + \sum_{j=1}^{i-1} \frac{E_{\lambda_j} + E_{\lambda_{j+1}}}{2} \Delta\lambda_j \tag{5}$$

where $\Delta\lambda_j = \lambda_{j+1} - \lambda_j$

$G(0 \rightarrow \lambda_1)$ is the contribution before the first tabulated wavelength. This is estimated as half of the first trapezoidal area interval as per Formula (6):

$$G(0 \rightarrow \lambda_1) = \frac{1}{2}\left(\frac{E_{\lambda_2} + E_{\lambda_1}}{2}\right)(\lambda_2 - \lambda_1) \tag{6}$$

Similarly, $G(\lambda_N \rightarrow \infty)$ the total irradiance beyond the last tabulated wavelength λ_N, is estimated as per Formula (7):

$$G(\lambda_N \rightarrow \infty) = \frac{1}{2}\left(\frac{G_{\lambda_N} + G_{\lambda_{N-1}}}{2}\right)(\lambda_N - \lambda_{N-1}) \tag{7}$$

Leading to an expression for the solar irradiance as given by Formula (8):

$$G(0 \rightarrow \infty) = G(0 \rightarrow \lambda_N) + G(\lambda_N \rightarrow \infty) \tag{8}$$

5 Validation of accuracy

The values of direct normal irradiance presented here refer to a 5,8° field-of-view corresponding roughly to the field of view of a normal incidence pyrheliometer, which allows a small amount of circumsolar (diffuse) radiation to be detected. For the type of atmospheric conditions modelled here, this circumsolar radiation adds parts per thousand to the measured direct irradiance. SMARTS simulations for clear-sky conditions with various loads of rural aerosols, composed of small aerosol particles, have shown that, for relatively low solar zenith angle, the relative proportion of the circumsolar irradiance in the measured DNI is less than 1 % for opening half-angles ranging from 2,5° to 2,9° (The current recommendation of the World Meteorological Organization for this half-angle is 2,5°).

In the spectral region of interest (280 nm to 4 000 nm) the SMARTS computer code has been adequately verified with experimental data. SMARTS model performance has been assessed in multiple comparisons with reference spectroradiometric data, with very good agreement over a variety of sun geometries and atmospheric conditions. Comparisons of SMARTS 2.9.2 and MODTRAN4 differ at most by 5 % in the ultraviolet region. Almost all of the differences in the results of computer codes can be traced to differences in the molecular absorption coefficients used as input to the codes.

Single aberrant values (caused by e.g. unsuitable shading methods) shall not be considered for the tables in this document.

6 Reference solar spectral irradiance

6.1 SMARTS model code

The reference solar spectral irradiance data are generated by the SMARTS(version 2.9.2)[1)] atmospheric transmission code. The reference spectral irradiance data are calculated for the conditions specified in Table A.1.

SMARTS is a spectral model and Fortran code to predict the direct beam, diffuse, and hemispherical irradiance incident on surfaces of any geometry at the Earth's surface. Besides the regular irradiance predictions needed for many possible applications, it can be used to simulate the spectral or broadband irradiance that would be measured by a radiometer, such as a spectroradiometer, a pyranometer, or a pyrheliometer. SMARTS users can specify conditions from any of standard atmospheres or their own data. Users can also specify output for one or many points in time or solar geometries.

6.2 Spectral table

6.2.1 The reference solar spectral distributions are given in https://standards.iso.org/iso/9845/-1/ed-2/en/. These are:

— direct normal spectral irradiance with a 5,8° field of view centered on the sun;

— and hemispherical solar spectral irradiance on a plane tilted at 37° toward the sun.

Figure B.1 is a plot of the direct normal and hemispherical spectral irradiance.

6.2.2 Direct normal irradiance in the wavelength ranges from 280 nm to 4 000 nm.

6.2.3 Hemispherical solar spectral irradiance incident on a sun-facing plane tilted to 37° from the horizontal in the wavelength ranges from 280 nm to 4 000 nm.

6.2.4 Data in the table relate to the air mass of 1,5. The direct normal irradiance contains a circumsolar component for a 5,8° field of view centered on the sun.

6.3 Columns in each table

6.3.1 Columns 1: wavelength λ_i in nanometre (nm).

1) At the time of publication of this document the SMARTS Version 2.9.2 and 2.9.5 spectral model code is available, free of charge, subject to the author's license agreement, at https://www.nrel.gov/rredc/smarts.
A copy of the model, not for distribution purposes, is kept under IEC TC 82 control.

