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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

Reference number
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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Fax: +41 22 749 09 47
Email: copyright@iso.org
Website: www.iso.org

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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 ISO/TC 180, *Solar energy*, Subcommittee SC 1, *Climate — Measurement and data*.

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.

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.

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

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 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].

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.

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

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

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).

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.

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 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.

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

all other processing steps carried out within the instrument that are not covered by the criteria a, b and c1 to c6.).

NOTE 1 The spectral selectivity used in ISO 9060:1990[1)] is not the spectral error. The spectral selectivity was defined as the maximum percentage deviation of the spectral responsivity within 0,35 µm and 1,5 µm from the mean spectral responsivity within 0,35 µm and 1,5 µm. For some sensors such as photodiode sensors the spectral responsivity can be 0 for some wavelengths in the defined wavelength range. Hence, the spectral selectivity can reach 100 % and more. Also some sensors with specific diffusors might have higher spectral selectivities or errors. The knowledge of the spectral range alone is not sufficient to determine the spectral selectivity or the spectral error. The specification of the spectral range also requires the specification of a percentage of the maximum spectral responsivity at which the wavelength limits are given (e.g. 50 %).

NOTE 2 Diffusometers are also included in this document. Diffusometers are partially classified by Table 1, as the used pyranometer can be classified according to Table 1. The remaining part of diffusometers is only described in this document by its type (shading disk, shading ball, shading ring, rotating shadowband or shading mask).

Table 1 — Pyranometer classification list

Specification parameter No. (see 4.3.2)	Parameter	Name of the classes, acceptance intervals and width of the guard bands (in brackets)		
	Name of the class	**A**	**B**	**C**
	Roughly corresponding class from ISO 9060:1990[1)]	*Secondary standard*	*First class*	*Second class*
a	Response time (see also 4.3.3 on fast response pyranometers): time for 95 % response	< 10 s (1 s)	< 20 s (1 s)	< 30 s (1 s)
b	Zero off-set:			
	a) response to −200 $W{\cdot}m^{-2}$ net thermal radiation	±7 $W{\cdot}m^{-2}$ (2 Wm^{-2})	±15 $W{\cdot}m^{-2}$ (2 Wm^{-2})	±30 $W{\cdot}m^{-2}$ (3 Wm^{-2})
	b) response to 5 $K{\cdot}h^{-1}$ change in ambient temperature	±2 $W{\cdot}m^{-2}$ (0,5 Wm^{-2})	±4 $W{\cdot}m^{-2}$ (0,5 Wm^{-2})	±8 $W{\cdot}m^{-2}$ (1 Wm^{-2})
	c) total zero off-set including the effects a), b) and other sources	±10 $W{\cdot}m^{-2}$ (2 $W{\cdot}m^{-2}$)	±21 $W{\cdot}m^{-2}$ (2 $W{\cdot}m^{-2}$)	±41 $W{\cdot}m^{-2}$ (3 $W{\cdot}m^{-2}$)
c1	Non-stability: percentage change in responsivity per year	±0,8 % (0,25 %)	±1,5 % (0,25 %)	±3 % (0,5 %)
c2	Nonlinearity: percentage deviation from the responsivity at 500 $W{\cdot}m^{-2}$ due to the change in irradiance within 100 $W{\cdot}m^{-2}$ to 1 000 $W{\cdot}m^{-2}$	±0,5 % (0,2 %)	±1 % (0,2 %)	±3 % (0,5 %)
c3	Directional response (for beam radiation): the range of errors caused by assuming that the normal incidence responsivity is valid for all directions when measuring from any direction (with an incidence angle of up to 90° or even from below the sensor) a beam radiation whose normal incidence irradiance is 1 000 $W{\cdot}m^{-2}$	±10 $W{\cdot}m^{-2}$ (4 $W{\cdot}m^{-2}$)	±20 $W{\cdot}m^{-2}$ (5 $W{\cdot}m^{-2}$)	±30 $W{\cdot}m^{-2}$ (7 $W{\cdot}m^{-2}$)
NOTE The acceptance intervals should not be used for uncertainty estimations for conditions different from the ones stated for each criterion. In particular the spectral error can be different under different conditions. The spectral error for diffuse horizontal irradiance measurements is also different from that for global horizontal irradiance.				

1) Now withdrawn.

Table 1 *(continued)*

Specification parameter No. (see 4.3.2)	Parameter	Name of the classes, acceptance intervals and width of the guard bands (in brackets)		
	Name of the class	**A**	**B**	**C**
	Roughly corresponding class from ISO 9060:1990[1)]	*Secondary standard*	*First class*	*Second class*
c4	Clear sky global horizontal irradiance spectral error: maximum spectral error observed for a set of global horizontal irradiance clear sky spectra defined in this document (see A.7 related to the calculation of the spectral error; see 4.3.3 on spectrally flat pyranometers)	±0,5 % (0,1 %)	±1 % (0,5 %)	±5 % (1 %)
c5	Temperature response: percentage deviation due to change in ambient temperature within the interval from −10 °C to 40 °C relative to the signal at 20 °C	±1 % (0,2 %)	±2 % (0,2 %)	±4 % (0,5 %)
c6	Tilt response: percentage deviation from the responsivity at 0° tilt (horizontal) due to change in tilt from 0° to 180° at 1 000 $W \cdot m^{-2}$ irradiance	±0,5 % (0,2 %)	±2 % (0,5 %)	±5 % (0,5 %)
c7	Additional signal processing errors	±2 $W \cdot m^{-2}$ (2 $W \cdot m^{-2}$)	±5 $W \cdot m^{-2}$ (2 $W \cdot m^{-2}$)	±10 $W \cdot m^{-2}$ (2 $W \cdot m^{-2}$)
NOTE The acceptance intervals should not be used for uncertainty estimations for conditions different from the ones stated for each criterion. In particular the spectral error can be different under different conditions. The spectral error for diffuse horizontal irradiance measurements is also different from that for global horizontal irradiance.				

4.3.3 Classification criteria

For the classification, the specifications given in Table 1 shall be verified by tests. Additional information on the specification items is given in Annex A. Table 1 roughly includes the three classes: moderate, good and high quality from Reference [3].

A specification is fulfilled if:

a) the value of the respective test result lies in the corresponding acceptance interval given in Table 1 for the specific class of instrument; and if

b) the sum of the absolute amounts of the expanded uncertainty of the test and the test result is less or equal to the absolute amount of the limit of the tolerance interval (guarded acceptance) — the tolerance interval is determined by the acceptance interval and the guard bands from Table 1.

The acceptance interval is given in Table 1 by "<*X*" with a single positive value *X* for one-sided acceptance intervals or as "±*X*" if the interval is two-sided and symmetrical around zero.

A pyranometer belongs to a specific class if all specifications (see Table 1) of the respective class are unambiguously met and if the classification is in conformity with the criteria given in 4.3.3 and 4.3.4.

The classification does not provide all required information for an accuracy calculation: a pyranometer might fulfil all criteria of class A, except one criterion that is irrelevant under the typical measurement conditions (e.g. tilt response in case of global horizontal measurements) for which only the class C is reached. In this case this class C pyranometer would typically be better than many class B pyranometers, if they are used for global horizontal irradiance measurements. The application of the instrument does not affect the classification (even if the instrument is only used for global horizontal irradiance measurements its classification still depends on all specifications from Table 1 including the tilt response).

This document also distinguishes between a pyranometer of a given class Y (e.g. class A pyranometer) and another category of pyranometers, the so-called "fast response pyranometer of class Y" (e.g. fast response pyranometer of class A). A pyranometer is a "fast response pyranometer of class Y" if it fulfils all requirements from the column in Table 1 for class Y pyranometers, and if the pyranometer also has a response time of < 0,5 s with 0,05 s guard bands. The possible benefits of fast response also require an adequate, high sampling rate.

Further additional classes are defined by adding the term "spectrally flat radiometer" before the name of the class. This is allowed if the pyranometer has a spectral selectivity of less than 3 % (guard bands 2 %) in the 0,35 µm to 1,5 µm spectral range.

The classification of pyranometers may be applied to individual instruments or to groups (particular types) of instruments, depending on the category. A pyranometer type (pyranometers of identical design) may be claimed to be of a particular class even without individual tests depending on the class if the appropriate quality control has shown that pyranometers of this type comply with the respective specifications.

For the classification of a pyranometer in the highest class, individual tests of temperature response and directional response are required.

The design of pyranometers of any class should allow to align the pyranometer tilt angle with an appropriate accuracy, for example by providing accurately mounted bubble levels or reference surfaces of the instrument body.

NOTE The classification is based on the pyranometer's final signal. This might refer to the result after the application of offset corrections or correction factors for systematic errors. The signal after the application of the corrections or correction factors can only be used for the classification if the correction is applied within the instrument or as part of the supplied measuring system (e.g. programmed to a processor within the instrument or the control unit). An example for such a correction could be a correction for the spectral error based on the air mass or other parameters. Also hardware enhancements are considered for the classification. If an instrument is always used e.g. with heating and ventilation, the classification is based on the signal with heating and ventilation (see also A.2). If the same instrument is used without the additional hardware the classification can be different.

4.3.4 Identification of classification

The classification of a particular pyranometer shall be specified by a written statement provided by the issuing laboratory. The issuing test laboratory shall disclose the testing procedures and results upon request. If a classification is not reached without additional hardware (e.g. ventilation) this shall be stated next to the specified class. In addition, if the user needs to take a specific action to activate the correction and if only the corrected signal fulfils the class, this shall be stated next to the specified class.

5 Instruments to measure direct solar radiation—Pyrheliometers

5.1 General physical design

The main parts of common pyrheliometers are as follows.

a) The sensor, the plane receiving surface in which the radiation is converted to a signal (for example, a dark surface on a thermopile, a photodiode sensor or a cavity to absorb the incoming radiation).

b) The view-limiting device (tube, collimator or diaphragm tube, also called a sky-occluding tube), which defines the field-of-view geometry. The length l of the tube, the radius r_a of the aperture and the radius r_r of the receiving surface determine the opening half-angle $\arctan(r_a/l)$ and the slope angle $\arctan[(r_a - r_r)/l]$.

Such pyrheliometers need an adjustable mount, which directs the pyrheliometer to the sun or permits it to be adjusted to do so. The adjustable mount can be an integral part by design of the instrument or a separate device to allow individual combination with an appropriate sun-following system.

Because the sun's disc has a radius of ~0,267° as seen from the Earth, a larger amount of the aureole, depending on the content of atmospheric aerosol, is included in the measurements of direct solar radiation (see 3.3).

The receiving surface of pyrheliometers used for continuous field measurements is protected against dirt, insects, wind and other weather phenomena by a window and/or other protective devices.

5.2 Types

5.2.1 Absolute pyrheliometer

An absolute pyrheliometer is principally a realization of the scale of irradiance.

It is necessary to subject such an instrument to a close examination of its properties by means of laboratory measurements and model calculations to determine its deviation from ideal behaviour. This procedure is called the "characterization" of the instrument and yields a reduction factor which is used to transform the output signals to irradiances. The uncertainty in this factor determines the absolute accuracy of the instrument.

Absolute pyrheliometers of modern design use black-body receivers and electrically calibrated differential heat-flux meters as sensors. They are operated in either "active" or "passive" mode. In the active mode the heat flux is maintained constant during both the shaded and the irradiated phase; the difference in electrical power during both phases is proportional to the radiative power. In the passive mode the electrical heating is maintained only during the shaded phase. In practice, when the pyrheliometer is in the active mode the radiation measurements will be interrupted periodically during the shaded phases of the measuring series, while in the passive mode the shaded phase occurs before the measuring series.

5.2.2 Compensation pyrheliometer

Pyrheliometers which include electrical substitution of the incident radiative power but are not characterized as described in 5.2.1 need to be calibrated.

The Angström compensation pyrheliometer, for example, is equipped with two adjacent receivers, in one tube, which function alternately; one receiver is irradiated by the sun while the other is simultaneously shaded and electrically heated. This means that during the shading phase of one receiver, the measured radiation value of the other can be obtained.

5.2.3 Pyrheliometers without self-calibration capability

These pyrheliometers need to be calibrated to give irradiance in W·m^{-2}. They allow continuous recording of radiation and are used as field instruments. They are typically provided with a weather-proof enclosure.

5.3 Classification

5.3.1 General

Pyrheliometers are classified on the basis of the measuring specifications of the instruments. However, the classification is not based upon manufacturing technologies but rather on criteria deduced from the various applications of pyrheliometers.

The classification can be understood as an accuracy ranking in the same way as for pyranometers. The letters indicate the typically reached accuracy for well-maintained measurements when compared under the same measurement conditions. The accuracy decreases with in alphabetic order (A reaches a better accuracy than B or C). An even higher accuracy than that of class A is indicated by multiple letters “A” (e.g. AA). However, the accuracy ranking does not mean that a radiometer of higher class is more accurate than another radiometer of lower class under all conditions, as explained in 4.3.1. As in the case of pyranometers, fast response pyrheliometers are defined using the same acceptance interval and guard band (see also 4.3.3). Spectrally flat pyrheliometers are also defined.

Note 1 to 4.3.2 which provides some information on the relation of the formerly used spectral selectivity with the spectral error also applies for pyrheliometers.

NOTE The accuracy of solar radiation data measured by pyrheliometers depends not only on the class of the instrument but also on the maintenance and the environmental conditions as explained in more detail in Note 1 on 4.3.1. Therefore, statements on the overall measurement uncertainty can only be made on an individual basis, taking into account all relevant factors and not only the class of the instrument.

5.3.2 Pyrheliometer specifications

Pyrheliometer specifications are given in Table 2. The specification parameters are nearly the same as those used for pyranometers (see 4.3.2). The “directional response” is excluded. Other deviations from the pyranometer specifications are found in the definition of the zero-offset and the angle interval for the tilt response. The clear sky spectral error is calculated using direct normal irradiance spectra. The definitions of the specifications used for the classification are identical in Table 2.

5.3.3 Classification criteria

The specifications given in Table 2 shall be verified by tests. Additional information on the specification items is given in Annex A. Table 2 roughly includes the two classes good and high quality from Reference [3].

A pyrheliometer belongs to a specific class if all specifications (see Table 2) of the respective class are unambiguously met.

A specification is fulfilled if:

a) the value of the respective test results for a group of instruments of the same model lies in the corresponding acceptance interval given in Table 2 for the specific class of instrument; and if

b) the sum of the absolute amounts of the expanded uncertainty of the test and the test result is less or equal to the absolute amount of the limit of the tolerance interval (guarded acceptance) — the tolerance interval is determined by the acceptance interval and the guard bands from Table 2.

The classification of pyrheliometers may be applied to individual instruments or to groups (particular types) of instruments, depending on the category. A pyrheliometer type (pyrheliometers of identical design) may be claimed to be of a particular class even without individual tests depending on the class if the appropriate quality control has shown that pyrheliometers of this type comply with the respective specifications. However, a highest-class instrument may only be designated as such on an individual basis. For the classification of a pyrheliometer in the second highest class, individual tests of temperature response are required.

NOTE The traceability is not used for the classification.

This document distinguishes between pyrheliometers of a given class Y (e.g. a pyrheliometer of class A) and another category of pyrheliometers, the so-called “fast response pyrheliometers” of the same class (e.g. a fast response pyrheliometer of class A). A pyrheliometer is a “fast response pyrheliometer of class Y” if it fulfils all requirements from the column in Table 2. for class Y, and if the pyrheliometer also has a response time of < 0,5 s with 0,05 s guard bands.

Same as for pyranometers, further additional classes for pyrheliometers are defined by adding the term “spectrally flat radiometer” before the name of the class. This is allowed if the pyrheliometer has a spectral selectivity of less than 3 % (guard bands 2 %) in the 0,35 µm to 1,5 µm spectral range.

Note to 4.3.3 on the use of corrections or correction factors and optional hardware enhancements as heating and ventilation also applies for pyrheliometers.

5.3.4 Identification of classification

The classification of a particular pyrheliometer shall be specified by a written statement provided by the issuing laboratory. The issuing test laboratory shall disclose the testing procedures and results upon request. If a classification is not reached without additional hardware (e.g. heating) this shall be stated next to the specified class. In addition, if the user needs to take a specific action to activate the correction and if only the corrected signal fulfils the class this shall be stated next to the specified class.

Table 2 — Pyrheliometer classification list

Specification parameter No. (see 4.3.2)	**Parameter**	**Name of the classes, acceptance intervals and width of the guard bands (in brackets)**			
	Name of the class	**AA**	**A**	**B**	**C**
	Roughly corresponding class from ISO 9060:1990[1)]	*See NOTE 1*	*Secondary Standard*	*First class*	*Second class*
a	Response time (see also 5.3.3 related to fast response radiometers): for 95 % response	See NOTE 2	< 10 s (1 s)	< 15 s (1 s)	< 20 s (1 s)
b	Zero off-set: a) response to 5 K·h^{-1} change in ambient temperature	±0,1 W·m^{-2} (0,05 W·m^{-2})	±1 W·m^{-2} (0,5 W·m^{-2})	±3 W·m^{-2} (0,5 W·m^{-2})	±6 W·m^{-2} (1 W·m^{-2})
	b) complete zero off-set including the effect a) and other sources	±0,2 W·m^{-2} (0,05 W·m^{-2})	±2 W·m^{-2} (0,5 W·m^{-2})	±4 W·m^{-2} (0,5 W·m^{-2})	±7 W·m^{-2} (1 W·m^{-2})
c1	Non-stability: percentage change in responsivity per year	±0,01 % (0,01 %)	±0,5 % (0,25 %)	±1 % (0,25 %)	±2 % (0,25 %)
c2	Nonlinearity: percentage deviation from the responsivity at 500 W·m^{-2} due to the change in irradiance within 100 W·m^{-2} to 1 000 W·m^{-2}	±0,01 % (0,01 %)	±0,2 % (0,1 %)	±0,5 % (0,2 %)	±2 % (0,2 %)

NOTE 1 There was no similar class defined in ISO 9060:1990[1)].

NOTE 2 Pyrheliometers of this class are mainly used as reference instruments for the calibration of other pyrheliometers. They are often absolute pyrheliometers, for which an unambiguous definition of response time is not possible. For instance, it depends on the mode of operation (e.g. “active” or “passive”). To avoid confusion and because the response time is of marginal significance for calibrations under stable sky conditions, the response time criteria is omitted for this class.

NOTE 3 The acceptance intervals should not be used for uncertainty estimations for conditions different from the ones stated for each criterion. In particular, the spectral error can be different under different conditions.

Table 2 *(continued)*

Specification parameter No. (see 4.3.2)	Parameter	Name of the classes, acceptance intervals and width of the guard bands (in brackets)			
	Name of the class	**AA**	**A**	**B**	**C**
	Roughly corresponding class from ISO 9060:1990[1)]	*See NOTE 1*	*Secondary Standard*	*First class*	*Second class*
c4	Clear sky direct normal irradiance spectral error: maximum spectral error observed for a set of direct normal irradiance clear sky spectra defined in this document (see A.7 related to the calculation of the spectral error; see 5.3.3 related to spectrally flat radiometers)	±0,01 % (0,005 %)	±0,2 % (0,05 %)	±1 % (0,5 %)	±2 % (1 %)
c5	Temperature response: percentage deviation due to change in ambient temperature within the interval from −10 °C to 40 °C relative to the signal at 20 °C	±0,01 % (0,01 %)	±0,5 % (0,25 %)	±1 % (0,5 %)	±5 % (0,5 %)
c6	Tilt response: percentage deviation from the responsivity at 0° tilt (horizontal) due to change in tilt from 0° to 90° at 1 000 W·m^{-2} irradiance	±0,01 % (0,1 %)	±0,2 % (0,2 %)	±0,5 % (0,2 %)	±2 % (0,5 %)
c7	Additional signal processing errors	±0,1 W·m^{-2} (0,1 W·m^{-2})	±1 W·m^{-2} (0,5 W·m^{-2})	±5 W·m^{-2} (2 W·m^{-2})	±10 W·m^{-2} (2 W·m^{-2})

NOTE 1 There was no similar class defined in ISO 9060:1990[1)].

NOTE 2 Pyrheliometers of this class are mainly used as reference instruments for the calibration of other pyrheliometers. They are often absolute pyrheliometers, for which an unambiguous definition of response time is not possible. For instance, it depends on the mode of operation (e.g. "active" or "passive"). To avoid confusion and because the response time is of marginal significance for calibrations under stable sky conditions, the response time criteria is omitted for this class.

NOTE 3 The acceptance intervals should not be used for uncertainty estimations for conditions different from the ones stated for each criterion. In particular, the spectral error can be different under different conditions.

6 Final remarks

In addition to the classification criteria specified in document, attention should be paid to the following points to ensure that instruments achieve adequate accuracy in solar radiation measurement:

a) proper calibration;

b) proper alignment;

c) regular maintenance including cleaning;

d) frequent timely quality control;

e) the use of recording devices with sufficient sensitivity, sampling rate and stability.

Shortcomings in the adjustment and maintenance can introduce errors that are much higher than the difference between typical errors found for correctly used radiometers from different instrument classes.

Annex A
(informative)

Comments on the specifications given in Tables 1 to 2

NOTE These comments are intended to highlight the reasoning for the choice of test parameters rather than to describe the details of the test methods.

A.1 Response time

Owing to the fact that in general the thermal balancing process of thermoelectric pyranometers can only be described by several time constants, the settling behaviour should be characterized by the time during which the instrument reaches 95 % of the reference value. The response time must be measured from the point where the input light level is changed in order to capture any latency introduced by the processing and communications. However, it should be emphasized that for accurate measurement of the irradiance of rapidly changing radiation sources, even the time taken for 99,5 % of the value should be considered. Care should be taken when the response time is determined after the application of software corrections as such corrections might only work for a specific shape of the signal change.

A.2 Zero off-set

The effects a) and b) for specification parameter No. “b” in Table 1 and Table 2 are only two common effects producing zero off-set. Therefore, the total zero off-set (“c”) is also used in this document. The case of rapid changes in body temperature, possibly affected by cold rain showers, is excluded.

Zero-offset specifications should be stated at wind speeds < 1 m/s. The specification may be improved using ventilators. It is possible that an instrument in its standard configuration does not comply with requirements of a class. It shall then be specified as non-complying. The same instrument may comply when ventilated. Only the combination may then claim compliance. In case heating is used, this may again result in non-compliance with requirements of a class. If this is the case, this shall also be clearly stated. Concluding, instrument compliance with requirements of a class should be clearly defined for the instrument, and separately as a function of ventilation and heating, including specification of the type/ model of accessory used to attain compliance.

For instance, the specified net thermal radiant flux density of $-200\ W{\cdot}m^{-2}$ is realized when, at a body temperature of 30 °C, the sky temperature is −10 °C.

The specified change in body temperature per hour may occur during the morning of a fine day.

A.3 Non-stability

Generally, the reproducibility in testing the responsivity of the radiometer is already within ± 0,5 %. Low stability of the radiometer responsivity can be compensated for by more frequent recalibrations in accordance with the level of tolerable uncertainty.

A.4 Nonlinearity

It is important that the nonlinearity is specified for the total range of useful irradiances (approximately $100\ W{\cdot}m^{-2}$ to $1\ 000\ W{\cdot}m^{-2}$).

