

ICS 97.195

English Version

Conservation of Cultural Property - Procedures and instruments  
for measuring temperatures of the air and the surfaces of  
objects

Conservation des biens culturels - Méthodes et instruments  
de mesure de la température de l'air et de la surface des  
objets

Erhaltung des kulturellen Erbes - Verfahren und Geräte zur  
Messung der Temperatur der Luft und der Oberflächen von  
Gegenständen

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**Contents**

Page

Foreword.....	3
Introduction .....	4
1 Scope .....	5
2 Normative references .....	5
3 Terms and definitions .....	5
4 Recommendations relating to measuring methods.....	8
4.1 Measurement of air temperature .....	8
4.2 Measurement of the effective temperature including radiant contribution.....	8
4.2.1 Black-globe thermometer .....	8
4.2.2 Measuring temperature with a blackbody strip target.....	8
5 Measurement of surface temperature .....	9
5.1 General.....	9
5.2 Thermometers with contact sensors .....	9
5.3 Infrared thermometers (remote temperature sensors) .....	10
5.4 Quasi-contact thermometers .....	10
6 Recommendations relating to variations in space of the thermal quantities .....	11
6.1 General.....	11
6.2 Recommendations relating to variations in time of the thermal quantities .....	11
6.3 Specifications relating to measuring instruments .....	11
7 Calibration .....	11
Annex A (normative) Characteristics of measuring instruments .....	13
Bibliography .....	14

## Foreword

This document (EN 15758:2010) has been prepared by Technical Committee CEN/TC 346 "Conservation of Cultural Property", the secretariat of which is held by UNI.

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of an identical text or by endorsement, at the latest by March 2011, and conflicting national standards shall be withdrawn at the latest by March 2011.

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## Introduction

This standard is intended to assist in providing an acceptable environment for tangible cultural heritage. The temperature of the air and of object surfaces constitute important aspects of that environment. Temperature is one of the factors which can have a profound effect on the preservation of objects. Physical characteristics of materials change as they absorb or release heat. Objects expand and contract as the temperature changes, become rigid and brittle if the temperature falls below the glass transition temperature, or are mechanically damaged by the melting and freezing of water. The rates of some important chemical reactions, such as the degradation of cellulose (paper, textiles) increase with rising temperature. Temperature influences the activity of fungi and insects responsible for the bio-deterioration of organic materials. Temperature may affect some minerals and masonry crystallisation. Temperature also has an important indirect effect: a rise in temperature causes lowering of the relative humidity, which results in the drying of moisture absorbing materials such as wood, paper or leather. Such drying may lead to shrinkage and embrittlement. When direct radiation from sun, lamps or radiant heaters reaches objects, the consequent temperature rise causes drying even when the relative humidity of the surrounding air remains constant. Whatever the air temperature, the water vapour may condense on cold surfaces if their temperature drops below the dew point.

The control of levels and variability of temperature contributes to a proper environment for cultural property and thereby reduces the risk of deterioration. Such control is an important preventive measure which will minimise the need for future conservation interventions.

This standard recommends procedures for measuring the temperature of the air and of the surfaces of cultural property in indoor and outdoor environments as well as specifying the minimum characteristics of instrument for such measurements. Although standards exist for measuring the air or surface temperature in other fields like meteorology, industry or medicine, this standard focuses on the specific requirements of cultural property. One of the main concerns has been the use of non-contact or remote methods to make possible measuring temperatures of fragile and precious surfaces without any physical contact. However, taking measurements of the object surface, whether using contact or non-contact methods, involves a degree of risk to the object and should not be undertaken without clear justification nor without consultation with a suitably qualified and experienced conservator, preferably as part of an interdisciplinary team.

This document is one of the series of European Standards intended for use in the study of environments of cultural property.

Any measuring system which meets or exceeds the requirements of this European Standard can be used. The description or listing of certain instruments signifies only that they are recommended. It is up to users to analyze the quality of instruments available on the market and verify whether they conform to this document.

## 1 Scope

This European Standard recommends the procedures for measuring the temperature of the air and of the surfaces of cultural property in indoor and outdoor environments, as well as specifying the minimum characteristics of instruments for such measurements.

This document contains recommendations for accurate measurements to ensure the safety of objects and it is addressed to any people with the responsibility of the environment, its diagnosis, the conservation or maintenance of buildings, collections, or single object.

## 2 Normative references

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

EN ISO 7726:2001, *Ergonomics of the thermal environment — Instruments for measuring physical quantities (ISO 7726:1998)*

## 3 Terms and definitions

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

### 3.1

#### **air temperature**

**T**

temperature read on a thermometer which is exposed to air in a position sheltered from direct solar radiation or other energy sources

NOTE This is expressed in degrees Celsius (°C).

### 3.2

#### **black-globe thermometer**

thermometer consisting of a black globe in the centre of which is placed a temperature sensor, and which records the effective air-radiant temperature which results from a thermal balance between air temperature, radiation coming from the different heat sources and convective motions

### 3.3

#### **blackbody strip target**

low thermal inertia, blackbody target, like a strip of black textile, which assumes an effective air-radiant temperature resulting from a thermal balance between air temperature, radiation coming from light, heat sources and convective motions

NOTE The surface temperature of the blackbody target is then measured with a quasi-contact or a remote thermometer.

### 3.4

#### **blackbody**

body which absorbs all the ultraviolet, visible and infrared radiation impinging on it, i.e. having surface emissivity 1

### 3.5

#### **contact sensor**

sensor placed in direct physical contact with the surface and devised to reach thermal equilibrium with it

NOTE The sensor may be pressed against the surface or coupled to it with a glue or paste in order to improve the heat exchange and achievement of the thermal equilibrium.

**3.6**

**dew-point temperature**

temperature to which air is cooled at constant pressure and constant water vapour content in order for saturation to occur

NOTE This is expressed in degrees Celsius (°C).

**3.7**

**emissivity**

relative power of a surface to emit heat by radiation expressed as the ratio of the radiant energy emitted by a surface to that emitted by a blackbody at the same temperature

NOTE This ranges from 0 to 1.

**3.8**

**infrared thermometer**

thermometer which permits remote measurements of surface temperature by measuring the flux of infrared radiation emitted and reflected from the target

**3.9**

**measuring range**

interval of values that are intended to be measured, or that are potentially measurable, or that have been measured, specified by their upper and lower limits

**3.10**

**probe**

small device placed in or on the object to make measurements or to protect the sensor

NOTE This is usually designed not to influence significantly the result.

**3.11**

**quasi-contact thermometer**

total radiation thermometer measuring the surface temperature of a target which comprises a sensor located in the focal point of a concave mirror, shielded against the infrared radiation from the surrounding sources

NOTE The thermometer is placed close to the target but not in contact with it. It measures and converts into the temperature the flux of infrared radiation emitted by the target.

**3.12**

**radiometric temperature**

temperature measured with an infrared thermometer

NOTE This is expressed in degrees Celsius (°C).

**3.13**

**repeatability**

ability of the measuring instrument to reproduce the same output when successively measuring the same value of the air or the surface under investigation, taken under the same conditions

NOTE This is expressed as  $\pm$  percent of the range.

**3.14**

**resolution**

smallest difference between indications of a displaying device that can be meaningfully distinguished

**3.15****response time**

time interval between the instant when the air, or the surface temperature, is subjected to a specified abrupt change and the instant when the response reaches and remains within specified limits around its final steady value

NOTE The response time is typically expressed as the time needed to reach 63,2 % of the final value and in this case is called time constant, or 90 % or 95 % of it. The 90 % response time is 2,3 times longer than the time constant and the 95 % response time is three times longer. The response time is independent of the span of the output change.

**3.16****sensor**

device that senses either the absolute value or a change in a physical quantity and converts it into a useful input signal for an information-gathering system

**3.17****stability**

ability of a measuring instrument to keep its metrological characteristics constant over a period of time

NOTE Stability should be expressed in terms of variation of temperature response in a year ( $^{\circ}\text{C}/\text{yr}$ ).

**3.18****surface temperature****TS**

temperature of a given surface of an object

NOTE This can be measured with contact thermometers, quasi-contact total radiation thermometers or remote infrared thermometers. The surface temperature is generally different from the air temperature, and varies between different objects and different places on the same object. It is expressed in degrees Celsius ( $^{\circ}\text{C}$ ). In general, the measured surface temperature is not representative of the whole object.

**3.19****target surface**

surface being in thermal equilibrium with the sensor

**3.20****thermometer**

instrument to measure temperature which comprises a sensor which is placed in thermal equilibrium with the air (if it measures the air temperature) or the surface, sometimes a probe that contains and protects the sensor, and a system that transforms the input from the sensor into an output expressed in degrees Celsius ( $^{\circ}\text{C}$ )

**3.21****time constant**

time interval between the instant when the air, or the surface temperature, is subjected to a specified abrupt change and the instant when the response reaches  $1 - 1/e = 0,632$  (63,2 %) and remains within specified limits around its final steady value

NOTE See also response time.

**3.22****uncertainty (of measurement)**

uncertainty is a non-negative parameter characterizing the dispersion of the values attributed to a measured quantity

## 4 Recommendations relating to measuring methods

### 4.1 Measurement of air temperature

Measurements should only be taken to answer questions which will help to solve environmental or conservation problems and they should always form part of an overall plan for environmental improvement.

Air temperature is monitored to establish a cause-and-effect relationship between atmospheric variables and the response of cultural heritage objects.

When measuring air temperature precautions should be taken to reduce the effect of thermal radiation and inertia of the probe.

Particular care should be taken to shield the air temperature sensors from radiation sources at different temperature levels, e.g.: direct solar radiation, incandescent lamps or radiant heaters. Screens should be made from reflecting materials and should have adequate natural or forced ventilation as described in EN ISO 7726:2001, Annex A. A thermometer placed in a given environment does not indicate the air temperature instantaneously but needs time to reach equilibrium. A measurement should not be made before a period has elapsed equal to at least 1,5 times the time constant of the probe and the output has reached 90 % of the difference between the initial and the equilibrium values. See EN ISO 7726:2001, Annex A for further details.

### 4.2 Measurement of the effective temperature including radiant contribution

#### 4.2.1 Black-globe thermometer

The effective temperature measured by the black-globe thermometer results from a thermal balance including air temperature, radiation from other bodies, object absorbance and convection. The measurement is important to characterize environments affected by intense visible light (from sun, or spot lights), or infrared radiation (from hot surfaces or heaters). The black-globe should absorb both visible and IR parts of the spectrum.

The black-globe-thermometer and the measurement of the effective temperature should conform to the requirements of EN ISO 7726.

The black-globe thermometer has a spherical shape because it was originally introduced for measuring the amount of radiant heat received by the human body. The shape is not appropriate for measurements for objects of very different geometries, for example flat paintings on canvas, wooden panels or tapestry.

The response time is generally long, from 20 min to 30 min, depending on the globe and the ambient conditions.

#### 4.2.2 Measuring temperature with a blackbody strip target

The surface temperature an object will have when hit by radiation shall be simulated and measured as described in the next clauses. This clause is concerned with diagnostics for preventive conservation and is relevant for the measurement of not only air temperature, but also the potential synergism of air temperature, visible and infrared radiation and convective air motions on an object (e.g. paintings on canvas, wooden panels or tapestry). It is particularly useful to know in advance the surface temperature which an object will reach when the object is due to be relocated for temporary or permanent exhibitions, or the environment should be changed for the installation of spot lamps or radiant heaters. The measurement is taken with a blackbody strip target located in the position planned for the object, or placed close to the object without contact with it. The blackbody strip target will simulate what happens to the object without making tests with the object itself. This simulation is representative of most of the materials used for cultural property, except for polished metals that have a very low emissivity and reflect most of the incoming radiation. The method is also useful to assess the level of the thermal comfort for visitors to museums, galleries, churches, historical buildings, etc., where heating should be reduced to a minimum acceptable level and/or to restricted areas.

The effective temperature resulting from a thermal balance between air temperature and radiation is determined with quick and easy measurement on a low thermal inertia, blackbody target, like a strip of black textile. The equilibrium temperature of the blackbody strip target should be accurately measured using procedures for the measurement of surface temperature described below.

A blackbody strip target is useful to measure temperature gradients from vertical or horizontal profiles, with high spatial resolution.

The blackbody strip target should have the following features:

- size representative of the surface of the object under study on the side hit by visible and IR radiation;
- it should be opaque to visible and IR radiation, i.e. show neither light nor IR transmission;
- known, high emissivity, above 0,92;
- known thermal inertia which should be low enough to ensure the required short response time.

## 5 Measurement of surface temperature

### 5.1 General

The surface temperature can be measured by contact thermometers or infra-red thermometers either remote or quasi-contact also called total radiation thermometers.

### 5.2 Thermometers with contact sensors

Contact measurements should be made when necessary and with caution because they are generally obtained by exerting a pressure against the object surface or using an adhesive or a conductive paste to improve the heat exchange between the surface and the sensor in order to reach the thermal equilibrium. Glues and pastes can have an irreversible effect on the surface of objects.

Such a measurement is potentially dangerous to the object. No contact measurement should be undertaken without consultation with an appropriate professional, i.e. in the case of building surfaces a qualified conservation architect and in the case of other heritage items a qualified, experienced conservator.

Contact sensors are usually miniaturized and enclosed in a small probe. The probe has a flat metal surface from one side to provide a good thermal contact with the object surface, and it is insulated from the other side so that the probe is unaffected by air temperature, infrared or visible radiation. Three types of sensors can be used: platinum resistor, thermistor or thermocouple.

NOTE They should conform to EN 60751, EN 60584-1, EN 60584-2, ASTM E879-01.

The probe is in contact with the object surface and alters in this area the heat exchange between the object and the environment. The problem becomes relevant when the object surface is exposed to intense IR or visible radiation; the surface temperature is measured on the area shadowed by the probe and the temperature is underestimated. This is especially a problem on materials with relatively low thermal conductivity.

Heat capacity of the contact thermometers may alter the surface temperature measured on objects of low inertia like paintings on canvas.

Contact measurements are technically possible only on smooth, flat and homogeneous surfaces which provide a good thermal contact with the probe.

Contact measurements are the only correct system for measuring the surface temperature on polished metals. Again great care shall be taken not to mar the surface.

### **5.3 Infrared thermometers (remote temperature sensors)**

Infrared thermometers, also called infrared radiometers, permit non-contact, remote measurement of surface temperature. This is a special advantage in case of surfaces difficult to reach, or mobile objects. However, generally, the uncertainty is high and the repeatability is low.

In infrared thermometers, the IR energy from the observed object is focused on an infrared detector that sends an output signal proportional to the incident radiation. The emission temperature of the surface is calculated from the measured IR flux, which is proportional to the surface emissivity and the fourth power of the surface temperature. However, the surface emissivity should be known or estimated. Once the instrument has reached thermal equilibrium with the environment, measurements are quick and easy.

Two types of infrared thermometers exist: imaging and non-imaging. The former provides an image of the object under examination, reproduced with false colours related to a temperature scale. This is particularly useful to get a general view of the temperature distribution and to recognize heat dispersion. The second provides a digital reading of the target temperature.

Infrared thermometers should be used to monitor the actual value of the surface temperature of an object at a certain instant, or to detect internal discontinuities operating under a dynamic regime, i.e. warming or cooling the object.

Remote sensing is generally characterized by a low accuracy because:

- the incident radiation measured includes also the IR reflected from the surface of the object and emitted by other objects;
- the IR emissivity of the surface is not precisely known.

The uncertainty of the measurements increases when the surface emissivity decreases; metals have very low emissivity and may reflect the thermal image of the operator. This procedure is not appropriate for polished metals but it can be used for heavily oxidized, or painted metals.

Some materials, like glass or plastic, are transparent at some wavelengths. If those coincide with the wavelengths used by the measuring instrument, the procedure cannot be used.

### **5.4 Quasi-contact thermometers**

Quasi-contact thermometers comprise a concave mirror which focuses IR emitted by the target surface on the infrared sensor. The device is placed close to the surface of the object. The external surface of the mirror shields the sensor from the IR from the surrounding radiant field. The internal surface of the mirror entraps, reflects and converges to the sensor the total (i.e. direct and diffused) IR radiation emitted by the object.

Under these conditions the sensor receives only the radiation emitted by the object surface whose emissivity becomes 1, whatever is the actual surface emissivity of the material in the absence of the mirror.

Generally, quasi-contact thermometers are very well suited for measurements of the surface temperature of cultural property:

- no physical contact with the surface, which is particularly advantageous in ensuring the safety of delicate objects;
- possibility of measuring curved, rough, or contaminated surfaces, or those composed of loose fibres. This is particularly advantageous when measuring the temperature of soft materials (e.g. textiles) or of objects with a very low thermal capacity (e.g. a sheet of paper) without the uncertainty generated by the conductive exchange of heat between the sensor and the object;

- knowledge of the surface emissivity where high accuracy is not necessary;
- fast and simple operation.

The surface temperature of polished metals, because of their extremely low surface emissivity, cannot be measured with this method and should be measured with contact sensors.

## 6 Recommendations relating to variations in space of the thermal quantities

### 6.1 General

Outdoor or indoor environments, historic buildings or individual objects generally show temperature distributions due to a complex energy balance, including the presence of heat sources like sunlight, heaters, spotlights, and heat sources and sinks like walls or ceilings, air leakage and doors opened by visitors. It may be necessary to monitor the temperature or temperature gradients of the environment surrounding the object, the surface of the building or the object and maybe inside cavities or spaces internal to the building or the object.

When the environment is thermally heterogeneous, temperature should be measured at one or several locations according to a precise plan, which takes into account locations of objects exposed to thermally induced risks as well as local thermal and airflow pattern. Specific problems to be studied should be defined.

Complex heterogeneous spaces can be divided into limited zones for which different plans for measurements are defined. When monitoring requires an array composed of several sensors, they should be of the same type.

### 6.2 Recommendations relating to variations in time of the thermal quantities

Changes in temperature may be characterised as cyclic or irregularly variable, on the long, medium and short term. Cycling may be seasonal or diurnal or a combination of the two. The variability may be due to weather and may be complicated by patterns of use, such as the entry of visitors and the running of lighting on and off. When the environment cannot be considered stationary, variations of the thermal quantities should be measured as a function of time according to a precise plan, which takes into account specific problems to be studied. Full year measurements are most satisfactory but more limited seasonal periods can be considered depending on the problem studied.

Sampling frequency should be adapted to the time scale, the dynamics and the fluctuations of the phenomena under investigation; so that the shortest variation of interest is well documented.

### 6.3 Specifications relating to measuring instruments

The measuring ranges, uncertainty, repeatability, resolution, response time and stability of the sensors for air and surface temperature are summarized in Table A.1. These characteristics should be considered to be minimum requirements. The "desired" uncertainty is preferable for indoor measurements, for example in museums or show-cases. Instruments should have readings expressed in degrees Celsius (°C).

## 7 Calibration

Measurements shall be performed with instruments periodically calibrated according to EN ISO 7726. At least one instrument (the primary instrument) should be traceable to national standards. The remainder should be of comparable technical quality and should be calibrated and maintained in accordance with EN ISO/IEC 17025. Such comparisons should be periodically made and adequately documented. The primary instrument used as a reference should be of higher class compared with the instruments under calibration. In general, the measurement uncertainty of the reference should be smaller than 1/3 of the uncertainty required for the instruments used.

NOTE The calibration certificate should report, for every temperature, the correction for the instrument reading as well as the related uncertainty in accordance with the European co-operation for accreditation EA 4/02 guideline [21].

## Annex A (normative)

### Characteristics of measuring instruments

Table A.1 — Characteristics of measuring instruments

Instruments	Symbol	Measuring range	Uncertainty	Repeatability	Resolution	Response time	Stability
Thermometer for air temperature	T	Outdoors - 40 °C to 60 °C Indoors - 20 °C to 60 °C	Required 0,5 °C  Desirable 0,2 °C	0,1 °C	0,1 °C	The shortest possible; not longer than 60 s	± 0,2 °C /year
Black globe thermometer	Trg	Outdoors - 40 °C to 100 °C Indoors - 20 °C to 100 °C	Required 1,0 °C  Desirable 0,5 °C	0,5 °C	0,1 °C	The shortest possible; not longer than 20 min	± 0,2 °C /year
Black Strip thermometer	Trs	Outdoors - 40 °C to 100 °C Indoors - 20 °C to 100 °C	Required 1,0 °C  Desirable 0,5 °C	0,5 °C	0,1 °C	The shortest possible; not longer than 200 s	± 0,2 °C /year
Surface temperature (contact or proximity sensors)	Ts	Outdoors - 40 °C to 100 °C Indoors - 20 °C to 80 °C	Required 1 °C + 0,01   T-Ts   Desirable 0,5 °C + 0,01   T-Ts	0,2 °C	0,1 °C	The shortest possible; not longer than 200 s	± 0,2 °C /year
Surface temperature (remote sensors)	Ts	Outdoors - 40 °C to 100 °C Indoors - 20 °C to 80 °C	Required 1 °C + 0,01   T-Ts   Desirable 0,5 °C + 0,01   T-Ts	0,5 °C	0,1 °C	The shortest possible; not longer than 60 s	± 0,2 °C /year

NOTE 1 The reported measuring range is convenient for most purposes; however, for specific purposes the range can be different, provided it includes the maximum and the minimum expectable values.

NOTE 2 The "desirable" uncertainty is preferable for indoor measurements.

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