INTERNATIONAL STANDARD

ISO 9059

First edition
1990-11-01

Solar energy — Calibration of field pyrheliometers by comparison to a reference pyrheliometer

Énergie solaire — Étalonnage des pyrhéliomètres de terrain par comparaison à un pyrhéliomètre de référence

Reference number
ISO 9059:1990(E)

Contents

© ISO 1990
All rights reserved. No part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from the publisher.

International Organization for Standardization
Case Postale 56 • CH-1211 Genève 20 • Switzerland

Printed in Switzerland

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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 9059 was prepared by Technical Committee ISO/TC 180, *Solar energy*.

Annexes A and B of this International Standard are for information only.

Introduction

This International Standard is one of a series of International Standards specifying methods and instruments for the measurement of solar radiation.

Pyrheliometers are used to measure direct solar irradiance. The data collected are used for

- the determination of the efficiency of concentrating collectors,
- the determination of the direct beam resource for concentrating solar energy devices as well as for determining their siting, sizing, etc., and
- the accurate determination of hemispherical solar radiation as a sum of the measured direct solar and diffuse solar radiation.

The calibration hierarchy of pyrheliometers specified in this International Standard follows the scheme developed by the World Meteorological Organization (WMO) [1], and the classification and specification used are prescribed in ISO 9060. During the elaboration of this International Standard, extensive reference was made to ASTM 816-81 [2].

Solar energy — Calibration of field pyrheliometers by comparison to a reference pyrheliometer

1 Scope

This International Standard describes the calibration of field pyrheliometers using reference pyrheliometers and sets out the calibration procedures and the calibration hierarchy for the transfer of the calibration.

This International Standard is mainly intended for use by calibration services and test laboratories to enable a uniform quality of accurate calibration factors to be achieved.

2 Normative reference

The following standard contains provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the edition indicated was 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 edition of the standard 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.*

3 Definitions

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

3.1 direct solar radiation: Radiation received from a small solid angle centred on the sun's disc, on a given plane. [ISO 9060:1990, 3.3.]

3.2 pyrheliometers: Radiometers 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 It follows from this definition that pyrheliometers are used to measure direct solar radiation at normal incidence. Typical field-of-view angles of pyrheliometers range from 5° to 10°. Unlike the windowless instruments, the spectral responsivity of field pyrheliometers is limited to the range approximately 0,3 µm to 3 µm, depending on the spectral transmittance of the window which protects the receiver surface. However, windowless instruments operate with a loss of energy of less than 1 % (see ISO 9060:1990, note 2 to 3.3).

3.3 field pyrheliometers: Pyrheliometers which are designed and used for long-term field measurements of direct solar radiation. These pyrheliometers are weather-proofed. The receiver is protected from wind, dirt, rain, snow and insects by a window (made of quartz) or alternatively by a system ensuring strong ventilation with air.

3.4 reference pyrheliometers: Pyrheliometers of any category serving as a reference in calibration procedures. They are selected and well-tested instruments (see ISO 9060:1990, table 2), which have a low rate of yearly change in responsivity. They are controlled on a routine basis by comparisons with other reference pyrheliometers.

NOTE 2 Generally, reference pyrheliometers are operated without protective windows.

To achieve the above-mentioned stability of the responsitivity, the use of a reference pyrheliometer should be restricted to comparisons and calibration activities. The instrument should be stored carefully in a laboratory under moderate ambient conditions.

3.5 primary standard pyrheliometers: Pyrheliometers, selected from the group of absolute pyrheliometers (also called absolute radiometers), which meet the requirements of ISO 9060:1990, 5.3.1.

3.6 secondary standard pyrheliometers: Pyrheliometers of high precision and stability whose calibration factors are derived from primary standard pyrheliometers. The group comprises absolute pyrheliometers, which do not fulfil the requirements of primary standard pyrheliometers, as well as compensation pyrheliometers and some other precise but out-dated instruments such as the silver disk pyrheliometer. (See also ISO 9060:1990, 5.3.2.)

3.7 first class and second class pyrheliometers: Pyrheliometers of a lower stability and accuracy than secondary standard pyrheliometers. Generally the group of field pyrheliometers belongs to this category. (See also ISO 9060:1990, 5.3.2.)

NOTE 3 These instruments are sometimes used as so-called "working standards" because they are simple to operate and are less dependent on weather conditions than the higher category instruments. Such working standards should be compared with pyrheliometers of higher category as frequently as possible.

4 Calibration hierarchy of pyrheliometers

The following calibration hierarchy of pyrheliometers shall apply.

All pyrheliometers shall be referred to the World Radiometric Reference (WRR) (see also ISO 9060:1990, 3.6).

Primary standard pyrheliometers shall be referred to the WRR by comparison with selected groups of well-maintained primary standards (see ISO 9060:1990, 5.3.1).

Primary standard pyrheliometers shall be used as reference for the calibration of secondary standard pyrheliometers and may be used as reference for first class and second class pyrheliometers.

The reference for calibration of any pyrheliometer in first class or second class categories shall be a pyrheliometer in the same or higher category.

If the reference pyrheliometer and the pyrheliometer being calibrated are in the same category, they shall be from the same manufacturer and shall be of the same model, and the reference pyrheliometer shall have been calibrated using a higher category pyrheliometer as its reference.

NOTE 4 It is recommended that more than one reference instrument be used in the case where the reference is of the same category as the pyrheliometer being calibrated.

5 Calibration requirements

The calibration of a field pyrheliometer by means of a reference pyrheliometer is accomplished by exposing the two instruments to the same radiation field and comparing their corresponding measuring signals. The calibration shall meet the requirements with respect to

— the choice of the radiation source,

— the limits of meteorological variables acceptable during the calibration procedure, and

— the choice of measuring equipment.

5.1 Radiation source

Pyrheliometers shall be exposed to the radiation field comprising direct solar radiation and parts of the circumsolar radiation. The irradiance should be not less than 300 $W \cdot m^{-2}$, but irradiance values exceeding 700 $W \cdot m^{-2}$ are preferred. The calibration conditions, in terms of the circumsolar contribution, shall be as close as possible to the routine measuring conditions in which the field pyrheliometer is used (see 5.2.3).

5.2 Meteorological variables

5.2.1 Wind speed

The wind speed during the calibration should be low, particularly when the wind is blowing from the direction of the sun's azimuth ($\pm$ 30°).

NOTE 5 Because of wind cooling, pyrheliometers with open tubes yield lower measuring values with a higher standard deviation. The magnitude of this effect depends on the type of pyrheliometer, and especially on the design of the diaphragms in the tube.

The wind-cooling effect may be reduced by installing wind screens. For instance, it may be beneficial to carry out the measurement from a balcony or an open window. A tolerable maximum wind speed for unprotected measurement conditions cannot be specified.

5.2.2 Ambient air temperature

In order to determine the temperature dependence of the calibration factor, if it is not already known from laboratory tests, the calibration should be carried out over a range of ambient air temperatures covering a large part of the temperature range which is typical for the field application.

5.2.3 Sky conditions

During calibration, clouds should have an angular distance from the sun of greater than 15°. Generally, good calibration conditions exist when the cloud cover is less than 12,5 %.

NOTES

6 Contrails of aeroplanes that are within 15° of the sun may be tolerated if the number of disturbed instantaneous measurements is small compared with the number of undisturbed measurements in a series (see 6.3.2).

7 Atmospheric water vapour in the pre-condensation phase occasionally causes variable atmospheric trans-

mission. Generally, the scattering of measuring data which is produced by these clusters is acceptable.

The atmospheric turbidity during calibration should be close to values typical for the field measuring conditions. Generally, the turbidity should be confined to conditions with Linke turbidity factors lower than 6 (see ISO 9060:1990, 3.7).

NOTE 8 Atmospheric turbidity is produced by scattering and absorption of direct solar radiation by aerosol particles and gases including water vapour.

The circumsolar radiation (aureole) originates from forward scattering of direct solar radiation. It decreases from the limb of the sun to an angular distance of about 15° by some orders of magnitude, depending on the type and concentration of the aerosol (see, for example, [3], [4] and [5]). The typical amount of circumsolar radiation within an angular distance of 5° from the sun represents only a few per cent of the direct solar radiation. If standard and field pyrheliometers have different field-of-view angles, the aerosol may strongly influence the accuracy of calibration. Calculated percentages of circumsolar contained in direct solar radiation, for different aerosol types and solar elevation angles [4], are given for information in table A.1.

5.3 Measuring equipment

5.3.1 Reference pyrheliometer

The reference pyrheliometer should be selected in accordance with the calibration hierarchy given in clause 4. Furthermore, it should have a field-of-view angle and a slope angle (see ISO 9060:1990, 5.1) similar to those of the field pyrheliometer.

5.3.2 Sun tracker

Sun trackers delivering separate movements in elevation and azimuth (altazimuth mount) as well as trackers turning the pyrheliometer in parallel with the solar equatorial plane (equatorial or parallactic mount) may be used.

Pyrheliometers with a rotationally non-symmetric sensor should follow the sun without rotation of the receiver around the tube axis. Therefore, in this case, only altazimuth trackers shall be used. The admissible misalignment of the sun tracker shall be less than the slope angle of the pyrheliometer minus 0,25°.

5.3.3 Data acquisition

Digital voltmeters capable of at least 0,05 % resolution of the maximum pyrheliometer reading shall be used for the read-out of the pyrheliometer signals. They shall have an accuracy, stable over at least 1 year and including temperature-generated drift, of better than ± 0,1 %.

NOTE 9 When operating a digital voltmeter outdoors its accuracy may be influenced by the ambient temperature. Protection of the instrument from direct sunlight is recommended. When operating a digital voltmeter indoors, low-noise cabling should be employed owing to the length of the cable.

The data logger system should have at least a four-channel capacity including the provision for the recording of temperatures. The read-out of the pyrheliometer signals shall be synchronous within 1 s and the rate of instantaneous measurement should be between 1 per 30 s and 1 per 120 s. If the data logger is able to deliver integrated pyrheliometer signals, the integration time should be not longer than about 20 min.

6 Calibration procedure

The calibration procedure comprises the preparation of the equipment, the data sampling and the mathematical treatment.

6.1 Preparation

6.1.1 Installation

Install and align the reference and the field pyrheliometers either together on one, or separately on two, sun-tracking mount(s) at least 30 min prior to starting the first measuring series (this 30 min interval allows equilibrium of the instruments with the ambient air temperature). Ensure that the distance between separately mounted instruments is less than 20 m.

NOTES

10 The sun trackers(s) may be operated manually.

11 Large distances between instruments can influence the results because of the inhomogeneity of the direct irradiance due to structured turbidity elements in the atmosphere.

Connect and switch on the data acquisition system to allow it to warm up at least 30 min prior to taking measurements. Follow all installation and operational procedures specified in applicable instruction manuals.

If required, install wind screens around or in front of the pyrheliometers that have open occluder or diaphragm tubes to prevent high speed winds (gusts) from disturbing the measurements.

6.1.2 Adjustments and tests

Adjust the pyrheliometers on their trackers, and the trackers, to align the instruments to the sun immediately prior to beginning the calibration measurements. Use the diopters or the sighting mechanisms provided for this purpose.

Carry out the checks for zero-point, polarity and nominal strength of signals, and reference voltages in accordance with the applicable instruction manuals.

6.1.3 Cleaning

Clean the windows of enclosed pyrheliometers prior to taking measurements.

6.2 Data sampling

Divide the measuring period into a minimum of 10, and preferably 20, data-taking sequences (measuring series or sets) 10 min to 20 min in length. Specify each series by the applicable mean solar elevation angle, the mean air temperature and the mean value of the atmospheric turbidity.

Take and record a minimum of 10 instantaneous readings or at least 1 integrated value during each measuring series.

NOTES

12 If it is necessary to determine the dependence of calibration factors on parameter values such as temperature, turbidity, solar elevation, etc., carry out a larger number of measuring series than specified above.

13 Owing to the operation mode of reference pyrheliometers it is frequently not possible to compare values which have been integrated over periods of longer than a few seconds. In this case, the minimum number of integrated data readings should also be 10.

Measure zero-points and other reference values immediately before and after each measuring series.

Determine the standard deviations of the measured values from the reference and from the field instrument within each series and between the average values of each series in order to determine the reliability of the data recorded (see 6.3.3).

Record all operational problems as well as any special environmental conditions and experimental arrangements in a log-book.

6.3 Mathematical treatment

6.3.1 Determination of calibration factor

6.3.1.1 From each reading i within a measuring series j, calculate

$$F(i,j) = \frac{E_{SP}(i,j)}{V_{FP}(i,j)} \qquad \ldots (1)$$

where

$E_{SP}(i,j)$ are the irradiance values of direct solar radiation given by the reference pyrheliometer;

$V_{FP}(i,j)$ are the signals of the field pyrheliometer (zero-value subtracted as specified in the instrument operation instructions).

6.3.1.2 Determine the preliminary calibration factor $F(j)$ of the field pyrheliometer from the n readings of a measuring series j using the following formula:

$$F(j) = \frac{\sum_{i=1}^{n} E_{SP}(i,j)}{\sum_{i=1}^{n} V_{FP}(i,j)} \qquad \ldots (2)$$

6.3.1.3 Derive the final calibration factor F of the field pyrheliometer from the total number m of measuring series using the formula:

$$F = \frac{1}{m} \sum_{j=1}^{m} F(j) \qquad \ldots (3)$$

6.3.2 Data rejection

If it has been noted in the log-book that data have been subject to operational problems, reject the corresponding data from all pyrheliometers.

Also reject the data if $F(i,j)$ [see equation (1)] deviates by more than ± 2 % from $F(j)$ [see equation (2)].

NOTE 14 According to experience, a deviation of 2 % indicates a disturbed value (see also the rejection procedure given in [6]).

Calculate the value of $F(j)$ using the "filtered" data and the final calibration factor F [using equation (3)] from the "filtered" data.

6.3.3 Statistical analysis

As a measure of the stability of the calibration conditions during a measuring series, determine the standard deviation of the $F(i,j)$ values from the $F(j)$ values. Determine the standard deviation of the $F(j)$ values from the F values; these represent the stability of the instrument and of the conditions during the whole calibration period.

7 Uncertainty

If the reference pyrheliometer is not a primary standard pyrheliometer, the uncertainty in the derived calibration factor of the field pyrheliometer is additionally influenced by the uncertainty in the calibration factor of the reference standard used (this is the so-called transfer uncertainty).

The uncertainty in the primary standard pyrheliometer is approximately $\pm$ 0,3 % (1σ). The transfer uncertainties depend on the meteorological conditions and on the performance of the pyrheliometer, and in particular on the distribution of circumsolar radiation and the view angle of the pyrheliometer. The uncertainty is lowest when all pyrheliometers in the chain of calibration transfer have the same view (and slope) angles or when the circumsolar radiation is small and strongly forward directed.

The mean uncertainty in the calibration procedure of a secondary standard pyrheliometer is approximately $\pm$ 0,3 %.

The uncertainty in the derived factor of a field pyrheliometer depends on the types of instruments and on the conditions during calibration.

NOTE 15 The influence of circumsolar radiation on the results of Angström-Compensation-Pyrheliometers is dealt with in [7] and [8].

8 Documentation

8.1 Certificate of calibration

The certificate of calibration shall state at least the following information:

a) the calibration method (reference);

b) the manufacturer, type, model and serial number of the field pyrheliometer;

c) the manufacturer, type, model and serial number of the reference pyrheliometer; a concise statement of the traceability of the calibration factor of the reference pyrheliometer to the primary reference pyrheliometer (WRR) shall be given;

d) the calibration conditions, i.e. the range of mean air temperature, the range of solar elevation angles, the range of turbidity (e.g. Linke turbidity factor), the range and the arithmetic mean value of the wind speed, and the range of irradiances;

e) the number of evaluated single measurements and the number of measuring days;

f) the results of the calibration derived from 6.3.1.3, which should be given as a calibration factor expressed in appropriate units, e.g. watt per square metre per millivolt ($W.m^{-2}{\cdot}mV^{-1}$). For some types of pyrheliometer the physical unit may differ from that stated. In special cases, however, arithmetic mean values may be given as a function of meteorological variables. (The scale used should be that of the World Radiometric Reference (WRR), see [1].)

8.2 Data storage

The raw data obtained during the calibration should be stored for at least 5 years, or until the next successful calibration has been completed, but preferably for the life of the instrument.

Annex A
(informative)

Calculated percentages of circumsolar radiation contained in direct solar radiation

Table A.1 gives an overview of the possible effect of aerosols on the relative contribution of circumsolar radiation $E_{s,rel}(\alpha)$ to the irradiance of direct solar radiation measured by means of pyrheliometers with different field-of-view angles α (see ISO 9060).

Four types of aerosol [urban, continental (background), maritime and desert] and three values (0,05, 0,2 and 0,4) of the spectral optical thickness δ_p (λ = 550 nm) which are respective measures of a low, medium and high total amount of aerosol particles are considered; the corresponding spectral Linke turbidity factors T (λ = 550 nm) are approximately 1,8, 3,4 and 5,4.

The percentages of circumsolar radiation given are for solar elevation angles γ = 60° and γ = 20°.

Table A.1 — Circumsolar radiation values for various atmospheric conditions

Aerosol			γ	$E_s(\alpha = 32')$ W·m⁻² (sun disc)	$E_{s,rel}(\alpha)$ %		
Type	δ_p (λ = 550 nm)	T (λ = 550 nm)			α = 5°	α = 10°	α = 20°
Urban	0,05	1,8	60°	985	0,1	0,2	0,5
	0,2	3,4		872	0,3	0,7	1,7
	0,4	5,4		746	0,5	1,3	3,1
	0,05	1,8	20°	736	0,1	0,5	1,2
	0,2	3,4		555	0,5	2,6	3,9
	0,4	5,4		389	1,2	2,9	6,9
Continental (background)	0,05	1,8	60°	979	0,4	0,6	1,0
	0,2	3,4		851	0,8	2,1	3,7
	0,4	5,4		707	1,8	4,1	7,3
	0,05	1,8	20°	725	0,7	1,4	2,6
	0,2	3,4		514	2,4	5,1	9,3
	0,4	5,4		328	4,1	9,8	17,6
Maritime	0,05	1,8	60°	972	0,7	1,2	1,8
	0,2	3,4		826	2,8	4,6	6,8
	0,4	5,4		668	5,2	9,1	13,4
	0,05	1,8	20°	711	1,6	2,9	4,5
	0,2	3,4		473	6,6	11,5	17,1
	0,4	5,4		275	12,9	22,7	33,6
Desert	0,05	1,8	60°	979		0,4	0,9
	0,2	3,4		852		1,4	3,1
	0,4	5,4		708		2,7	6,1
	0,05	1,8	20°	724		0,9	2,2
	0,2	3,4		511		3,4	7,7
	0,4	5,4		325		6,5	14,5

Annex B
(informative)

Bibliography

[1] World Meteorological Organization, *Guide to Meteorological Instruments and Methods of Observation*, No. 8, 5th edition, WMO, Geneva, 1983.

[2] ASTM 816-81, *Method for calibration of secondary reference pyrheliometers and pyrheliometers for field use.*

[3] EIDEN, R. Calculations and measurements of the spectral radiance of the solar aureole. *Tellus*, 1968, vol. 20, No. 3, pp. 380-399.

[4] THOMALLA, E., KÖPKE, P., MÜLLER, H. and QUENZEL, H. Circumsolar radiation calculated for various atmospheric conditions. *Solar Energy*, 1983, vol. 30, No. 6, pp. 575-587.

[5] ANGSTRÖM, A. and RODHE, B. Pyrheliometer measurements with special regard to the circumsolar sky radiation. *Tellus*, 1966, vol. 10, No. 1, pp. 25-32.

[6] GRÉGOIRE, P. *Pyrheliometer Comparison.* Trappes: Météorologie Nationale S.E.T.I.M., 1984.

[7] MAJOR, G. A method for determining the circumsolar sky function. *Tellus*, 1980, vol. 32, No. 4, pp. 340-347.

[8] MAJOR, G. An effect of the circumsolar sky radiation on the Angström Pyrheliometer scale. *Tellus*, 1973, vol. 25, No. 4, pp. 396-399.

UDC 551.521.1:535.214.4.089.6

Descriptors: solar energy, solar radiation, radiation measurement, radiation measuring instruments, pyrheliometers, calibration.

Price based on 7 pages