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Plastics — Methods for the calibration of black-standard and white-standard thermometers and black-panel and white-panel thermometers for use in natural and artificial weathering

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National foreword

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A list of organizations represented on this committee can be obtained on request to its secretary.

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Plastics - Methods for the calibration of black-standard and white-standard thermometers and black-panel and white-panel thermometers for use in natural and artificial weathering

Plastiques - Méthodes d'étalonnage des thermomètres à étalon noir et à étalon blanc et des thermomètres à panneau noir et à panneau blanc pour utilisation en vieillissement naturel et artificiel

Kunststoffe - Kalibrierverfahren für Schwarz- und Weißstandard-Thermometer und Schwarz- und Weißtafel- Thermometer für die Verwendung bei natürlicher und künstlicher Bewitterung

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European foreword

This document (EN 16465:2015) has been prepared by Technical Committee CEN/TC 249 “Plastics”, the secretariat of which is held by NBN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by March 2016, and conflicting national standards shall be withdrawn at the latest by March 2016.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

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Introduction

The relevant weather factors with regard to material testing both outdoors and in devices include natural and simulated solar radiation, heat, humidity and rain as well as pollutants in the air.

Different technologies are available to simulate natural solar radiation in a weathering device. One category of exposure devices, which include xenon-arc weathering devices and devices using metal halide gas discharge radiation source, is designed to simulate the entire spectral range of natural solar radiation. In these instruments and like natural solar radiation, the ultraviolet, the visible and the infrared radiation during exposure increases the specimen surface temperature above the ambient air temperature of the surrounding air.

As an influencing weathering variable, heat is characterized by the sample surface temperature. Absorbed solar radiation can heat the surface to a temperature up to a ΔT of more than 40 K above ambient air. The possible surface temperature is characterized by a white panel or white standard temperature as its lower limit, and a black panel or standard temperature as its upper limit. It is then assumed that the actual sample temperature lies between the two cited limits. Surface temperatures of specific specimens can be higher or lower (e.g. massive black polymers and transparent polymers). The white panel/standard and black panel/standard temperatures can be easily determined using conventional measuring techniques.

In one category of exposure devices, only the short UV range of the natural solar radiation is simulated with fluorescent UV radiation source radiation. In these devices, there is no significant increase in surface temperature of a specimen, because these radiation sources have no significant visible and infrared radiation.

An additional category of exposure devices uses a mercury medium pressure radiation source to induce critical photo-degradation reactions that are typical of natural solar exposures. Even this specific radiation source does not provide significant visible and infrared radiation. For this reason, as in the previous category, these exposures do not increase significantly the specimen surface temperature above ambient.

NOTE For fluorescent UV and mercury medium pressure radiation sources, the ambient air temperature surrounding the specimen is the main variable influencing the specimen temperature. The relative humidity may have a small effect on the specimen temperature as well.

Black/white standard thermometers and black/white panel thermometers are defined in EN ISO 4892-1. They are used in weathering applications to characterize the temperature level (maximum and minimum temperature) under given weathering exposure conditions. The accuracy of these thermometers depends on their design and especially on a well-defined and traceable calibration method. Such methods are the content of this standard.

Two methods are defined in this standard. Each method requires calibration of a black panel/standard or white panel/standard to a traceable reference from a national metrological institute (NMI).

Historically, the contact calibration method (e.g. calibration in a water bath) has been used for weathering applications: recently a contactless calibration method has been developed.

Any requirement to use one method versus the other method is not justified, and both calibration methods are suitable for most weathering applications. However, because of a lack of data comparing the two methods as of the time of publication of this standard, preference or equivalency of results for these two methods is unknown. Both methods may provide different calibration results that are not interchangeable.

The European Committee for Standardization (CEN) draws attention to the fact that it is claimed that compliance with Method B of this document may involve the use of European patent EP1500920, concerning the surface temperature calibration process discussed in 7.2.3.

CEN takes no position concerning the evidence, validity and scope of these patent rights. The holder of these patent rights has ensured CEN that he is willing to negotiate licenses under reasonable and non-discriminatory terms and conditions with applicants throughout the world. In this respect, the statement of the holder of these patent rights is registered with CEN. Information may be obtained from:

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1 Scope

This European Standard specifies traceable calibration methods of black-standard thermometers (BST), white-standard thermometers (WST), black-panel thermometers (BPT) and white-panel thermometers (WPT) for use in natural and artificial weathering:

— method A, a contact method, uses a traceable calibrated resistance standard thermometer;

— method B, a contactless method, uses a traceable calibrated pyrometer.

A basic design of types of the thermometers is described in EN ISO 4892-1.

NOTE 1 Historically method A has been used for weathering applications for many years: Method B has been developed recently. Both methods are qualified for weathering applications. They may provide different calibration results that are not interchangeable.

NOTE 2 Annex A gives information on the characteristics of BST/WST and BPT/WPT.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN ISO 291, *Plastics — Standard atmospheres for conditioning and testing (ISO 291)*

EN ISO 4892-1, *Plastics — Methods of exposure to laboratory light sources — Part 1: General guidance (ISO 4892-1)*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
master reference thermometer
MRT
instrument traceable to a national metrological institute (NMI)

3.2
reference calibration thermometer
RCT
instrument used in an accredited calibration laboratory to calibrate a field calibration thermometer (FCT)

3.3
field calibration thermometer
FCT
instrument used to realize a standard measurement value with respect to a recognized master reference thermometer with a stated path of traceability to recognized standards and a stated measurement uncertainty

Note 1 to entry: Field calibration thermometers are used to calibrate BST/BPT or WST/WPT field thermometers in weathering devices (for daily use).

3.4
field thermometer
instrument used permanently outdoor or in a laboratory accelerated-weathering device used for the routine measurement of temperature, with a calibration traceable to a reference calibration thermometer

4 Abbreviated terms

BPT black-panel thermometer (uninsulated black panel thermometer)

BST black-standard thermometer (or insulated black panel thermometer)

MRT master reference thermometer

NMI national metrological institute

RTD resistance thermometer detector

WPT white-panel thermometer (uninsulated white panel thermometer)

WST white-standard thermometer (or insulated white panel thermometer)

5 Principle

To characterize surface temperature of specimens which are exposed to weathering conditions, either BST and WST or BPT and WPT are used, all of them combining a coated panel, an electrical sensor element, and a monitoring system.

The thermometer to be calibrated is exposed to natural or artificial radiation under controlled conditions and adjusted to the temperature reading of an independent and traceable temperature measuring system.

Method A is a contact method using a master reference thermometer traceable to a NMI standard thermometer and method B is a non-contact method using a master reference pyrometer traceable to a NMI standard thermometer.

Any requirement to prefer one method versus the other method is not permitted. However, because of a lack of data comparing the two methods as of the time of publication of this standard, equivalency of results of these two methods is unknown.

6 Method A

6.1 General

This calibration method consists of the calibration (contact method) and additional verification in a test chamber with exposure to a radiation source.

6.2 Apparatus

6.2.1 Master reference thermometer

A master reference thermometer that is calibrated traceable to a national metrology institute (NMI) and/or a designated institute (DI) is required. Recalibration by a qualified laboratory shall be performed every year.

The requirements for the master reference thermometer are the following:

- temperature range: 0 °C to 140 °C;
- Uncertainty: (k = 2) ± 0,2°C.

6.2.2 Thermally insulated device

A thermally insulated device constructed from inert material, e.g. an insulated beaker or a dewar, shall be used. The thermally insulated device should be filled with a liquid medium and equipped with a stirrer to avoid significant temperature gradients.

6.2.3 Test chamber

The test chamber shall be constructed from inert material and shall be equipped with a blower system that generates a defined airflow to be directed across the sample(s).

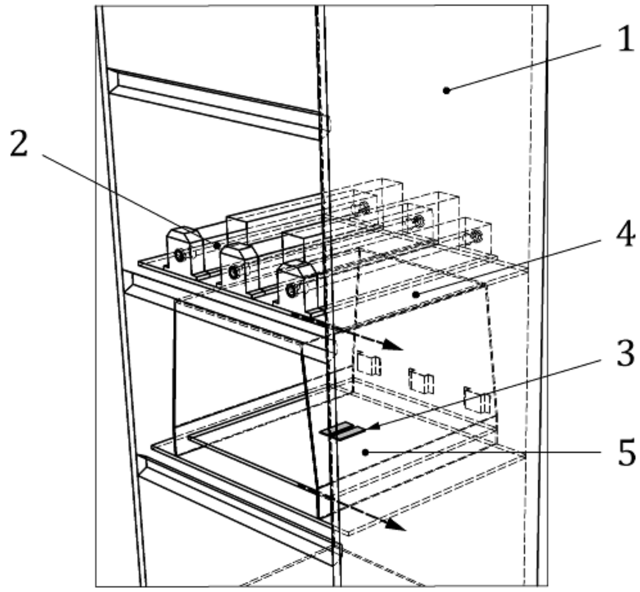
6.2.4 Radiation source

Xenon-arc radiation sources or metal halide radiation sources are suitable as radiation sources. The radiation output of the radiation source shall be able to be regulated.

6.2.5 Sample holder

The test chamber shall be provided with a holder which ensures a defined position of the coated surface of the reference calibration thermometer and of the thermometer being calibrated with respect to the radiation source and to the airflow. The orientation of the irradiated plane of the reference calibration thermometer and the thermometer being calibrated shall be parallel to any arbitrary plane running through the radiation source, as shown in Figure 1.

The thermometer to be calibrated shall be next to the reference calibration thermometer.



Key

1 test chamber

2 radiation source

3 reference calibration thermometer and field calibration thermometer

4 plane of light source(s)

5 plane of the reference calibration thermometer and field calibration thermometer

Figure 1 — Example of parallel orientation of black panel plane compared to the plane of full spectrum radiation source(s)

6.2.6 Air flow

Provision shall be made such that there is airflow at the surface of the reference calibration thermometer and the field calibration thermometer. The difference between the chamber air temperature and the reference calibration thermometer should be approximately 15 K to 25 K for BPT/BST and 0 K to 10 K for WPT/WST.

6.2.7 Ambient air

The test chamber shall contain a measuring instrument to register the ambient air temperature.

6.3 Calibration procedure

6.3.1 Principle

A reference calibration thermometer is calibrated to the master reference thermometer (MRT) at different temperatures within the expected range. To ensure accuracy of the procedure, a series of three reference calibration thermometers shall be used. Each reference calibration thermometer shall be capable to measure within 0,5 °C of each other.

The master reference thermometer and one of the three reference calibration thermometers are then used to calibrate the field calibration thermometer. Field calibration thermometers may be used to calibrate BST/BPT or WST/WPT field thermometers in weathering devices.

The reference calibration thermometer, the field calibration thermometer and the field thermometer are similar in construction and in accordance with EN ISO 4892-1.

6.3.2 Calibration procedure

6.3.2.1 Procedure for calibrating reference calibration thermometers

6.3.2.1.1 Place a minimum of three reference calibration thermometers and a master reference thermometer (MRT) into the thermally insulated device. Fill the device with a suitable liquid at approximately 0 °C and allow time for equilibrating the liquid and the thermometers. Circulate or stir the liquid to ensure temperature uniformity within the thermally insulated device. Repeat this step at approximately 100 °C.

Adjust the reference calibration thermometers by an offset p calculated by using Formula (1).

$$p = \frac{1}{2}\left[\left(T_{M1} + T_{M2}\right) - q\left(T_{C1} + T_{C2}\right)\right] \quad (1)$$

where

p is the offset, expressed in degrees Celsius (°C);

q is the slope, expressed as a dimensionless ratio, calculated by using Formula (2);

$$q = \frac{T_{M2} - T_{M1}}{T_{C2} - T_{C1}} \quad (2)$$

T_{M1} is the temperature measured by the master reference thermometer at low temperature, expressed in degrees Celsius (°C);

T_{M2} is the temperature measured by the master reference thermometer at high temperature, expressed in degrees Celsius (°C);

T_{C1} is the value measured by the reference calibration thermometer to be calibrated at low temperature, expressed in degrees Celsius (°C);

T_{C2} is the value measured by the reference calibration thermometer to be calibrated at high temperature, expressed in degrees Celsius (°C).

NOTE A linear relationship between the reference calibration thermometer and the master reference thermometer is assumed.

6.3.2.1.2 Place the three reference calibration thermometers on the sample holder in the test chamber (6.2.3), in a first position. Operate the test chamber and the radiation source to allow a BPT/BST of approximately 90 °C or a WPT/WST temperature of approximately 65 °C. Allow the chamber conditions to stabilize and record the reference calibration thermometer temperature. Move the reference calibration thermometers to a second position on the sample holder and repeat the procedure. Record the average temperature of the two positions. Decrease the temperature in the test chamber to approximately 50 °C if using a BPT/BST or approximately 40 °C if using a WPT/WST. Repeat the described steps.

The maximum allowable difference between any two of the reference calibration thermometer average temperature readings is 0,5 °C. This combined procedure allows to detect technical or mechanical damages, e.g. loose wiring, bad thermal contacts or scratched coatings and increases the reliability and certainty of the calibration process. Therefore it not allowed to carry out only one part of the combined procedure mentioned above.

NOTE For details of handling see ASTM G 179 [1].

At least one of the minimum three reference calibration thermometers shall be retained as a primary reference temperature device for use in 6.3.2.2. This primary reference calibration thermometer shall be stored in a 23/50 standard atmosphere according to EN ISO 291 and shielded from any radiation source.

6.3.2.2 Procedure for calibration of the field calibration thermometer

Repeat the calibration steps described above (6.3.2.1.1 to 6.3.2.1.2.) with the following changes:

a) for the step described in 6.3.2.1.1 replace the three reference calibration thermometers by the field calibration thermometer being calibrated;

NOTE One field calibration thermometer is sufficient.

b) for the step described in 6.3.2.1.2 the field calibration thermometer is validated against one of the primary reference calibration thermometers in two different positions.

6.4 Calibration report

The calibration report shall include the following information:

a) a reference to this European Standard and the relevant method (i.e. EN 16465, method A);

b) the name and address of the laboratory where the measurements are carried out;

c) all the information necessary for identification of the field calibration thermometer;

d) information regarding the method used;

e) a description of the as-received condition of the field calibration thermometer;

f) the laboratory conditions, i.e. the temperature and the relative humidity;

g) the test results, i.e. the initial and adjusted temperature reading of the field calibration thermometer and the deviation from the master reference thermometer, expressed in degrees Celsius;

h) data regarding the measurement uncertainty;

i) the date of calibration.

7 Method B

7.1 Apparatus

7.1.1 General

The calibration equipment comprises a test chamber, a radiation source which generates UV-, VIS and infrared radiation similar to solar radiation with an appropriate filter system providing appropriate cooling to the radiation source and filters and a contactless surface temperature device (pyrometer).

NOTE 1 For outdoor weathering, the actual temperature of BST/BPT is often out of the calibration range of Method B.

NOTE 2 By calculation the temperature gradient from front to back side of the black coated metal plate of a BST is smaller than 0,1 K. In practice, the temperature gradient is higher. This might lead to different test results in weathering devices if BST are not calibrated according to the same method.

7.1.2 Test chamber

The test chamber shall be constructed from inert material and shall be equipped with a blower which generates a defined airflow to be directed across the sample.

7.1.3 Radiation source

Xenon medium pressure radiation sources and metal halide radiation sources are suitable as radiation sources. The irradiance of the source shall be adjustable, e.g. by the variation of the electrical power.

7.1.4 Holder

The apparatus shall contain a holder which permits a defined positioning of the surface of the thermometer being calibrated with respect to the radiation source and to the airflow.

The sensor holder shall permit a defined orientation of the coated surface towards the radiation source and with respect to the airflow. The orientation of the irradiated plane of the sensor shall be parallel to the radiation source. In addition the surface of the radiated plane shall be horizontal with respect to the radiation source.

The surface of the thermometer to be calibrated may be perpendicular to the observation angle of the pyrometer.

If the thermometer to be calibrated is not perpendicular to the observation angle of the pyrometer, a cosine-correction has to be applied.

7.1.5 Air flow

Provision shall be made that there is airflow at the surface of the thermometer being calibrated. The temperature of that surface should be higher than the air temperature of the test chamber. Approximate minimum values are 15 K for a BST/BPT and 10 K for WST/WPT.

7.1.6 Blower

The blower directs airflow across the coated surface of the thermometer to be calibrated.

A blower and power supply with controlled air flow characteristics may be used.

7.1.7 Pyrometer

The pyrometer shall be traceable calibrated to a national or international standard. Recalibration by a qualified laboratory shall be performed every year.

The minimum requirements for the pyrometer are as follows:

— temperature range: 20 °C to 150 °C (traceable calibrated with blackbody radiator);

— spectral response: 8 µm to 14 µm;

— IR detector: e.g. silicon based thermopile;

— uncertainty: ± 0,6 % (in the considered temperature range);

— spot size (diameter): maximum 30 mm.

7.1.8 Chamber air temperature and relative humidity

Measuring instrument(s) that record(s) the air temperature and the relative humidity while being shielded from irradiation during the calibration shall be installed in the test chamber. A temperature accuracy of ± 0,5 K and relative humidity accuracy of ± 5 % RH are adequate.

7.2 Calibration procedure

7.2.1 Principle

The black panel is irradiated by the radiation source. A defined airflow is directed across the panel. Non-contact surface temperature measurement in the spectral range between 8 µm and 14 µm is performed by a traceable calibrated pyrometer. The ambient air temperature and relative humidity may be recorded.

7.2.2 Emissivity (ε)

The temperature of a given object can only be measured correctly if its exact emissivity (ε) in the wavelength range between 8 µm and 14 µm is known and the pyrometer is set up accordingly. The emissivity (ε) of a surface is the ratio between the level of radiation emitted by this surface and the level of radiation emitted by a black body radiator at the same temperature..

The emissivity (ε) of a coated surface can be measured by an appropriate laboratory. In principle the emissivity (ε) is dependent on wavelength, temperature and angle of emission.

7.2.3 Calibration process

Temperatures of approximately 35 °C and approximately 100 °C for BST and BPT, respectively, and 30 °C and 70 °C for WST and WPT, respectively, are adjusted at the surface to be calibrated.

The pyrometer measures the set point for the surface temperature (T_{P1} (low temperature) and T_{P2} (high temperature)) at both temperature adjustments.

The thermometer, being calibrated, measures the actual value [T_{R1} (low temperature) and T_{R2} (high temperature)].

The offset p and the slope q are calculated from these four values by using Formulae (3) and (4). Then they are used as the basis for calculation of the surface temperature $T_{surface}$ by using Formula (5) under practical conditions in weathering application.

$$q = \frac{T_{P2} - T_{P1}}{T_{R2} - T_{R1}} \tag{3}$$

$$p = \frac{1}{2}\left[\left(T_{P1} + T_{P2}\right) - q\left(T_{R1} + T_{R2}\right)\right] \tag{4}$$

where

- q is the slope, expressed as a dimensionless ratio;
- p is the offset, expressed in degrees Celsius (°C);
- T_{P1} is the surface temperature measured by the pyrometer at low temperature, expressed in degrees Celsius (°C);
- T_{P2} is the surface temperature measured by the pyrometer at high temperature, expressed in degrees Celsius (°C);

T_{R1} is the actual value measured by the thermometer at low temperature, expressed in degrees Celsius (°C);

T_{R2} is the actual value measured by the thermometer at high temperature, expressed in degrees Celsius (°C).

NOTE A linear relation between T_{RTD} and T_{PYR} is assumed.

$$T_s = p + qT_R \quad (5)$$

where

T_s is the surface temperature, expressed in degrees Celsius (°C);

q is the slope, expressed as a dimensionless ratio;

p is the offset, expressed in degrees Celsius (°C) ;

T_R is the actual value measured by the thermometer, expressed in degrees Celsius (°C).

After performing the calibration procedure check the calibration formula of the calibrated sensor at three different temperature points.

7.3 Calibration report

The calibration report shall include the following information:

a) a reference to this European Standard and the relevant method (i.e. EN 16465, method B);

b) the name and address of the laboratory where the measurements are carried out;

c) all the information necessary for identification of the thermometer calibrated;

d) information regarding the procedure used;

e) the description of the condition of the thermometer being calibrated;

f) the laboratory conditions: temperature and relative humidity;

g) the test results, i.e. T_{P1}, T_{P2}, T_{R1}, T_{R2} and the offset (p), expressed in degrees Celsius, and the slope (q), expressed as a dimensionless ratio;

h) data regarding the measurement uncertainty;

i) the date of calibration.

Annex A
(informative)

Characteristics of BST/WST and BPT/WPT

The black and white panel thermometers (BPT/WPT) have been developed at first to measure the limited surface temperatures at weathering tests (highest and lowest level). However, there are different sensor types available that can lead to different temperatures. At a later date, it has been realized that the black panel thermometers with no insulation on the back side do not characterize the possible maximal surface temperature of maximal absorbing massive polymer samples. This was the start for the development of a sensor element, the so called black standard thermometer (BST), which is provided with insulation on the back of the coated base sensor element.

The black panel as well as the black standard thermometer are equipped, at least at the irradiated side, with a black coating that absorbs as much as possible all incident radiation. Both thermometer types are described in EN ISO 4892-1. The white panel or white standard thermometer is described as well as an additional resource.

With regards to the sensor, the most important characteristics which have an influence on the measured surface temperature are the following:

a) the dimensions;

b) the ageing durability of the black or white coated surface;

c) the spectral reflectance of the black or white coating;

d) the base material of the coated plate;

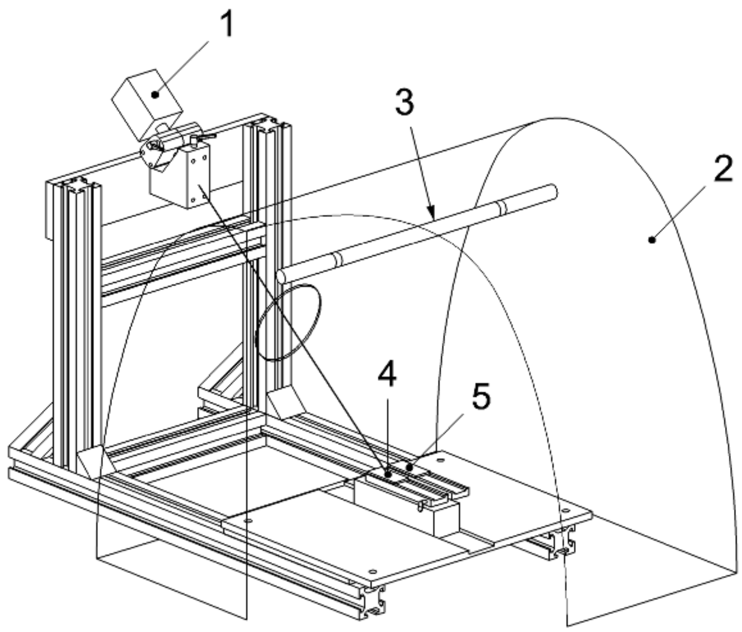
e) the method used to attach the thermometer;

f) the quality of the thermal contact of the electrical sensor on the back (black or white standard) or on the front side (black or white panel) of the base material;

g) the type and thickness of any insulation at the rear side of the panel. It is very important to cause very good heat contact between the black panel and the RTD.

Annex B
(informative)

Example of calibration equipment



Key

1 pyrometer

2 test chamber

3 xenon radiation source

4 surface temperature sensor

Figure B.1 — Example of calibration equipment

Bibliography

[1] ASTM G179, *Standard Specifications for Metal Black Panel and White Panel Temperature Devices for Natural Weathering Tests*

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