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Solar energy — Specification and classification of instruments for measuring hemispherical solar and direct solar radiation

Énergie solaire — Spécification et classification des instruments de mesurage du rayonnement solaire hémisphérique et direct

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Foreword

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This second edition cancels and replaces the first edition (ISO 9060:1990), which has been technically revised. The main changes compared to the previous edition are as follows:

— in addition to thermopile radiometers, other technology options have been included such as photoelectric sensors as long as they fulfil the requirements specified in this document;

— the spectral error is used to characterize the spectral responsivity;

— to further characterize the radiometers, the additional properties “spectrally flat” and “fast response” can be added to the classification if the radiometers fulfil specific criteria;

— more intuitive names have been introduced for the classes: “A”, “B”, “C”.

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.

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Introduction

This document is one of a series of standards that specify methods and instruments for the measurement of solar radiation in support to solar energy utilization.

Accurate solar radiation data are used in meteorology and are needed for developing solar energy appliances, in particular for performance testing, solar radiation simulation and resource assessment.

The measurement of radiation is needed for determination of the conversion efficiencies of solar appliances. The specification and classification of these instruments are needed in order to enable the comparison of solar radiation data on a worldwide basis. In addition, this classification is intended to assist end users/consumers and entities requiring and tendering radiometers with the choice or comparison of instruments, to protect end users/consumers and to offer a level playing field for manufacturers.

The specification and classification of solar radiometers specified in this document provides an accuracy ranking and focuses on application specific requirements and qualities. However, solar radiometers are used in a wide range of applications with often conflicting requirements. The best radiometer for one application may be inadequate for a different application. In order to address this issue at least partly, a sensor of a given class can be assigned the additional properties “fast response” and/or “spectrally flat” to further characterize the radiometers.

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Solar energy — Specification and classification of instruments for measuring hemispherical solar and direct solar radiation

1 Scope

This document establishes a classification and specification of instruments for the measurement of hemispherical solar and direct solar radiation integrated over the spectral range from approximately 0,3 µm to about 3 µm to 4 µm.

Instruments for the measurement of hemispherical solar radiation and direct solar radiation are classified according to the results obtained from indoor or outdoor performance tests. This document does not specify the test procedures.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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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:

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

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

3.1
hemispherical solar radiation
solar radiation received by a plane surface from a solid angle of 2π sr

Note 1 to entry: Approximately 97 % to 99 % of the hemispherical solar radiation incident at the Earth's surface is contained within the wavelength range from 0,3 µm to 3 µm[1]. Generally, hemispherical solar radiation is composed of direct solar radiation and diffuse solar radiation (solar radiation scattered in the atmosphere) as well as solar radiation reflected by the ground.

3.2
global horizontal irradiance
hemispherical solar radiation received by a horizontal plane surface

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

3.3
direct solar radiation
radiation received from a small solid angle centred on the sun's disc, on a given plane

Note 1 to entry: In general, direct solar radiation is measured by instruments with field-of-view angles of up to 6°. Therefore a part of the scattered radiation around the sun's disc (circumsolar radiation or aureole) is also included (see 5.1). Historic pyrheliometers of the Angström type (compensation pyrheliometer) have a larger field of view of up to 15°. A more detailed definition of circumsolar radiation and related parameters can be found in Reference [2].

Note 2 to entry: Approximately 97 % to 99 % of the direct solar radiation received at the ground is contained within the wavelength range from 0 µm to 3 µm[1].

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Note 3 to entry: The tilt angle of the receiver surface should be specified, e.g. horizontal or normal to the direct solar radiation.

3.4
diffuse solar radiation
diffuse radiation
hemispherical solar radiation minus coplanar direct solar radiation

Note 1 to entry: For the purposes of solar energy technology, diffuse radiation includes solar radiation scattered in the atmosphere as well as solar radiation reflected by the ground, depending on the inclination of the receiver surface.

Note 2 to entry: The tilt angle and the azimuth of the receiver surface should be specified, e.g. horizontal.

3.5
pyranometer
radiometer designed for measuring the irradiance on a plane receiver surface which results from the radiant fluxes incident from the hemisphere above within the wavelength range from approximately 0,3 µm to about 3 µm to 4 µm

Note 1 to entry: The spectral range (50 % transmittance points) given is only nominal. Depending on the radiometer design, the spectral limits of its responsivity can be different from the limits mentioned above.

3.6
pyrheliometer
radiometer designed for measuring the irradiance which results from the solar radiant flux from a well-defined solid angle the axis of which is perpendicular to the plane receiver surface

Note 1 to entry: It follows from this definition that pyrheliometers are used to measure direct solar radiation at normal incidence. Typical opening half angles of common and historical pyrheliometers range from 2,5° to 7,5°. Reference [3] recommends that the opening half-angle is 2,5° ($6\ 10^{-3}$ sr) and the slope angle 1° for all new designs of direct solar radiation instruments. The opening half-angle is measured from the centre of the (circular) receiver aperture to the edge of the view-limiting aperture. The slope angle is the opening half-angle of the cone defined by both apertures. For mathematical definitions of the angles, see 5.1 b). A more detailed description of the influence of circumsolar radiation on the pyrheliometers can be found in Reference [2].

Note 2 to entry: The spectral responsivity of field pyrheliometers is often limited to the range of approximately 0,3 µm to 3 µm, depending on the radiometer properties. The spectral range (50 % points) given is only nominal. Depending on the radiometer design, the spectral limits of its responsivity can be different from the limits mentioned above.

3.7
diffusometer
radiometer designed for measuring the diffuse solar radiation, consisting of a pyranometer and a shading structure which can be a shading ball, a shading disk, a shading ring, a rotating shadowband or a shading mask

Note 1 to entry: Shading balls and disks shall be tracked to the sun, so that the pyranometer is shaded. Shading disks and their tracking are defined in ISO 9846[4]. The centre of a shading ball is tracked to the same point as the centre of a shading disk. The diameter of the ball corresponds to the diameter of the disk. The shaded opening angle and slope angle of shading balls and -disks for the sun in the zenith shall be 2,5° and 1°.

Note 2 to entry: Shading rings are positioned such that the pyranometer is shaded for all solar positions occurring throughout approximately two days. Shading rings shall be adjusted approximately every two days. Shading rings therefore prevent not only the direct radiation, but also a part of the diffuse radiation from reaching the pyranometer and only an approximation of the diffuse radiation can be measured.

Note 3 to entry: A rotating shadowband is rotated around the pyranometer so that this pyranometer is shaded for some time during the rotation. The pyranometer measures an approximation of the diffuse radiation when the shadowband shades the sensor. The pyranometer measures the hemispherical radiation when the shadowband is below the pyranometer's field-of-view. When the shadowband's shadow is close to the sensor, but not on the sensor the hemispherical radiation except of the blocked diffuse radiation is measured. With these three measurements so-called rotating shadowband irradiometers determine the diffuse radiation.

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Note 4 to entry: Shading masks throw a shadow on one or various pyranometers depending on the solar position.

3.8
offset correction
value added algebraically to the uncorrected result of a measurement to compensate for systematic error

Note 1 to entry: The offset correction is equal to the negative of the estimated systematic error.

Note 2 to entry: Since the systematic error cannot be known perfectly, the compensation cannot be complete.

3.9
correction factor
numerical factor by which the uncorrected result of a measurement is multiplied to compensate for systematic error

Note 1 to entry: Since the systematic error cannot be known perfectly, the compensation cannot be complete.

[SOURCE: ISO/IEC Guide 98-3:2008, B.2.24]

3.10
acceptance interval
interval of permissible measured quantity values

[SOURCE: BIPM, 2012[6], 3.3.9]

3.11
tolerance interval
interval of permissible values of a property

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[SOURCE: BIPM, 2012[6], 3.3.5]

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3.12
guard band
interval between a tolerance limit and a corresponding acceptance limit

[SOURCE: BIPM, 2012[6], 3.3.11]

3.13
accuracy class
class of measuring instruments or measuring systems that meet stated metrological requirements that are intended to keep measurement errors or instrumental uncertainties within specified limits under specified operating conditions

[SOURCE: ISO/IEC Guide 99:2007, 4.25, modified — Notes have been deleted.]

4 Instruments to measure hemispherical solar radiation — Pyranometers

4.1 General physical design

Pyranometers are radiometers used to measure hemispherical solar radiation (see 3.1, 3.2, 3.4, 3.5 and 3.7).

Thermal sensors transform radiant energy into thermal energy with a consequent rise in the temperature of the receiving surface. This rise in temperature is balanced by various kinds of heat losses to thermal sinks (e.g. the body of the pyranometer and ambient air).

The thermal sensor of a pyranometer is protected from wind, rain and dust as well as the exchange of thermal radiation by one or two transparent domes and/or a diffusor whose spectral transmittance confines the spectral range of responsivity to the interval between approximately 0,3 µm and 3 µm (50 % transmittance points).

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Photodiode pyranometers use photodiodes as sensors that convert the incoming radiation in electrical energy. The photodiodes are often placed below a diffusor.

Because of the spectral limits of the measurement, thermal sensors have an advantage compared to photodiode sensors as they can achieve a nearly uniform spectral responsivity required for low spectral errors. The spectral irradiance error is the error introduced by the change in the spectral distribution of the incident solar radiation and the difference between the spectral responsivity of the radiometer with respect to a radiometer with completely homogeneous spectral responsivity in the wavelength range of interest.

Other technologies exist that are not mentioned in this document.

The main parts of common pyranometers are:

a) the sensor;

b) the transparent dome(s) or diffusor, which cover(s) concentrically the receiving surface; and

c) the body, which is often shielded by a sun-screen, and used as a thermal reference.

4.2 Types

One type of pyranometer is the "thermoelectric" pyranometer which is equipped with a thermopile (sometimes called a thermobattery) measuring the difference in temperature between the receiving surface (active junctions) and the body (passive junctions). The position and number of the active and passive junctions vary depending on the different pyranometer models. Generally, these sensors are covered by one or two concentric glass dome(s) or a diffusor.

Another type of pyranometer is the "photoelectric" pyranometer which is equipped with a photoelectric receiver (using e.g. silicon photodiode or photovoltaic cell) measuring photovoltaic power. This type of pyranometer is usually called "Si-pyranometer". Often these sensors are placed below a diffusor. The diffusor can have the shape of a cylinder or other shapes.

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4.3 Classification

4.3.1 General

The classification of pyranometers is based exclusively on the measuring specifications of the instruments. The classification is not based upon manufacturing technologies but rather on criteria deduced from the various applications of pyranometers. Following this principle, any technical device which produces a signal when irradiated (e.g. a photovoltaic cell) could be classified as a pyranometer according to this document.

Most of the classification criteria (see Table 1) are of general relevance, whereas others may be important only for specific applications.

Therefore statements about the overall measurement uncertainty can only be made on an individual basis, taking all relevant factors into account.

The classification scheme is based on various specifications, as given in 4.3.2 and various classification criteria, as given in 4.3.3.

The classification can be understood as an accuracy ranking. The letters indicate the typically reached accuracy for well-maintained measurements when compared under the same measurement conditions. The accuracy decreases in alphabetic order (A reaches a better accuracy than B or C). However, the accuracy ranking does not mean that a radiometer of higher accuracy class is more accurate than another radiometer of lower class under all conditions. First of all, as different radiometers can have different maintenance requirements and e.g. susceptibility to soiling, the term "well-maintained" is important in the previous statement. Furthermore, depending on the application and the measurement conditions, a sensor of a lower class can be more appropriate in some cases. For example, radiometers

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have different response times. In order to be able to identify radiometers that are adequate for the measurement of highly variable data (e.g. overirradiance events), additional classes are defined by adding the term “fast response” before the name of the class (e.g. fast response pyranometer of class A; see also 4.3.3). Furthermore, comparing fast response sensors to slower sensors is more complex. A fast response sensor of the same class has a higher accuracy for high temporal resolution than a slower sensor of the same class if the response time is the only difference between the sensors and if the sampling rate of the datalogger is adequate to the response time. For a high variability of the irradiance, a fast response radiometer of a given class might even be more appropriate than a slower sensor of a higher class.

Spectral errors can be an issue depending on the site’s meteorological conditions if the radiometer has a significant spectral selectivity. The spectral selectivity is the percentage deviation of the spectral responsivity from the corresponding mean within the range 0,35 µm and 1,5 µm[12]. A low spectral selectivity is also desirable for the measurement of reflected irradiance and albedo. Therefore, further additional classes are defined by adding the term “spectrally flat radiometer” before the name of the class.

NOTE 1 The accuracy of measured solar radiation data depends not only on the instrument characteristics used for the classification of the instrument but also on:

a) the calibration procedure;

b) the measurement conditions and maintenance including cleaning;

c) the environmental conditions; and

d) data logger uncertainty and setting (e.g. sampling rate) if the instrument provides an analogue signal.

NOTE 2 The most accurate determination of global irradiance under stable conditions is believed to be that derived from the direct irradiance as measured by a highest-class pyrheliometer and the diffuse solar irradiance as measured by a highest-class pyranometer shaded from the sun by a disc or a ball.

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4.3.2 Pyranometer specifications

Pyranometer specifications are given as the acceptance intervals and guard bands for certain parameters. The specifications can be grouped as follows.

a) The response time (a measure of the stabilization period for an accurate reading under realistic irradiance changes).

b) The zero off-set including zero offsets of electronics (a measure of the stability of the zero-point specified for the effect of thermal radiation, for a temperature transient and other influences).

c) The dependence of responsivity on:

   1) ageing effects (a measure of the long-term stability, assuming regular and proper maintenance including cleaning of the pyranometer);

   2) the level of irradiance (a measure of the nonlinearity);

   3) the direction of the irradiance (a measure of the deviations from the ideal “cosine behaviour” and its azimuthal variation);

   4) the clear sky spectral error for the most relevant irradiance component (a measure of the deviation of the spectral responsivity of the radiometer from a completely flat spectral responsivity);

   5) the temperature of the radiometer body;

   6) the tilt angle of the receiving surface; and

   7) additional signal processing errors (The additional signal processing errors contain data acquisition and analogue to digital conversion that might be carried out in the instrument and