EKO INSTRUMENTS

ISO/IEC 17025

Pyranometer & Pyrheliometer Calibration Procedures

Rev 3: March 2025

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EKO Instruments Co. Ltd. Calibration Laboratory is accredited to perform calibration of pyranometers and pyrheliometers in accordance with **ISO/IEC 17025:2017**.

EKO
Beyond Accuracy.

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Solar Sensor Calibration Procedures

At EKO Instruments Co. Ltd.

ISO/IEC 17025:2017

ilac-MRA

PJLA Calibration
#74158

EKO Instruments Co., Ltd. (EKO) calibration laboratory is accredited and certified by PJLA (Ref: **#74158**) to perform pyranometer and pyrheliometer calibrations per the requirements of **ISO/IEC 17025:2017**, which are relevant to calibration and testing.

EKO offers a manufacturer calibration service for pyranometers and pyrheliometers in-house. Based on the applied calibration methods, EKO exhibits the highest level of technical and managerial expertise for solar sensor calibrations compliant to the international standards defined by **ISO/IEC 17025:2017** for ISO9847 (Indoor method) and ISO9059 (Outdoor/Indoor method), as defined by the scope of calibrations Appendix 1.

ISO/IEC 17025:2017 provides a globally accepted basis for laboratory accreditation that specifies the most stringent management and technical requirements. With calibrations performed at the EKO Instruments laboratory, we enable our customers to:

- Clearly identify the applied calibration methods and precision.
- Be traceable to the World Radiation Reference (WRR) through defined industrial standards:
    - ISO9846 Calibration of a pyranometer using a pyrheliometer
    - ISO9847 Calibration of pyranometers by comparison to a reference pyranometer
    - ISO9059 Calibration of field pyrheliometers by comparison to a reference pyrheliometer
- Obtain repeatable and reliable calibration test results through consistent operations yearly examined independently to assure strict compliance to the requirements.

Customers will obtain the highest level of confidence when purchasing an **ISO/IEC 17025:2017** calibrated sensor. EKO's accredited laboratory is regularly re-examined to ensure that they maintain their standards of technical expertise.

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CALIBRATION

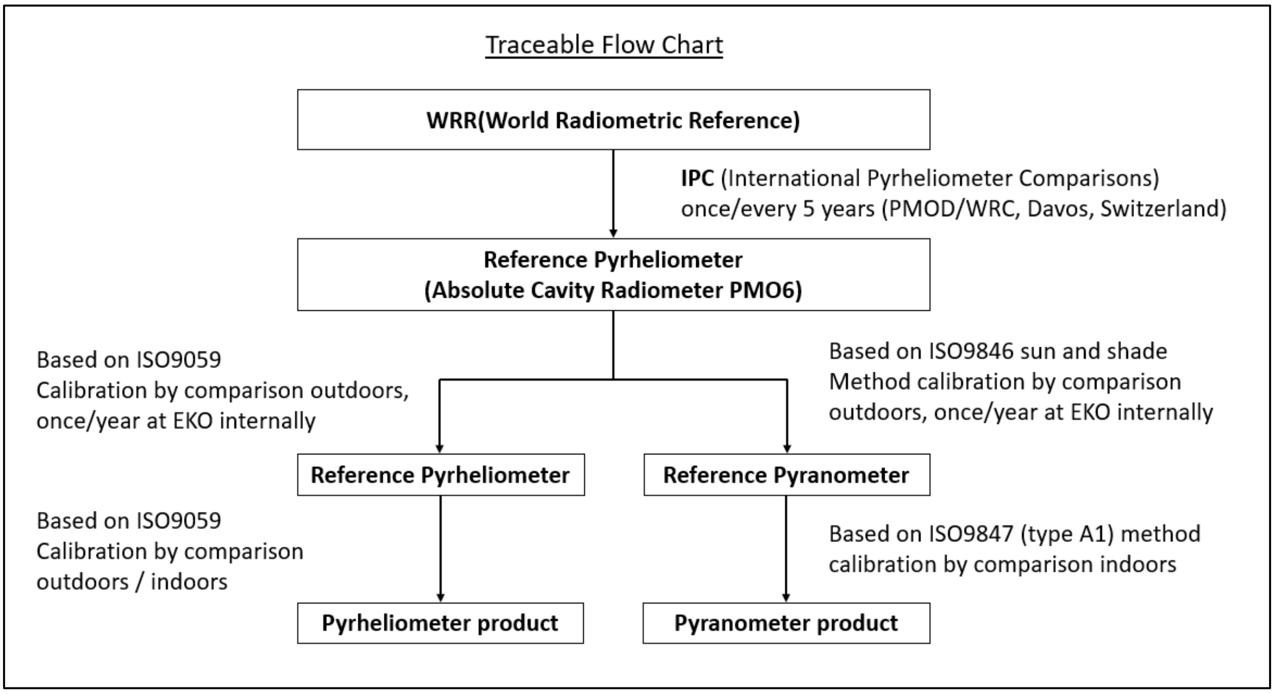
Calibration is the process of comparing the output signal of a sensor with the standard value in a defined calibration environment. Calibration is necessary to establish the correct value, and proper accuracy, of a sensor.

For pyranometers or pyrheliometers, we aim to determine the correlation between the detector response (e.g., µV) and irradiance (W/m^2), known as sensitivity (µV/ (W/m^2)).

The following section provides a summary of the calibration methods and definitions of terms used.

Calibration Traceability

According to the traceability flow chart below, EKO pyranometers and pyrheliometers are calibrated and traceable to the 'World Radiometric Reference' (WRR).



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Reference Sensor Units

Reference sensor units used for calibration:

- Absolute Cavity Radiometer PMO6: This unit belongs to EKO and is traceable to the WRR maintained at the World Radiation Centre (WRC) in Davos, Switzerland. The PMO6 is categorised under ISO 9060:2018 as a Class AA pyrheliometer.

- Every 5 years, the PMO6 is calibrated against the WRR during the International Pyrheliometer Comparison (IPC) to maintain its reference status. The WRR is based on a cluster of 6 models of Absolute Cavity Radiometers, referred to as the World Standard Group (WSG).

- EKO's MS-57 reference Pyrheliometers are calibrated directly against the EKO PMO6, according to the standard method defined by 'ISO 9059:1990, Solar energy -- Calibration of field pyrheliometers by comparison to a reference pyrheliometer'. These reference pyrheliometers are calibrated once per year.

- Pyrheliometer products are calibrated according to the standard method defined by 'ISO 9059:1990 Solar energy -- Calibration of field pyrheliometers by comparison to a reference pyrheliometer'. This involves comparing the sensor against a reference Pyrheliometer, using measurements taken outdoors simultaneously.

- Reference Pyranometer units are established for each product model and calibrated according to the standard method defined by 'ISO 9846:1993 Solar energy -- Calibration of a pyranometer using a pyrheliometer'. These sensors are compared against the PMO6, using measurements taken outdoors simultaneously. Reference pyranometers are calibrated once per year.

- Pyranometer products are calibrated according to the standard method defined by 'ISO 9847:2023 solar energy -- Calibration of pyranometers by comparison to a reference pyranometer', with measurements taken indoors.

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Calibration Procedures

Reference Pyrheliometer Unit

An EKO MS-57 Pyrheliometer is used as a reference for outdoor calibrations of pyrheliometers.

This unit is itself calibrated through outdoor measurements and compared against the Absolute Cavity Radiometer PMO6; per the calibration method defined by 'ISO 9059:1990 Solar energy -- Calibration of field pyrheliometers by comparison to a reference pyrheliometer', and 'Pyrheliometer Calibration', Chapter 7, Section 7.2.1.4 in the 'Guide to Instruments and Methods of Observation 2018' published by the World Meteorological Organisation (WMO).

Calibration Procedure

a) The PMO6 and MS-57 reference Pyrheliometer units are mounted on an STR-22G Sun Tracker and aligned normally with the sun.

b) (PMO6) Measurement interval: 90 sec. (Dark phase: 45sec. including stabilizing time 5sec. / Open phase: 45sec. including stabilizing time 5sec.)

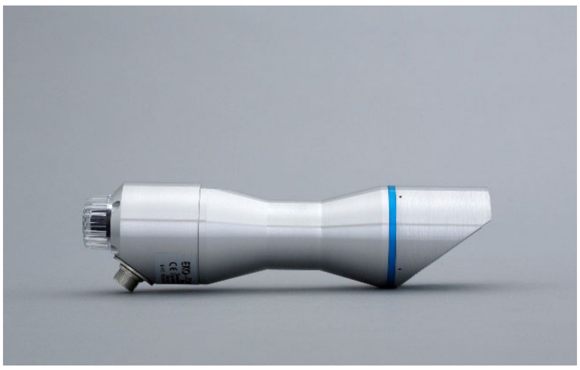
c) (Reference Pyrheliometers) Sampling Interval: 1sec. (averaging time: 5sec.)

d) Number of data points: 40 stable measurement data points or more.

e) The measurement values obtained by the PMO6 (W/m^2) and the Reference pyrheliometers (output signal: µV / sensor temperature: °C) are logged with precise time stamps. The reference pyrheliometers' output signal is temperature corrected based on the measured sensor temperature and known temperature characteristics.

f) The reference Pyrheliometer units' calibration figures are calculated from the measurement values of the PMO6 according to the measurement data criteria.

g) Environmental conditions are applied as defined in appendix 4.



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Measurement Data Criteria

1. Standard deviation: Apply data less than 0.5% at 2σ normal distribution
2. Measurement time: Apply data taken over 4 hours, centred at the culmination time
3. Solar irradiance conditions: Apply measurement data exceeding 700W/m^2

Calculation of Sensitivity Value

a) Acquire the signal output V (µV) produced by the reference pyrheliometer at the same time as the PMO6 irradiance, and apply temperature correction 'Tcoeff' (%, Relative ratio against the output at 20°C) to each signal output.

b) The sensitivity value of reference pyrheliometer S (µV/W/m^2) is obtained by dividing each signal output V (µV) by the solar irradiance E↓Cavity (W/m^2), measured simultaneously by the PMO6 and calculating the average value.

$$S = \frac{1}{n}\sum_{i=1}^{n} f\left(\frac{V\,T_{coeff}}{E_{\downarrow cavity}}\right)$$

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Calibrating a Field Pyrheliometer

Field pyrheliometers are calibrated by comparison against the reference pyrheliometer outdoors, according to the 'ISO 9059:1990 Solar energy -- Calibration of field pyrheliometers by comparison to a reference pyrheliometer' and 'Calibration of Pyrheliometers' as stated under Chapter 7, Section 7.2.1.4 on the 'Guide to Meteorological Instruments and Methods of Observation 2008' issued by the WMO.

Calibration Procedure

a) The reference pyrheliometer unit and the field pyrheliometer are mounted on the STR-22G Sun Tracker and aligned directly with the sun.

b) Sampling Interval: 200msec. (averaging time 15sec.)

c) Number of data points: 400 stable measurement data points or more.

d) The field pyrheliometer and the reference pyrheliometer unit's measurement values are corrected based on the temperature characteristics of the detector.

e) The voltage output (µV) of the field pyrheliometer is averaged and matched with the data points (>400) of the reference Pyrheliometer (µV, Vavg). To obtain the sensitivity figure S (µV/W/m^2) is multiplied by the temperature coefficient (Tcoeff.) and divided by the direct solar irradiance (W/m^2, E ↓ ref) measured by the reference pyrheliometer.

$$S = \frac{1}{n}\sum_{i=1}^{n} f\left(\frac{V\,T_{coeff}}{E_{\downarrow ref}}\right)$$

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Reference Pyranometer Unit

EKO pyranometer models MS-80, MS-802, MS-60 and MS-40 are used as a reference for the indoor calibration of pyranometers per 'ISO 9846:1993 Solar Energy – Calibration of a pyranometer using a pyrheliometer' and the method defined in 'Alternate calibration using a pyrheliometer ("A new method for calibrating reference and field pyranometers" (Forgan, 1996)', Chapter 7, Section 3.1.3 of the 'Guide to Instruments and Methods of Observation 2018' published by the World Meteorological Organisation (WMO).

Calibration Procedure

a) The PMO6 and 2 reference pyranometer units of the same model are mounted on the STR-22G Sun Tracker and aligned to face direct sunlight.

b) One reference pyranometer is shaded by a shading disk, or ball, attached to the Sun Tracker's arm to measure diffuse normal solar irradiance, while the other reference pyranometer remains unshaded to measure global normal solar irradiance. Each reference pyranometer alternates between being shaded and un-shaded near and at the solar noon.

c) (PMO6) Measurement interval: every 90 sec. (Dark phase: 45sec including stabilizing time 5sec / Open phase: 45 sec. including stabilizing time 5sec.)

d) (Reference Pyranometers) Sampling interval: 1sec. (averaging time: 5sec.).

e) Number of data: 40 stable measurement data points or more.

f) The measurement values obtained by the PMO6 (W/m^2) and reference Pyranometers (signal output: µV and sensor temperature: °C) are logged with precise time stamps. The pyranometer output signals will be temperature corrected based on the measured sensor temperature and known temperature characteristics.

g) The sensitivity figures (µV/ W/m^2) of the two reference pyranometers can be calculated from the direct solar irradiance (W/m^2) measured by the PMO6 and the measured voltage (µV) of each reference pyranometer unit according to the measurement data criteria in the next paragraph.

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Measurement Data Criteria

1. Standard deviation: Apply data less than 0.5% at 2σ normal distribution
2. Measurement time: Apply data taken over 4 hours, centred at the culmination time
3. Solar irradiance conditions: Apply measurement data exceeding 700W/m^2

Calculation of Sensitivity Value

The sensitivity values of 2 reference pyranometers are calculated using an equation, and based on data gathered simultaneously under the same solar elevation angle, with reference irradiance measured by PMO6, diffuse solar irradiance, and global normal surface solar irradiance measured by 2 pyranometers.

The following equation (a) shows the signal output V_{dA} (µV) of the diffuse solar irradiance measured by the reference pyranometer "A" and the signal output V_{gB} (µV) of the inclined surface solar irradiance measured by the reference pyranometer "B" and direct solar irradiance E_{di} (W/m^2) measured by PMO6 before the culmination time (t0).

Equation (b) shows the signal output V_{dB} (µV) of the diffuse solar irradiance measured by the reference pyranometer "B" and the signal output V_{gA} (µV) of the global normal surface solar irradiance measured by reference pyranometer "A" and direct solar irradiance E_{dir} measured by PMO6 after the culmination time (t1).

R_A and R_B in equations (a) and (b) indicate the sensitivity value (µV/W/m^2) of the 2 reference pyranometers. R_A and R_B are obtained using simultaneous formula (a) and (b) by assuming that the sensitivity constants are the same even when the diffuse solar irradiance and the global normal surface solar irradiance are measured.

a) Extract the signal output V_A, V_B (µV) measured by the reference pyranometers at the same time as the PMO6, and apply temperature correction T_{coeff} (%, Relative ratio against the output at 20°C) to each signal output. Pair the data measured under the same solar elevation angle.

b) R_A and R_B can be obtained by calculating the sensitivity constant of the pyranometer standard from the data of each pair using the following equations (c) and (d) and then calculating the average value.

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$$\frac{V_{gB(t_0)}}{R_B} = E_{dir}(t_0) + \frac{V_{dA(t_0)}}{R_A} \quad \cdots(a)$$

$$\frac{V_{gA(t_1)}}{R_A} = E_{dir}(t_1) + \frac{V_{dB(t_1)}}{R_B} \quad \cdots(b)$$

$$R_B = \frac{V_{dA(t_0)}\, V_{dB(t_1)} - V_{gB(t_0)}\, V_{gA(t_1)}}{V_{dA(t_0)}\, E_{dir(t_1)} - V_{gA(t_1)}\, E_{dir(t_0)}} \quad \cdots(c)$$

$$R_A = \frac{V_{dA(t_0)}\, V_{dB(t_1)} - V_{gB(t_0)}\, V_{gA(t_1)}}{R_B\, E_{dir(t_0)} + V_{gB(t_0)}} \quad \cdots(d)$$

Calibrating a Field Pyranometer

EKO's field pyranometers are calibrated indoors according to the method defined in 'ISO 9847:2023 Solar energy -- Calibration of pyranometers by comparison to a reference pyranometer (type A1)'.

Field pyranometers are calibrated against reference pyranometers of the same model using a AAA class Solar Simulator (1000W/m^2, AM1.5G, +/-0.5% temporal stability) with an automated shutter.

The indoor calibration environment is controlled with an ambient temperature range of 25± 3°C.

Calibration Procedure

a) Before calibration can be performed, the solar simulator requires 30 minutes or longer to stabilize.

b) The reference and field pyranometers are installed in a horizontal, automatic, 2-dimensional optical stage with high positioning precision, controlled by a PC with dedicated calibration software.

c) A few minutes after the stabilization time, the offset output V_{dref} (µV) and V_{dtest} (µV) are measured in the dark.

d) The automatic stage moves the reference pyranometer to a specific position under the solar simulator. The sensor entrance optics remains aligned with the radiation source; the shutter opens automatically, and the irradiation starts.

e) After irradiating for the time specified for each pyranometer model, record 10 points of the signal output of the reference pyranometers V_{iref} (µV).

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f) The automatic stage then moves the field pyranometer to alternate it with the reference pyranometer and places the field pyranometer under the same irradiation conditions.

g) After irradiating for the same amount of time as the reference pyranometer, record 10 points of the signal output of the field pyranometers V_{itest} (µV).

h) The automatic stage moves the reference pyranometer back to the same position, alternates it with the field pyranometer, and exposes it again to the radiation source.

i) After irradiating for the same specified time, record 10 points of the signal output of the reference pyranometers V_{iref} (µV).

j) After the measurement process is completed, the software automatically determines whether the standard deviation of the signal output of the reference pyranometer V_{iref}, the 20 points recorded before and after the measurement of the product, meets the acceptance criteria.

k) Calculate the average solar irradiance $E_{\downarrow ref}$ by subtracting the offset output V_{dref} in the dark state from the measurement data of the reference pyranometer V_{iref} and dividing by the sensitivity constant S_{ref}.

l) The sensitivity value of the field pyranometer S is calculated by subtracting the output V_{dtest} in the dark state from the output at the time of irradiation V_{itest} and dividing it by the solar irradiance $E_{\downarrow ref}$ obtained by the reference pyranometer.

$$E_{\downarrow ref} = \frac{1}{20} \sum_{i=1}^{20} f\left(\frac{V_{iref} - V_{dref}}{S_{ref}}\right)$$

$$S = \frac{1}{10} \sum_{i=1}^{10} f\left(\frac{V_{itest} - V_{dtest}}{E_{\downarrow ref}}\right)$$

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APPENDIX

1. Scope of ISO/IEC 17025:2017 Calibrations

The scope of accreditation (certificate ref: L19-266 / www.pjlabs.com) specifies the Calibration and Measurement Capability (CMC) for the applicable sensor categories, calibration methods and measurement uncertainty with a confidence level of 95% (k=1.96).

The CMC states that the accredited processes represent the smallest measurement uncertainties attainable by the laboratory when performing a nearly ideal device's routine calibration under nearly ideal conditions. The actual measurement uncertainty associated with a specific calibration performed will typically be larger than the CMC specified for the same calibration since the device's capability and performance, and the conditions related to the calibration may reasonably be expected to deviate from ideal to some degree.

Sample

EKO Instruments' Certificate of Accreditation' ISO17025 (published in 2023): Calibration scope and Uncertainty of Calibration in EKO Instrument calibration laboratory

PERRY JOHNSON LABORATORY ACCREDITATION, INC.

Certificate of Accreditation

Perry Johnson Laboratory Accreditation, Inc. has assessed the Laboratory of:

EKO Instruments Co., Ltd.
1-21-8 Hatagaya Shibuya-ku, Tokyo 151-0072

(Hereinafter called the Organization) and hereby declares that Organization is accredited in accordance with the recognized International Standard:

ISO/IEC 17025:2017

This accreditation demonstrates technical competence for a defined scope and the operation of a laboratory quality management system (as outlined by the joint ISO-ILAC-IAF Communiqué dated April 2017):

Calibration of rotational viscometer, pyrheliometer, pyranometer and silicon-pyranometer
(As detailed in the supplement)

Accreditation claims for such testing and/or calibration services shall only be made from addresses referenced within this certificate. This Accreditation is granted subject to the system rules governing the Accreditation referred to above, and the Organization hereby covenants with the Accreditation body's duty to observe and comply with the said rules.

For PJLA:

Tracy Szerszen
President

Perry Johnson Laboratory Accreditation, Inc. (PJLA)
755 W. Big Beaver, Suite 1325
Troy, Michigan 48084

Initial Accreditation	*Issue Date:*	*Expiration Date:*
May 8, 2013	July 3, 2023	July 31, 2025

Accreditation No.:	*Certificate No.:*
74158	L23-506

The validity of this certificate is maintained through ongoing assessments based on a continuous accreditation cycle. The validity of this certificate should be confirmed through the PJLA website: www.pjlabs.com

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Certificate of Accreditation: Supplement

EKO Instruments Co., Ltd.
1-21-8 Hatagaya Shibuya-ku, Tokyo 151-0072
Contact Name: Minoru Kita Phone: 03-3469-6711

Accreditation is granted to the facility to perform the following calibrations:

Optical

MEASURED INSTRUMENT, QUANTITY OR GAUGE	RANGE OR NOMINAL DEVICE SIZE AS APPROPRIATE	CALIBRATION AND MEASUREMENT CAPABILITY EXPRESSED AS AN UNCERTAINTY (±)	CALIBRATION EQUIPMENT AND REFERENCE STANDARDS USED
Pyrheliometer (outdoor calibration) ISO9060:2018 Class A^F	700 W/m² to 1 200 W/m²	0.47 % of reading	Pyrheliometer and Pyranometer Calibration Operating Instructions (Clause 2) (LM-10) On basis of: WMO-No.8:2018 and ISO9059:1990 Standard Pyrheliometer (MS-57) Data logger (CR1000X)
Pyrheliometer (indoor calibration) ISO9060:2018 Class A^F	700 W/m² to 1 200 W/m²	0.45 % of reading	Pyrheliometer Indoor Calibration Operating Instructions (Clause 2) (LM-10A) On basis of: WMO-No.8:2018 and ISO9847:2023 Standard Pyrheliometer (MS-57) Digital multi-meter (34401A)
Pyranometer ISO9060:2018 Class A^F	700 W/m² to 1 400 W/m²	0.49 % of reading	Pyrheliometer and Pyranometer Calibration Operating Instructions (Clause 3) (LM-10) On basis of: WMO-No.8:2018 and ISO9847: 2023 Class A : Standard pyranometer (MS-802) and (MS-80) Class B : Standard pyranometer (MS-60) Class C : Standard pyranometer (MS-40) Digital multi-meter (34401A)
Pyranometer ISO9060:2018 Class B^F		1.0 % of reading	
Pyranometer ISO9060:2018 Class C^F		1.2 % of reading	
Silicon-pyranometer (ML-01), (ML-02) ISO9060:2018 Class C^F	700 W/m² to 1 400 W/m²	1.5 % of reading	Pyrheliometer and Pyranometer Calibration Operating Instructions (Clause 3) (LM-10) On basis of: WMO-No.8:2018 and ISO9847: 2023 Standard silicon-pyranometer (ML-01) Digital multi-meter (34401A)

Issue: 07/2023 *This supplement is in conjunction with certificate #L23-506* *Page 3 of 4*

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2. Solar Irradiance Definitions

Solar Irradiance E↓ is the rate at which radiant energy from the sun is incident on a surface per unit area of surface, commonly expressed in [W/m^2].

a) Global Solar Irradiance (*Eg*↓)

The power density incident on a surface per unit area from the hemispheric sky (hemisphere: 2π steradian). The rate at which solar irradiance is received directly from the sun and from the atmosphere on the earth's surface. It is equal to the sum of the direct solar irradiance and the diffuse solar irradiance.

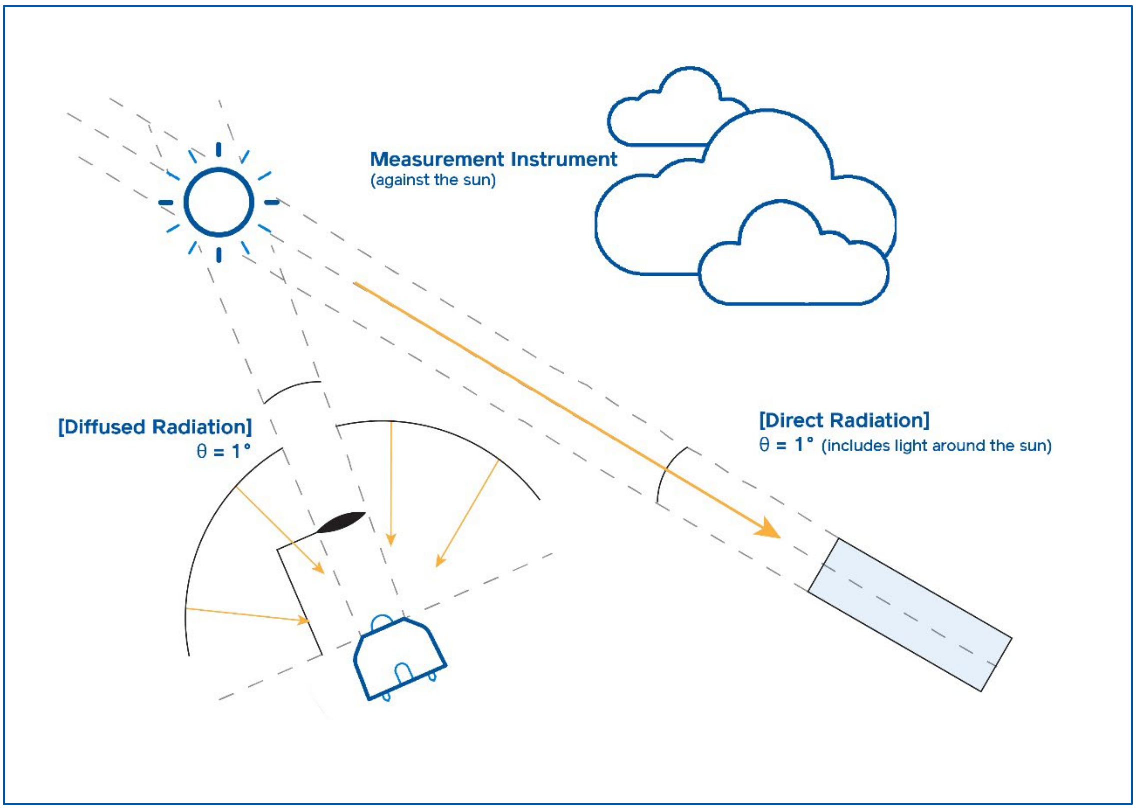
b) Direct Solar Irradiance (*E*)

The power density incident on a surface per unit area from a small solid angle of solar radiation directly from the sun disk.

Reference Solar Spectrum: For clear sky condition a standard irradiance spectrum is defined by ISO 9845 (Air mass 1.5 solar spectrum / Direct normal incidence up to 5.8° FOV / hemispherical radiation on an equator-facing, 37° tilted plane for an albedo of 0.2 / spectral range 285 – 4000 nm.

c) Diffuse Solar Irradiance (*Ed*↓)

The rate at which solar radiation reaches the earth's surface per unit area after it is scattered by molecules, aerosols, clouds and other particles in the air.



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3. Measurement Devices

The specifications and classifications of pyrheliometers and pyranometers are prescribed in 'ISO 9060:2018, Specification and classification of instruments for measuring hemispherical solar and direct solar radiation'.

a) Pyrheliometer

Pyrheliometer designed for measuring direct normal irradiance with a limited Field of View (FOV) of ∠5° (opening half-angle of ∠2.5°). The captured solar energy is absorbed in the wavelength range 0.3~3.0µm.

b) Pyranometer

Pyranometer designed for measuring global irradiance on a plane receiver surface in the wavelength range of 0.3~3.0µm.

c) Sun Tracker

A Sun Tracker is an automated device to track the sun with high angular precision (slope angle allowance less than 0.25°). It is based on a dual-axis motion control system, which can rotate in zenith and azimuth directions. EKO uses the STR-22G Sun Tracker, which has a higher tracking accuracy of less than 0.01°.

d) Data Acquisition System

A digital multi-meter or data-logger, capable of recording and collecting data from pyrheliometers and pyranometers. The resolution of the device used for calibration is less than 0.05%.

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4. Criteria and Environmental Conditions

The following environmental conditions and criteria apply to the outdoor calibration of the reference pyranometer and reference pyrheliometer.

a) Direct Solar Irradiance ($Eg\downarrow$)

Direct solar irradiance (measured by the Absolute Cavity Radiometer) exceeding 700W/m^2. Ratio (direct solar irradiance intensity / global solar irradiance intensity) is greater than 0.85.

b) Environmental Parameter 1 (Wind Speed)

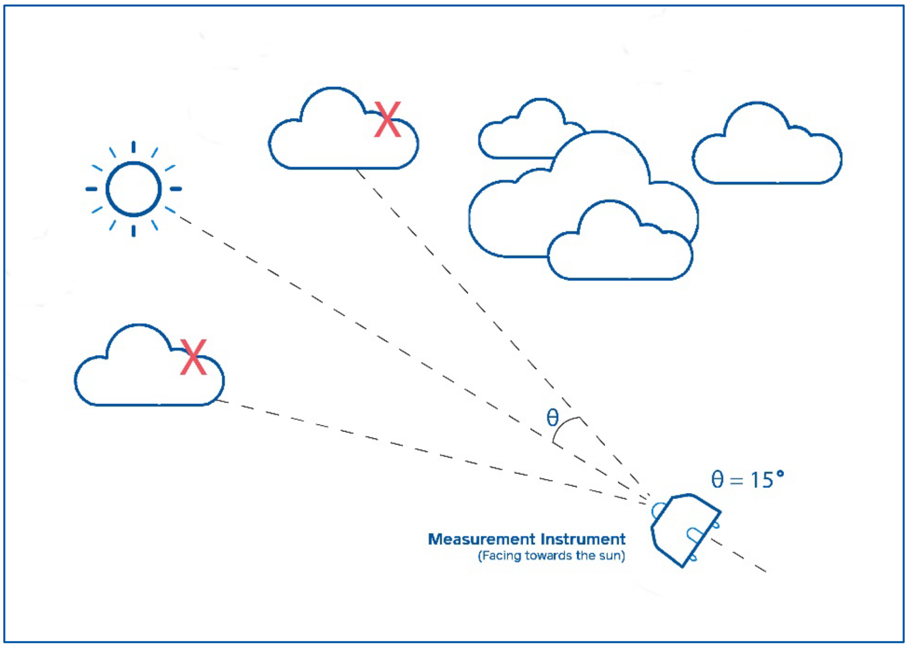
Low wind speed conditions are preferable. Measurements in the case of wind speeds exceeding > 5.0m/s must be avoided, especially when the wind direction is within +/- 30° of the sun's direction. The wind could potentially blow inside the Absolute Cavity Radiometer and may cause larger uncertainties.

c) Environmental Parameter 2 (Ambient Temperature)

The ambient temperature should be within the specified operating temperature of the Absolute Cavity Radiometer, reference pyrheliometer and reference pyranometer.

d) Environmental Parameter 3 (Atmospheric Conditions)

Only days with few clouds and stable atmospheric conditions allow for outdoor calibration (clouds amount must be less than 12.5% in order to take stable measurements). No clouds are accepted within the sensor field of view of 15° during the period of measurements. In cases where clouds cross this range during the measurement series, record its time period and remove the measurement data.



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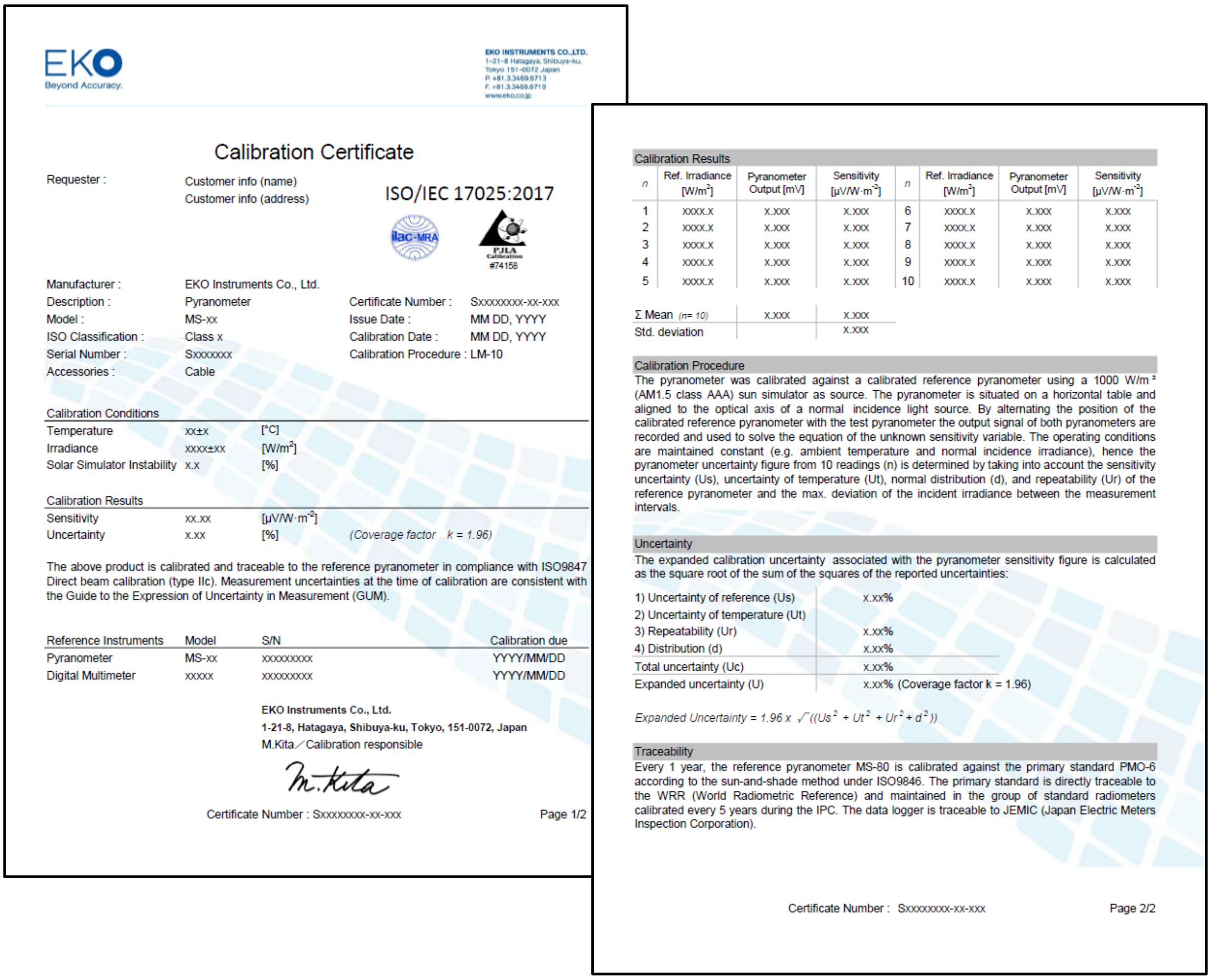
5. Calibration Certificates

A calibration certificate is produced for each pyranometer or pyrheliometer and contains the following information.

a) Identification of the calibration
b) Calibration conditions
c) Calibration results
d) Reference instruments
e) Calibration procedure
f) Calibration uncertainties
g) Traceability
h) Authorisation of the calibration and report

Sample

Calibration Certificate for Pyranometer



EKO Beyond Accuracy.

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Calibration Certificate

Requester : Customer info (name)
Customer info (address)

ISO/IEC 17025:2017

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PJLA Calibration #74158

Manufacturer :	EKO Instruments Co., Ltd.		
Description :	Pyranometer	Certificate Number :	Sxxxxxxxx-xx-xxx
Model :	MS-xx	Issue Date :	MM DD, YYYY
ISO Classification :	Class x	Calibration Date :	MM DD, YYYY
Serial Number :	Sxxxxxxx	Calibration Procedure :	LM-10
Accessories :	Cable		

Calibration Conditions		
Temperature	xx±x	[°C]
Irradiance	xxxx±xx	[W/m²]
Solar Simulator Instability	x.x	[%]

Calibration Results			
Sensitivity	xx.xx	[μV/W·m⁻²]	
Uncertainty	x.xx	[%]	*(Coverage factor k = 1.96)*

The above product is calibrated and traceable to the reference pyranometer in compliance with ISO9847 Direct beam calibration (type IIc). Measurement uncertainties at the time of calibration are consistent with the Guide to the Expression of Uncertainty in Measurement (GUM).

Reference Instruments	Model	S/N	Calibration due
Pyranometer	MS-xx	xxxxxxxxx	YYYY/MM/DD
Digital Multimeter	xxxxx	xxxxxxxxx	YYYY/MM/DD

EKO Instruments Co., Ltd.
1-21-8, Hatagaya, Shibuya-ku, Tokyo, 151-0072, Japan
M.Kita／Calibration responsible

M.Kita

Certificate Number : Sxxxxxxxx-xx-xxx Page 1/2

Calibration Results

n	Ref. Irradiance [W/m²]	Pyranometer Output [mV]	Sensitivity [μV/W·m⁻²]	*n*	Ref. Irradiance [W/m²]	Pyranometer Output [mV]	Sensitivity [μV/W·m⁻²]
1	xxxx.x	x.xxx	x.xxx	6	xxxx.x	x.xxx	x.xxx
2	xxxx.x	x.xxx	x.xxx	7	xxxx.x	x.xxx	x.xxx
3	xxxx.x	x.xxx	x.xxx	8	xxxx.x	x.xxx	x.xxx
4	xxxx.x	x.xxx	x.xxx	9	xxxx.x	x.xxx	x.xxx
5	xxxx.x	x.xxx	x.xxx	10	xxxx.x	x.xxx	x.xxx

Σ Mean *(n= 10)*	x.xxx	x.xxx
Std. deviation		x.xxx

Calibration Procedure

The pyranometer was calibrated against a calibrated reference pyranometer using a 1000 W/m² (AM1.5 class AAA) sun simulator as source. The pyranometer is situated on a horizontal table and aligned to the optical axis of a normal incidence light source. By alternating the position of the calibrated reference pyranometer with the test pyranometer the output signal of both pyranometers are recorded and used to solve the equation of the unknown sensitivity variable. The operating conditions are maintained constant (e.g. ambient temperature and normal incidence irradiance), hence the pyranometer uncertainty figure from 10 readings (n) is determined by taking into account the sensitivity uncertainty (Us), uncertainty of temperature (Ut), normal distribution (d), and repeatability (Ur) of the reference pyranometer and the max. deviation of the incident irradiance between the measurement intervals.

Uncertainty

The expanded calibration uncertainty associated with the pyranometer sensitivity figure is calculated as the square root of the sum of the squares of the reported uncertainties:

1) Uncertainty of reference (Us)	x.xx%
2) Uncertainty of temperature (Ut)	
3) Repeatability (Ur)	x.xx%
4) Distribution (d)	x.xx%
Total uncertainty (Uc)	x.xx%
Expanded uncertainty (U)	x.xx% (Coverage factor k = 1.96)

Expanded Uncertainty $= 1.96 \times \sqrt{(Us^2 + Ut^2 + Ur^2 + d^2)}$

Traceability

Every 1 year, the reference pyranometer MS-80 is calibrated against the primary standard PMO-6 according to the sun-and-shade method under ISO9846. The primary standard is directly traceable to the WRR (World Radiometric Reference) and maintained in the group of standard radiometers calibrated every 5 years during the IPC. The data logger is traceable to JEMIC (Japan Electric Meters Inspection Corporation).

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6. Measurement Uncertainty

The uncertainty of measurements is defined for each type of measurement and sensor model. According to the 'Guide of the Expression of Uncertainty in Measurement' (GUM), all parameters that contribute to measurement uncertainty are identified and taken into account using the standard analysis methods.

Sample

Budget Sheet: Calculated Uncertainty value of Class A pyranometer product (Rev. 2019)

Type	Symbol	Uncertainty factor	Division	Value (±)	Unit	Distribution	Divisor	Standard Uncertainty	Squared value	Remarks
B	STD	Reference unit	Reference Pyranometer	**0.567**	%	Std. deviation	1.96	**0.28**	**0.0802**	Reference unit (Including measurement variation)
A	GSI	Variation of measurement data	Pyranometer	**0.008**	%	− − −	1	**0.008**	**0.00006**	Uncertainty of the mean value of the sensitivity constant
A	RP	Repeatability	Pyranometer	**0.02**	%	− − −	1	**0.02**	**0.00028**	Measurement repeatability (Including light source stability)
B	Td	Temperature response	Pyranometer	**0.12**	%	Rectangular	√3	**0.069**	**0.0048**	TC response error due to the change of the controlled room temperature at 25±3°C (6°C)
B	DM	Measurement uncertainty	Digital multimeter	**0.0075**	%	Rectangular	√3	---	---	Specification value (Ignored: Too small value and has no effect)
B	NL	Non-linearity	Pyranometer	**0.2**	%	Rectangular	√3	---	---	Specification value (Excluded: Due to irradiate with a constant value around 1000W/m2)
B	ZO1	Zero offset A	Pyranometer	**7**	W/m^2	Rectangular	√3	---	---	Actual value (Omitted the offset when measured in the dark)
B	ZO2	Zero offset B	Pyranometer	**2**	W/m^2	Rectangular	√3	---	---	Actual value (Excluded: Due to calibrate in a constant temperature environment)
B	CR	Cosine response	Pyranometer	**10**	W/m^2	Rectangular	√3	---	---	Specification value (ExclucED: Due to irradiate from zenith angle 0deg only)
B	TI	Tilt response	Pyranometer	**0.17**	%	Rectangular	√3	---	---	Sepecification value (Excluded: Due to place and irradiate on a horizontal plane)
	uc( )	Combined Uncertainty			%	Std. deviation		**0.292**	**0.085**	
	U	Expanded Uncertainty			%	Std. deviation (k=1.96)		**0.584**		

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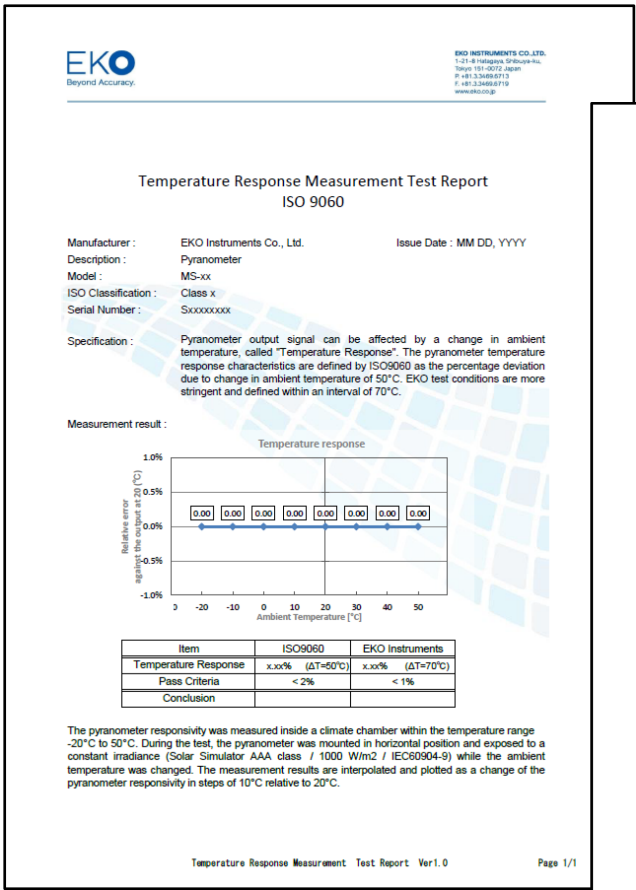
7. Sensor Characteristics

Measurement results are provided for each class A pyranometer and class A pyrheliometer.

Sample

Fig1. (Left) Temperature Response Measurement Test Report for Pyranometer

Fig2. (Right) Directional Response Measurement Report for Pyranometer



EKO Beyond Accuracy.

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Temperature Response Measurement Test Report
ISO 9060

Manufacturer : EKO Instruments Co., Ltd. Issue Date : MM DD, YYYY
Description : Pyranometer
Model : MS-xx
ISO Classification : Class x
Serial Number : Sxxxxxxxx

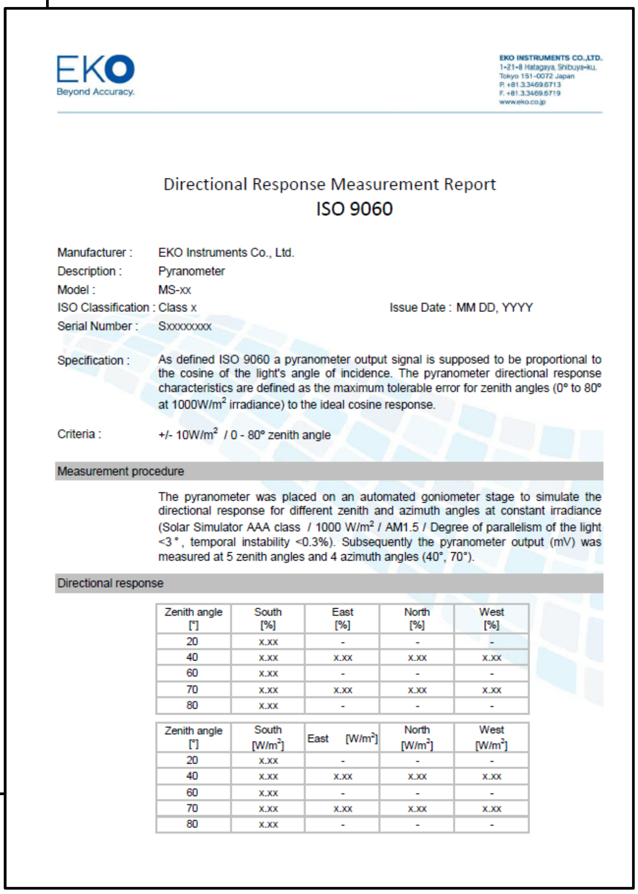
Specification : Pyranometer output signal can be affected by a change in ambient temperature, called "Temperature Response". The pyranometer temperature response characteristics are defined by ISO9060 as the percentage deviation due to change in ambient temperature of 50°C. EKO test conditions are more stringent and defined within an interval of 70°C.

Measurement result :

Item	ISO9060	EKO Instruments
Temperature Response	x.xx% (ΔT=50°C)	x.xx% (ΔT=70°C)
Pass Criteria	< 2%	< 1%
Conclusion		

The pyranometer responsivity was measured inside a climate chamber within the temperature range -20°C to 50°C. During the test, the pyranometer was mounted in horizontal position and exposed to a constant irradiance (Solar Simulator AAA class / 1000 W/m2 / IEC60904-9) while the ambient temperature was changed. The measurement results are interpolated and plotted as a change of the pyranometer responsivity in steps of 10°C relative to 20°C.

Temperature Response Measurement Test Report Ver1.0 Page 1/1



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Directional Response Measurement Report
ISO 9060

Manufacturer : EKO Instruments Co., Ltd.
Description : Pyranometer
Model : MS-xx
ISO Classification : Class x Issue Date : MM DD, YYYY
Serial Number : Sxxxxxxxx

Specification : As defined ISO 9060 a pyranometer output signal is supposed to be proportional to the cosine of the light's angle of incidence. The pyranometer directional response characteristics are defined as the maximum tolerable error for zenith angles (0° to 80° at 1000W/m² irradiance) to the ideal cosine response.

Criteria : +/- 10W/m² / 0 - 80° zenith angle

Measurement procedure

The pyranometer was placed on an automated goniometer stage to simulate the directional response for different zenith and azimuth angles at constant irradiance (Solar Simulator AAA class / 1000 W/m² / AM1.5 / Degree of parallelism of the light <3°, temporal instability <0.3%). Subsequently the pyranometer output (mV) was measured at 5 zenith angles and 4 azimuth angles (40°, 70°).

Directional response

Zenith angle [°]	South [%]	East [%]	North [%]	West [%]
20	x.xx	-	-	-
40	x.xx	x.xx	x.xx	x.xx
60	x.xx	-	-	-
70	x.xx	x.xx	x.xx	x.xx
80	x.xx	-	-	-

Zenith angle [°]	South [W/m²]	East [W/m²]	North [W/m²]	West [W/m²]
20	x.xx	-	-	-
40	x.xx	x.xx	x.xx	x.xx
60	x.xx	-	-	-
70	x.xx	x.xx	x.xx	x.xx
80	x.xx	-	-	-

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