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Solar energy — Calibration of field pyranometers by comparison to a reference pyranometer

Énergie solaire — Étalonnage des pyranomètres de terrain par comparaison à un pyranomètre de référence

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Contents

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Foreword

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Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 9847 was prepared by Technical Committee ISO/TC 180, *Solar energy*, Sub-Committee SC 1, *Climate -- Measurement and data*.

Annexes A, B, C, D and E of this International Standard are for information only.

Introduction

Accurate and precise measurements of the irradiance of the global (hemispherical) solar radiation are required in

a) the determination of the energy available to flat-plate solar collectors,

b) the assessment of irradiance and radiant exposure in the testing of solar and non-solar-related materials technologies, and

c) the assessment of the direct versus diffuse solar components for energy budget analysis, geographic mapping of solar energy, and as an aid in the determination of the concentration of aerosol and particulate pollution and the effects of water vapour.

Although meteorological and resource assessment measurements generally require pyranometers oriented with their axis vertical, applications associated with flat-plate collectors and the study of the solar exposure of related materials require calibrations of instruments tilted at a predetermined non-vertical orientation. Calibrations at fixed tilt angles have applications which seek state-of-the-art accuracy, requiring corrections for cosine, tilt and azimuth.

Solar energy — Calibration of field pyranometers by comparison to a reference pyranometer

1 Scope

1.1 This International Standard specifies two preferred methods for the calibration of field pyranometers using reference pyranometers.

1.2 One method, the outdoor calibration or type I, employs solar radiation as the source, while the other method, the indoor calibration or type II, employs an artificial radiation source.

1.2.1 The outdoor calibration of field pyranometers may be performed with the pyranometer in a horizontal position (i.e. zero tilt) (type Ia), in a tilted position (type Ib), or at normal incidence (type Ic) maintaining the receiver surface perpendicular to the sun's beam component.

1.2.2 The indoor calibration of field pyranometers may be performed using an integrating sphere with shaded (type IIa) or unshaded (type IIb) lamp(s), or at normal incidence (type IIc) frequently using an optical bench to present the receiver surface perpendicular to the beam of the lamp.

Types IIa and IIb correspond to an outdoor calibration under conditions of overcast and sunny sky with large light cloud fields, respectively. Type IIc is comparable with the normal incidence calibration of type Ic.

1.3 The methods of calibration specified are traceable to the world radiometric reference (WRR); traceability to the International Pyrheliometric Scale of 1956 is not permitted.

1.4 This International Standard is applicable to most types of field pyranometers regardless of the type of radiation receptor employed. In general, all pyranometers used for long-term monitoring of incident solar irradiance may be calibrated by using the described methods, provided that the reference pyranometer has been calibrated at essentially the same tilt from horizontal as the tilt employed in the calibration.

NOTE 1 Pyranometers used for collector tests should be calibrated using a reference pyrheliometer (see ISO 9846).

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 9060:1990, *Solar energy — Specification and classification of instruments for measuring hemispherical solar and direct solar radiation.*

ISO 9846:—[1], *Solar energy — Calibration of a pyranometer using a reference pyrheliometer.*

3 Definitions

For the purposes of this International Standard, the following definitions apply.

3.1 altazimuth mount: A tracking mount capable of rotation about orthogonal altitude and azimuth axes; tracking may be manual or by a follow-the-sun servomechanism. (See also ISO 9846.)

3.2 global (solar) irradiance: Hemispherical solar irradiance received by a horizontal plane surface. (See also ISO 9060.)

1) To be published.

3.3 integrating sphere [hemisphere]: A sphere [hemisphere], generally from 1 m to 4 m in diameter, provided with a planar segment (usually a horizontal bottom segment) on which to mount pyranometers (to be compared with an artificial light source), the sphere wall of which is coated with a flat, white paint that is as lambertian as possible to provide uniform illumination.

3.4 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 0,3 µm to 3 µm. (See also ISO 9060.)

3.5 field pyranometer: Pyranometer usually meeting second class[2)] specifications or first class specifications, designed for field use and (typically) continuous exposure.

3.6 reference pyranometer: Well-maintained pyranometer, selected for its stability and quality, used exclusively to calibrate other instruments.

3.7 test pyranometer: Pyranometer being calibrated, regardless of its classification or its photoreceptor type.

3.8 tilt angle: Angle between the vertical and the pyranometer axis (which is equal to the angle between the horizontal plane and the plane of the detector surface).

3.9 calibration factor: Multiplicator, used to derive the global solar irradiance from the measured output (voltage). The units are those of the reciprocal value of the responsivity (e.g. watts per square metre per microvolt).

4 Apparatus

4.1 Digital electronic readout device

Any digital microvoltmeter having an accuracy of better than ± 0,1 % may be employed. Data loggers with print-out shall be capable of a measurement frequency of at least two per minute. A data logger having at least a three-channel capacity may be useful.

4.2 Reference pyranometer

The reference pyranometer shall be specially selected, tested and maintained as follows.

4.2.1 For outdoor calibration (type I)

The reference pyranometer for outdoor calibration (type I) should be typically of a higher class (in accordance with the classification given in ISO 9060) than the test pyranometer, and should exhibit a particularly high long-term stability. The dependence of its responsivity on temperature, irradiance, tilt and angles of incidence shall be determined.[3)] Within 12 months prior to its use for calibrating field pyranometers, the reference pyranometer should itself be recalibrated outdoors by comparison to a pyrheliometer (see ISO 9846). This recalibration should be carried out under conditions typical of those in which the field pyranometer and reference pyranometer will be used. The calibration history of the reference pyranometer should be well documented.

If the measuring conditions during calibration deviate strongly from those during the typical use of the field pyranometer (by more than ± 5 °C and ± 15° azimuth angle), a reference pyranometer of the same type that has been calibrated under similar conditions should be used.

4.2.2 For indoor calibration (type II)

The reference pyranometer for indoor calibration (type II) shall be of the same type as the test pyranometer (to avoid errors that may be caused by the artificial radiation employed; these errors may arise mainly from imperfect homogeneity of the source beam or from an imperfect match to the solar spectrum). In addition, the pyranometer shall meet the requirements specified in 4.2.1.

4.3 Integrating sphere or hemisphere

For type IIa or IIb calibration (see 5.3.1), an integrating sphere or hemisphere (see 3.3) is required. Suitable apparatus are described in annex A for information.

4.4 Precision calibration table

A precision calibration table is required for all horizontal and fixed-angle tilt calibrations. It shall be level at 0° tilt (i.e. horizontal) and shall be able to be tilted over a suitable range of angles from the horizontal with an uncertainty of less than 0,3°.

NOTE 2 The deviation between the tilt angle of the reference pyranometer and that of the field pyranometer should be not more than 0,1° which means that the tilt of the pyranometers has to be finely adjusted. If the calibration tables are mechanically and thermally stable it is necessary to check the tilt only after periods longer than a week.

2) For the classification of pyranometers, see ISO 9060.

3) Test methods to determine the dependence of the responsivity of a pyranometer on temperature, irradiance, tilt and angle of incidence will form the subject of a future International Standard.

4.5 Sun-tracking mount

The mount, whether power driven or manually operated, shall be capable of maintaining the reference pyranometer and all test pyranometers normal to the sun for the entire test period. The tracking precision shall be such that for all data-taking periods, deviations from the exact normal to the sun do not exceed

a) ± 4° where the reference and test pyranometers are mounted on separate trackers;

b) ± 10° where the reference and test pyranometers are mounted on the same tracker.

NOTE 3 An altazimuth mount is preferred for pyranometers with a responsivity dependent on the altazimuth angle of the tilted receiver. The requirements for tracking a pyranometer at normal incidence are less stringent than those for tracking a pyrheliometer. For example, the cosine of 4° is 0,997 6, and only an insignificant uncertainty in normal incident calibration will result from a deviation of this magnitude.

5 Calibration procedure

5.1 General considerations

A number of possible interferences and precautions relating directly to the methods specified in this International Standard are given for information in annex B.

Particular care shall be taken to correct for zero off-sets. The off-set of signals of the reference and test pyranometers shall be checked, as a minimum, at the start and the end of a measurement series.

5.2 Outdoor calibration (type I)

5.2.1 General (types Ia, Ib and Ic)

5.2.1.1 Mount the reference pyranometer and the test pyranometer outdoors on a common calibration table for horizontal calibration (type Ia) and calibration at tilt (type Ib) and on an altazimuth or sun-pointing mount for normal-incidence calibration (type Ic). Adjust both instruments to a common elevation facing the equator. Ensure that the azimuth reference marks point in a common direction.

NOTE 4 Convention is to use the electrical connector as the azimuth reference and to point it towards the equator and downwards.

5.2.1.2 Adjust the calibration table to the required tilt (which may be 0°) from the horizontal.

5.2.1.3 Connect the reference and test pyranometers to their respective, or common, digital voltmeter, using proper shielding. Check the instruments for electrical continuity, signal polarity, signal strength and stability. Clean the domes of the pyranometers (see [13]). Check that the radiant fluxes of the foreground on both instruments are equal at the relevant tilt angle by transposing the positions of the pyranometers.

5.2.2 Horizontal calibration for meteorological and resource measurements (type Ia)

5.2.2.1 Stable cloudless sky conditions

For stable cloudless sky conditions, simultaneously take instantaneous voltage readings on both instruments for a minimum of fifteen 10 min to 20 min measurement series, each consisting of 21 or more instantaneous readings. Take these measurement series over a 2 day to 3 day period, or over a longer period to cover a larger range of environmental conditions. Obtain data from early morning, through and including solar noon, to late afternoon to ensure that data are taken during the period that the solar elevation angle exceeds 20°.

5.2.2.2 Unstable sky conditions with some cloud

For unstable sky conditions, with clouds at a distance from the sun of greater than 30° (see B.2), simultaneously take instantaneous voltage readings on both instruments continuously at from 1 min to 5 min intervals from sunrise to sunset for a minimum of 5 days (and for as long as 2 weeks). The length of time should be chosen such that a minimum of fifteen series of 21 or more measurements are obtained that represent steady radiation spanning a period from forenoon to afternoon (with sun elevation angle ⩾ 20°).

Alternatively, take a minimum of fifteen measurement series integrated over 1 min to 5 min intervals in such a manner that data are spread over the period from forenoon to afternoon, including solar noon.

5.2.2.3 Cloudy sky conditions

For cloudy sky conditions take simultaneous readings integrated over more than fifty 1 h intervals on both instruments. Take this hourly data for a minimum of 10 days at different solar elevation angles, and different types of cloudiness if the hourly mean of global irradiance is greater than 100 $W \cdot m^{-2}$.

5.2.3 Calibration at tilt (type Ib)

Calibration at tilt shall be carried out only under clear sky conditions with clouds at a distance from the sun of greater than 30°. Use as the tilt from horizontal, that tilt which will be employed in testing solar collectors. Care should be taken that the albedo from the ground is approximately the same at both receivers.

Take data in accordance with 5.2.2.1.

5.2.4 Calibration at normal incidence (type Ic)

Take a minimum of fifteen 10 min to 20 min measurement series consisting of 21 or more instantaneous voltage readings centred around solar noon. Ensure that all data are taken while the hemispherical normal-incident solar irradiance exceeds 600 $W \cdot m^{-2}$.

NOTE 5 For determining the ratio of the directional response (see ISO 9060:1990, table 1) of the reference pyranometer to that of the test pyranometer, a special procedure which operates the mount in an azimuth tracking mode is given in annex D for information.

5.2.5 Mathematical treatment

Apply the general mathematical treatment described in 5.4.1.

5.3 Indoor calibration (type II)

5.3.1 Integrating sphere calibration (with pyranometer horizontal: type IIa and with pyranometer tilted: type IIb)

5.3.1.1 Mount the reference and test pyranometers on the common instrument support in the integrating sphere. Ensure that the reference and test pyranometers have exactly the same orientation and that their relationships to the source (if type IIb) and to the hemisphere are geometrically symmetrical.

5.3.1.2 Connect the reference and test pyranometers to their respective, or common, digital voltmeter, using proper shielding. Check the instruments for electrical continuity, signal polarity, signal strength and stability. If necessary, clean the domes of the pyranometers. About 30 min before the first reading, energize the lamp (or lamps) to the power level required.

5.3.1.3 Check that the loci of both instruments receive the same irradiance by transposing the positions of the pyranometers.

5.3.1.4 Either

a) simultaneously take ten series of 21 point instantaneous voltage readings of the reference and test pyranometers, or

b) take simultaneous integrated voltage readings of the reference and test pyranometers over a minimum of five periods of sufficient length (about 8 min) to ensure an accuracy of 0,25 % and a precision of ± 0,25 %.

5.3.1.5 Measure the temperature of the pyranometer bodies and of the wall of the integrating sphere.

5.3.1.6 Apply the general mathematical treatment described in 5.4.1.

5.3.2 Direct beam calibration (type IIc)

5.3.2.1 Check that the reference and test pyranometers are of the same type.

5.3.2.2 Mount the reference and test pyranometer horizontally on a movable support which allows an exchange of the position of the instruments (see A.3). Adjust the position of the instruments and the spirit level. Ensure that the reference and test pyranometers have the same azimuthal orientation. Optical tools should be installed above the receivers of the pyranometers in order to create the vertical beams' homogeneity and divergence.

5.3.2.3 About 30 min or more before the first reading, switch on the data acquisition electronics and energize the lamp to stabilize the radiant flux of the lamp and the field of thermal radiation around the bench.

Connect the reference and test pyranometers to their respective, or common, digital voltmeter, using proper shielding. Check the instruments for electrical continuity, signal polarity, signal strength and stability. If necessary, clean the domes of the pyranometers.

5.3.2.4 Take periodic readings of both pyranometers (which are alternately shaded and unshaded). Follow for example the time tables of readings given in A.3 for the two different methods in use. The number of readings to be taken depends on the stability of the interim results.

5.3.2.5 If the pyranometer mount can be tilted, repeat the reading procedure used in 5.3.2.4 at the desired tilt (tilt angle β), which corresponds to an angle of incidence of β.

5.3.2.6 Apply the special mathematical treatment described in 5.4.3.

5.4 Mathematical treatment

5.4.1 Determination of the calibration factor (general treatment)

The following general treatment is applicable to all types of calibration except type IIc, for which the special treatment given in 5.4.3 applies.

5.4.1.1 First step

This step applies to instantaneous readings.

From each reading i within a measurement series j, calculate the ratio

$$F(ij) = \frac{V_R(ij)}{V_F(ij)} F_R \qquad \ldots (1)$$

where

$V_R(ij)$ and $V_F(ij)$ are the voltages (for example in millivolts) measured using the reference and the field pyranometers respectively, with the corresponding zero value subtracted;

F_R is the calibration factor, watts per square metre per microvolt, of the reference pyranometer, which has been adjusted for the typical field conditions, in the case where the field and reference pyranometers are of the same type and have the type-inherent measurement specification (for instance in the temperature response).

Where F_R as defined above is not applicable, it is replaced, for each measurement series, by a value of $F_R(j)$ which is fitted to the calibration conditions (for instance, mean temperature) and which gives the most accurate value of irradiance $E(ij)$ according to the formula

$$F_R(j) V_R(ij) = E(ij)$$

5.4.1.2 Second step

Determine the series of calibration factors of the field pyranometer from n readings of a measurement series j using the formula

$$F(j) = \frac{F_R \sum_{i=1}^{n} V_R(ij)}{\sum_{i=1}^{n} V_F(ij)}$$

or

$$F(j) = \frac{F_R [V_R(j)]_{int}}{[V_F(j)]_{int}} \qquad \ldots (2)$$

where $[V(j)]_{int}$ are integrated values (types IIa and IIb).

5.4.1.3 Data rejection

Reject any data which have been subject to operational problems for both pyranometers. Also, reject those data for which $F(ij)$ [see equation (1)] deviates by more than ± 2 % from $F(j)$ [see equation (2)]. Repeat the calculation of $F(j)$ on the basis of the "clean" data. Compute the final calibration factor in accordance with equation (4) or (5) from the "clean" $F(j)$ data.

5.4.1.4 Statistical analysis

Determine the stability of the calibration conditions during a measurement series by calculating the standard deviation $F(ij)$ about their mean for set values. (The standard deviations of $F(j)$ around its mean value represent the stability of the conditions during the entire calibration.)

5.4.1.5 Determination of the temperature-corrected final calibration factor

If during a measurement series j the temperature T deviates markedly (i.e. by more than $\pm$ 10 °C) from the desired typical value T_N, and if the temperature response of the field pyranometer is known to deviate markedly from that of the reference pyranometer, then calculate the final temperature-corrected calibration factor F_{corr} at T_N as follows. Correct the $F(j)$ data using the formula

$$F_{corr}(j, T_N) = F(j) \frac{R_T[T(j)]}{R_T(T_N)} \qquad \ldots (3)$$

and calculate F_{corr} as

$$F_{corr} = \frac{1}{m} \sum_{j=1}^{m} F_{corr}(j, T_N) \qquad \ldots (4)$$

where

$T(j)$ is the mean air temperature during the measuring series j, in degrees Celsius;

$R_T[T(j)]$ and $R_T(T_N)$ are the responsivities of the field pyranometer at $T(j)$ and T_N respectively, where $R = 1/F$.

NOTE 6 For some types of pyranometer, temperature coefficients α of the responsivity are specified; in this case the relation $R[T(j)] = \{1 + \alpha [T(j) - T_N]\} R(T_N)$ is applicable.

5.4.1.6 Determination of the final calibration factor without temperature correction of data

In cases where it is not necessary or not possible to correct the data relative to the temperature response, derive the final calibration factor of the field pyranometer from the total number m of measurement series from the formula

$$F = \frac{1}{m} \sum_{j=1}^{m} F(j) \qquad \ldots (5)$$

5.4.2 Selection of calibration factors for special values of solar angles

In the case where

a) for special meteorological and resource assessment purposes the calibration factor calculated by an averaging process using equation (4) is not accurate enough (since within a larger range of calibration parameters special values of solar elevation angles have to be considered for the end-use application of the field pyranometer),

b) the directional response (or cosine error, see ISO 9060:1990, table 1) of the field pyranometer is not yet known, or

c) the directional response of the reference pyranometer is well-known and is used to introduce cosine-error-corrected reference data in equation (2),

carry out the following mathematical treatment.

Plot all $F(j)$ values as a function of the corresponding mean solar elevation γ (for horizontal or fixed-tilt instruments respectively) using the formula

$$\sin\gamma = \sin\phi \, \sin\delta + \cos\phi \, \cos\delta \, \cos\omega$$

where

ϕ is the geographical latitude of the point of observation;

δ is the solar declination;

ω is the solar hour angle, in degrees (i.e. the angle between the hour circle of the sun and the meridian at the time of observation), which can be calculated from the True Solar Time (TST) from $\omega = (\text{TST} - 720)/4$, where TST is in minutes.

Plot also a best-fit regression curve of the data. Read the calibration factor from the regression curve at the representative solar elevation angle.

NOTES

7 An outdoor method to determine approximately the ratio of directional response of the field pyranometer to that of the reference pyranometer is described in annex D. Recommended laboratory test procedures will form the subject of a future International Standard. With a given directional response function $f(\gamma, \psi)$ the calibration factor can be extrapolated to solar angles γ_0, ψ_0 (see ISO 9846:—, annex B) outside the measured range of angles by using the formula

$$F(\gamma_0, \psi_0) = F(j) \frac{f[\gamma(j), \psi(j)]}{f(\gamma_0, \psi_0)}$$

8 If global or hemispherical solar irradiation is determined for daily sums, the use of a daily average solar elevation is recommended. An expedient means for computation of the daily average solar angle is given in annex C for information.

5.4.3 Special treatment for type IIc calibration

a) Simultaneous readings (see A.3.1)

Calculate the measured values V from the readings taken using the following formulae:

$$V_R = V_{R,u} - V_{R,s}$$

$$V_T = V_{T,u} - V_{T,s}$$

$$V'_R = V'_{R,u} - V'_{R,s}$$

$$V'_T = V'_{T,u} - V'_{T,s}$$

Check whether the condition

$$(1 - k) < \frac{V_R V'_T}{V'_R V_T} < (1 + k)$$

is fulfilled for $k \leqslant 0{,}005$, where k is a factor:

$$0 < k < 0{,}005$$

If the condition is fulfilled, calculate the responsivity of the test pyranometer from

$$R_T = \frac{V_T + V'_T}{V_R + V'_R} R_R$$

b) Alternate readings (see A.3.2)

Calculate the measured values V from the readings taken at time t (in minutes) for the reference pyranometer using

$$V_R(t) = V_{R,u}(t) - 0{,}5[V_{R,s}(t-2) + V_{R,s}(t+2)]$$

and for the test pyranometer using

$$V_T(t) = V_{T,u}(t) - 0{,}5[V_{T,s}(t-2) + V_{T,s}(t+2)]$$

Check whether the means

$$\overline{V}_{R,1} = 0{,}5[V_R(4) + V_R(8)]$$

and

$$\overline{V}_{R,2} = 0{,}5[V_R(28) - V_R(32)]$$

deviate by more than $\pm 0{,}5$ %, and whether the three $V_T(t)$ values deviate by more than $\pm 0{,}5$ % from their mean $\overline{V}_T$.

If the deviation is less than or equal to $\pm 0{,}5$ % in both cases, calculate the responsivity of the test pyranometer R_T using the formula

$$R_T = \frac{\overline{V}_T}{0{,}5(\overline{V}_{R,1} + \overline{V}_{R,2})} R_R$$

6 Certificate of calibration

The certificate of calibration shall as a minimum state the following information on

a) the test pyranometer:

— manufacturer, type and serial number;

— position (i.e. inclination angles, azimuthal orientation and tracking);

— special remarks on the state of the pyranometer;

b) the reference pyranometer:

— manufacturer, type and serial number;

— hierarchy of traceability;

— corrections applied;

c) the procedure:

— type of procedure (i.e. reference to this International Standard);

— site (i.e. latitude, longitude and altitude);

— date and time of calibration;

— number of measurement series and single readings;

— ranges of measuring parameters (i.e. solar elevation angle, hemispherical solar irradiance, turbidity and temperature);

d) the result of the calibration:

— responsivity (for instance in microvolts per watt per square metre) or calibration factor (for instance in watt square metres per millivolt);

— standard deviation;

— absolute uncertainty (total uncertainty);

— range of validity (parameters: solar elevation angle, temperature, etc.).

7 Precision and accuracy

7.1 The precision of the outdoor determination of the calibration factor of a field pyranometer is particularly dependent on sky conditions and solar elevation when performing measurements at low angles. Repeatability within any 21 point or more set of values of the same test scan performed at or near solar noon under stable irradiance conditions should be such that the standard deviation is less than ± 0,5 % of the calibration value of the instrument. If this requirement cannot be met, indoor calibration should be considered.

7.2 The accuracy of the calibration factor has to be derived on a case by case basis, taking into account

a) the quality of the reference instrument and the field instrument, and

b) the measurement conditions,

and also bearing in mind the intended use of the instrument.

Annex A
(informative)

Calibration devices using artificial sources

A.1 General

Suitable apparatus that have been used in different laboratories to calibrate pyranometers indoors are described in A.2 and A.3.

A.2 Integrating sphere devices

A.2.1 US Weather Bureau device

The US Weather Bureau (see [1]) has used a 15 ft integrating sphere. The source is a 5 000 W tungsten lamp mounted at the centre of the sphere. The reference and test pyranometers are clustered at the bottom of the sphere where the irradiance is 60 mW/cm^2. Air cooling maintains the test instruments at 29 °C. As described in [1], there is no baffle between the source and the pyranometers. Hence, the irradiation of the pyranometers is very non-uniform, comprising a strong direct beam on the instrument axes with much weaker diffuse radiation incident over the entire hemispherical field of view.

A.2.2 Canadian NARC device (type IIa)

The Meteorological Service of Canada (see [2] and [3]) maintains a 6 ft integrating sphere. The source is three 660 W quartz-iodine lamps mounted on a plate near the centre of the sphere. Reference [2] suggests that the lamps and instruments are mounted in the lower hemisphere and on opposite sides of a baffle. (It should be noted that figure 1 in [2] is printed upside down.) The sphere is air cooled and the results are temperature corrected to 27 °C.

A.2.3 Eppley Laboratory device (type IIa)

The Eppley Laboratory (see [4]) maintains an 8 ft integrating hemisphere. The source comprises twelve 200 W and twelve 300 W tungsten lamps disposed near the rim of the hemisphere. The total power is about 5,5 kVA, and the irradiance at the instruments is 60 mW/cm^2 to 70 mW/cm^2. The sphere wall and instrument locations are temperature controlled: the latter are maintained at 27 °C.

The instruments are baffled from the light sources; hence the irradiance is totally diffuse.

A.2.4 UK Meteorological Office National Radiation Centre device (type IIa)

The UK Meteorological Office maintains a 2 m integrating "sector sphere" (see [5]). The source comprises six 600 W tungsten-halogen lamps disposed beneath the rim of the sectors. Three pyranometers can be exposed in the centre of the sphere to a diffuse irradiance of about 50 mW/cm^2. The pyranometers are temperature controlled at 22 °C by air conditioners. To average out local inhomogeneities of the irradiance, the pyranometers can be rotated through 360° within 10 min, during which 60 readings are taken and stored.

A.3 Direct beam apparatus (type IIc)

A.3.1 Kipp & Zonen device and procedure

The Kipp & Zonen calibration device and reading procedure are described in [6]. The directed vertical beam (divergence, 3,5°) is produced by the combination of

a) a 1 000 W tungsten-halogen filament (Osram type SPL 1 000 Studio, fed by an a.c. voltage stabilizer, and cooled by ventilation) with diffuse reflector (concave mirror with a diameter of 7,5 cm) above the lamp (Osram type Halogen Superphot), and

b) diaphragms (to minimize stray light).

The reference and test pyranometers are mounted horizontally on a table which can rotate to exchange the position of both instruments. The distance between the reflector and pyranometers is 1,2 m, and the irradiance at the pyranometers is approximately 500 W/m^2.

The procedure is based on a sequence of simultaneous readings as shown in table A.1.

Table A.1 — Procedure for use with Kipp & Zonen device

Reading time after start [7] s	Reference pyranometer		Test pyranometer		Remarks
	unshaded	shaded	unshaded	shaded	
90	$V_{R,u}$	—	$V_{T,u}$	—	Pyranometers in initial position
180	—	$V_{R,s}$	—	$V_{T,s}$	
270	$V'_{R,u}$	—	$V'_{T,u}$	—	Pyranometers transposed
360	—	$V'_{R,s}$	—	$V'_{T,s}$	

The reading procedure shall be repeated if the ratio

$$\frac{(V_{R,u} - V_{R,s})(V_{T,u} - V_{T,s})}{(V'_{R,u} - V'_{R,s})(V'_{T,u} - V'_{T,s})}$$

deviates more than $\pm k$ % from unity, where k may decrease to 0,5 or lower values representing higher stability.

The pyranometers should be ventilated, especially if the reference pyranometer is used continuously.

A.3.2 MetObs Hamburg device and procedure

The directed vertical beam (divergence, ± 1,5°) is produced by a combination of

a) a 450 W xenon lamp (Osram type X B0) with condensor optics and air cooling, stabilized by feedback of the lamp output (monitoring of a split beam by a silicon photovoltaic cell),

b) an optical integrating device (to homogenize the radiant flux density of the beam), and

c) a flat mirror tilted to 45° (to turn the beam from horizontal to vertical).

The reference and test pyranometers (of the same type) are mounted horizontally side by side on a rolling and tiltable platform which can be shifted by a control cable so that the pyranometers are alternately exposed to the beam. The centres of the receivers of both pyranometers must have the same coordinates when they are exposed to the beam (diameter, approximately 10 cm; irradiance, 70 W/m^2; homogeneity of irradiance, ± 2 % within a circle of 24 mm). The pyranometer platform and the mirror are installed in a black-painted climatic chamber which reduces stray light and ensures constant environmental conditions.

NOTE 9 A climatic chamber and turning mirror are not essential for this method.

The procedure for taking readings is shown in table A.2; an alternative procedure is shown in table A.3. The tables are examples.

The reading procedure must be applied independently of the adjusted tilt angle.

Table A.2 — Procedure for use with MetObs Hamburg device

Reading time after start min	Reference pyranometer unshaded	 shaded	Test pyranometer unshaded	 shaded	Remarks
2		$V_{R,s}$			
4	$V_{R,u}$				
6		$V_{R,s}$			
8	$V_{R,u}$				
10		$V_{R,s}$			
					Exchange of position
12				$V_{T,s}$	
14			$V_{T,u}$		
16				$V_{T,s}$	
18			$V_{T,u}$		
20				$V_{T,s}$	
22			$V_{T,u}$		
24				$V_{T,s}$	
					Exchange of position
26		$V_{R,s}$			
28	$V_{R,u}$				
30		$V_{R,s}$			
32	$V_{R,u}$				
34		$V_{R,s}$			

Table A.3 — Alternative procedure for use with MetObs Hamburg device

Reading time after start min	Reference pyranometer unshaded	 shaded	Test pyranometer unshaded	 shaded	Remarks
2		$V_{R,s}1$	$V_{T,u}1$		Calculate
4	$V_{R,u}2$			$V_{T,s}2$	$k2$
6		$V_{R,s}3$	$V_{T,u}3$		
8	$V_{R,u}4$			$V_{T,s}4$	$k4$
10		$V_{R,s}5$	$V_{T,u}5$		
12	$V_{R,u}6$			$V_{T,s}6$	$k6$
14		$V_{R,s}7$	$V_{T,u}7$		
16	$V_{R,u}8$			$V_{T,s}8$	$k8$
18		$V_{R,s}9$	$V_{T,u}9$		
20	$V_{R,u}10$			$V_{T,s}10$	$k10$
22		$V_{R,s}11$	$V_{T,u}11$		
					mean

Annex B
(informative)

Interferences and precautions

B.1 Choice of reference pyranometers

In order to minimize systematic errors, the reference and test pyranometers should be as nearly alike as possible in all respects. This does not contradict the recommendation for a higher class reference instrument (see 4.2) which implies obvious advantages for the measurement accuracy.

Additionally a proper characterization of the reference pyranometer allows a correct interpretation of the calibration results.

Typically the outdoor calibration according to this International Standard reveals only a small spectrum of response of the field pyranometer. Generalization on the relation between the indoor and outdoor calibrations cannot be made. However, simulation of the natural light source with respect to angular and spectral distribution and homogeneity makes the similarity of pyranometer design mandatory.

Any mismatch between the indoor and outdoor calibration conditions requires that the reference pyranometer be of the same type as the test pyranometer.

B.2 Sky conditions

The calibration of pyranometers which are to be employed in solar energy monitoring applications shall be performed only under conditions when the sun is unobstructed by clouds throughout a data-taking period. The minimum acceptable direct solar irradiance on the horizontal surface, given by the product of the measurement and the cosine of the incident angle, shall be 80 % of the global solar irradiance as measured by the pyranometer. Also, no cloud formation shall be within 30° of the sun during the data-taking period.

In case of automatic data acquisition this criterion can be replaced by a minimum irradiance threshold which indicates the interference by clouds.

B.3 Instrument orientation, cosine and azimuth errors

The result of the pyranometer calibration is influenced by the tilt and azimuthal orientation of the instrument. For the axis vertical orientation, tilt is not a consideration. However, since the calibration is performed with the sun in a range of azimuths, the azimuthal angle between the sun and the direction of the cable connector or other reference varies significantly.

This International Standard permits the pyranometer to be tested with its axis directed towards the sun; in this case, there are no significant cosine and azimuth errors during calibration and during use of the pyranometer as a transfer instrument in the tilted mode. The incident angles of the direct solar radiation and hence the cosine and azimuth errors are small in most applications.

When the pyranometer is calibrated at a fixed tilt, the calibration factor includes the cosine and azimuth errors of the pyranometer at each incident angle. The accuracy of the calibration is therefore limited by the cosine and azimuth correction uncertainties.

For cosine and azimuth uncertainties, see also ISO 9060.

B.4 Applicability of calibration result

In the calibration methods specified in this International Standard the accuracy of the values obtained is assumed to be independent of the time of year within the constraints imposed by the test instrument's temperature compensation (neglecting cosine errors). The methods permit the determination of possible tilt effects on the responsivity of the test instrument's radiation receptor.

B.5 Corrections within the calibration transfer computations

The principal advantage of outdoor calibration of pyranometers is that all types of pyranometers are related to a single reference under realistic irradiance conditions. For outdoor calibrations, the reference pyranometer shall be well characterized. The characterization should be employed in the calibration transfer computations.

B.6 Objects on the horizon

Precautions shall be taken to ensure that the horizon is substantially free of natural or man-made objects that exceed an angle of elevation of 5° (see 9.4.3 in [12]). Special attention shall be paid to ensure that any objects visible above the horizon do not reflect sunlight onto the calibration facility.

B.7 Practical equivalence of outdoor and integrating sphere calibration

In type IIa and IIb calibrations non-uniformity of integrating-sphere radiance can result in errors in the calibration if the reference and test instruments have different effective fields of view or different cosine response behaviour.

The principal disadvantage of the integrating sphere is that the radiance distribution and the ambient temperature do not match field conditions properly. For this reason, the practical equivalence which justifies the method must be demonstrated by experiment.