BS EN 13032-4:2015

BSI Standards Publication

Light and lighting — Light and lighting — Measurement and presentation of photometric data of lamps and luminaires

Part 4: LED lamps, modules and luminaires

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National foreword

This British Standard is the UK implementation of EN 13032-4:2015.

The UK participation in its preparation was entrusted to Technical Committee EL/1, Light and lighting applications.

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

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Lumière et éclairage - Mesure et présentation des données photométriques des lampes et des luminaires - Partie 4: Lampes, modules et luminaires LED

Licht und Beleuchtung - Messung und Darstellung photometrischer Daten von Lampen und Leuchten - Teil 4: LED-Lampen, -Module und -Leuchten

This European Standard was approved by CEN on 19 March 2015.

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Foreword

This document (EN 13032-4:2015) has been prepared by Technical Committee CEN/TC 169 “Light and Lighting”, the secretariat of which is held by DIN.

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of an identical text or by endorsement, at the latest by December 2015, and conflicting national standards shall be withdrawn at the latest by December 2015.

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.

This standard was developed in collaboration with CIE TC2.71, which developed CIE S 025, to produce two technically-harmonized standards at CEN and CIE level.

Acknowledgement is given to CIE for their support in the preparation of this standard.

According to the CEN/CENELEC Internal Regulations, the national standards organisations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

Introduction

This standard provides requirements to perform reproducible photometric and colorimetric measurements on LED lamps, LED modules and LED luminaires (LED devices). It also provides advice for the reporting of the data.

The availability of reliable and accurate photometric data for LED devices is a basic requirement for designing good lighting systems and evaluating performance of products. By obtaining these data through measurements in specific normalized measuring conditions the consistency of the data should be ensured between different laboratories (within the limits of the declared measurement uncertainty) and comparison of different products on the same basis is possible.

This standard aims in particular to cover measurement methods for testing the compliance of LED devices with the photometric and colorimetric requirements of LED performance standards (see Clause 2) issued by IEC/TC 34/CLC/TC 34 “Lamps and related equipment” and/or relevant European regulations.

LED devices offer a large variety of configurations in respect to geometry and/or colour. For each configuration the photometric and colorimetric performances are considered individually.

1 Scope

This European Standard specifies the requirements for measurement of electrical, photometric, and colorimetric quantities of LED lamps, LED modules and LED luminaires, for operation with AC or DC supply voltages, possibly with associated LED control gear. LED light engines are assimilated to LED modules and handled accordingly. Photometric and colorimetric quantities covered in this standard include total luminous flux, luminous efficacy, partial luminous flux, luminous intensity distribution, centre-beam intensity, luminance and luminance distribution, chromaticity coordinates, correlated colour temperature (CCT), colour rendering index (CRI), and angular colour uniformity.

This European Standard does not cover LED packages and products based on OLEDs (organic LEDs).

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 11664-1:2011, *Colorimetry - Part 1: CIE standard colorimetric observers (ISO 11664-1:2007)*

EN ISO 11664-2:2011, *Colorimetry - Part 2: CIE standard illuminants (ISO 11664-2:2007)*

EN ISO 11664-3:2013, *Colorimetry - Part 3: CIE tristimulus values (ISO 11664-3:2012)*

EN 12665, *Light and lighting - Basic terms and criteria for specifying lighting requirements*

EN 13032-1:2004+A1:2012, *Light and lighting - Measurement and presentation of photometric data of lamps and luminaires - Part 1: Measurement and file format*

EN 61341:2011, *Method of measurement of centre beam intensity and beam angle(s) of reflector lamps (IEC/TR 61341:2010)*

EN 62504:2014. *General lighting -Light emitting diode products and related equipment-Terms and definitions (IEC 62504:2014)*

prEN 62717:2014, *LED modules for general lighting - Performance requirements (IEC 62717:2014)*

ISO/IEC Guide 98-3:2008, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

ISO/IEC Guide 98-4:2012, *Uncertainty of measurement — Part 4: Role of measurement uncertainty in conformity assessment*

ISO/IEC Guide 99:2007, *International vocabulary of metrology — Basic and general concepts and associated terms (VIM)*

CIE/DIS 024/E:2013, *Light Emitting Diodes (LEDs) and LED Assemblies – Terms and Definitions*

CIE 13.3, *Method of Measuring and Specifying Colour Rendering of Light Sources*

CIE 15, *Colorimetry*

CIE 84:1989, *Measurement of Luminous Flux*

CIE 198:2011, *Determination of Measurement Uncertainties in Photometry*

CIE 198:2011-SP1, *Determination of Measurement Uncertainties in Photometry – Supplement 1: Modules and Examples for the Determination of Measurement Uncertainties*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 12665, EN 13032-1 and the following apply.

3.1
electric light source
primary light source that transforms electrical energy into optical radiation

[SOURCE: CIE/DIS 024/E:2013, 3.3]

3.2
light-emitting diode
LED
solid state device embodying a p-n junction, emitting incoherent optical radiation when excited by an electric current

Note 1 to entry: This definition is independent from the existence of enclosure(s) and of terminals.

Note 2 to entry: The output is a function of its physical construction, material used and exciting current. The optical emission may be in the ultraviolet, visible, or infrared wavelength regions.

Note 3 to entry: “LED” term represents the LED die (or chip) or LED package. It is also used as a generic term representing the technology.

Note 4 to entry: “LED” term should not be used for reporting product performance (like luminous flux, colour rendering, lifetime…) instead use for example “luminous flux of the LED module”.

[SOURCE: EN 62504:2014, 3.24]

3.3
LED package
single electrical component encapsulating principally one or more LED dies, possibly including optical elements and thermal, mechanical, and electrical interfaces

Note 1 to entry: The component does not include the control unit of the control gear, does not include a cap, and is not connected directly to the supply voltage.

Note 2 to entry: A LED package is a discrete component and part of the LED module or LED lamp.

[SOURCE: EN 62504:2014, 3.20]

3.4
LED light source
electric light source based on LED technology

Note 1 to entry: A luminaire may include LED light sources but is not considered itself as a light source.

Note 2 to entry: LED light source(s) for a LED luminaire represent(s) one or more LED lamp(s) or LED module(s).

[SOURCE: EN 62504:2014, 3.16]

3.5
LED lamp

LED light source provided with (a) cap(s) incorporating one or more LED module(s) and possibly including one or more of the following: electrical, optical, mechanical, and thermal components, interfaces and control gear

Note 1 to entry: A LED lamp may be integrated (LEDi lamp) or semi-integrated (LEDsi lamp) or non-integrated (LEDni lamp).

Note 2 to entry: Single and double-capped lamps are included.

Note 3 to entry: A LED lamp is designed so that it can be replaced by an ordinary person (as defined in IEC 60050–18–03, 826)

[SOURCE: EN 62504:2014, 3.15]

3.6
integrated LED lamp (LEDi lamp)

LED lamp, incorporating control gear, and any additional elements necessary for stable operation of the light source, designed for direct connection to the supply voltage

Note 1 to entry: In some documents the term self-ballasted LED lamp is still used.

[SOURCE: EN 62504:2014, 3.15.1 modified by note1,added]

3.7
semi-integrated LED lamp (LEDsi lamp)

LED lamp which carries the control unit of the control gear, and is operated by the separated power supply of the control gear

Note 1 to entry: In some documents the term semi-self-ballasted LED lamp is still used.

[SOURCE: EN 62504:2014, 3.15.4 modified by note 1, added]

3.8
non-integrated LED lamp (LEDni lamp)

LED lamp which needs a separate control gear to operate

Note 1 to entry: In some documents the term non-self-ballasted LED lamp is still used.

[SOURCE: EN 62504:2014, 3.15.2 modified by note1, added]

3.9
retrofit LED lamp

LED lamp, intended as a replacement of a non-LED lamp without requiring any internal modification of the luminaire

[SOURCE: EN 62504:2014, 3.15.3]

3.10
LED module

LED light source having no cap, incorporating one or more LED package(s) on a printed circuit board, and possibly including one or more of the following: electrical, optical, mechanical, and thermal components, interfaces and control gear

Note 1 to entry: A LED module may be integrated (LEDi module) or semi-integrated (LEDsi module) or non-integrated (LEDni module).

Note 2 to entry: The LED module is usually designed to be part of a LED lamp or LED luminaire.

[SOURCE: EN 62504:2014, 3.19]

3.11
integrated LED module (LEDi module)

LED module, incorporating control gear and any additional elements necessary for stable operation of the light source, designed for direct connection to the supply voltage

Note 1 to entry: In some documents the term self-ballasted LED module is still used.

[SOURCE: EN 62504:2014, 3.19.4 modified by note 1,added]

3.12
semi-integrated LED module (LEDsi module)

LED module which carries the control unit of the control gear, and is operated by the separated power supply of the control gear

Note 1 to entry: In some documents the term semi-self-ballasted LED module is used.

[SOURCE: EN 62504:2014, 3.19.6 modified by note 1 added]

3.13
non-integrated LED module (LEDni module)

LED module which needs a separate control circuitry or control gear to operate

Note 1 to entry: In some documents the term non-self-ballasted LED module is used.

Note 2 to entry: One or more LED packages on a printed circuit board or substrate in a geometric structure are regarded as LED array. No further components are included like electrical, optical, mechanical and thermal components.

[SOURCE: EN 62504:2014, 3.19.5 modified by note 1, added]

3.14
integral LED module

LED module, generally designed to form a non-replaceable part of a luminaire

[SOURCE: EN 62504:2014, 3.19.3]

3.15
control gear for LED module
LED control gear

unit inserted between the electrical supply and one or more LED modules which serves to supply the LED module(s) with its (their) rated voltage or rated current. The unit may consist of one or more separate components and may include means for dimming, correcting the power factor and suppressing radio interference, and further control functions

Note 1 to entry: The control gear consists of a power supply and a control unit.

Note 2 to entry: The control gear may be partly or totally integrated in the LED module.

Note 3 to entry: When no confusion is expected like used in a LED standard, “control gear” may also be used.

Note 4 to entry: Both terms “controlgear” or “control gear” are acceptable.

[SOURCE: EN 62504:2014, 3.6.1, modified, Note 4 to entry added]

3.16
LED light engine

integrated assembly or set consisting of LED module(s) and LED control gear for direct connection to the electrical supply system

Note 1 to entry: A LED light engine typically shall have defined electrical, mechanical, thermal and control interfaces, and specific photometric properties.

Note 2 to entry: A LED light engine may incorporate a heat sink or not.

[SOURCE: CIE/DIS 024/E:2013, 3.13]

3.17
LED luminaire

luminaire designed to incorporate one or more LED light source(s)

Note 1 to entry: The LED light sources(s) may be an integral part of a LED luminaire

[SOURCE: EN 62504:2014, 3.17 modified by note1, added]

3.18
LED device

generic term to designate LED lamps, LED modules, LED light engines or LED luminaires for the purpose of this standard

3.19
beam angle

the angle between two lines in a plane through the optical beam axis, such that these lines pass through the centre of the front face of the device and through points at which the luminous intensity is 50 % of the centre beam intensity, where the centre beam intensity is the value of luminous intensity measured on the optical beam axis

Note 1 to entry: Beam angle is expressed in degrees (°)

Note 2 to entry: This angle is a full angle measure, not a half angle measure.

Note 3 to entry: The optical beam axis is the axis about which the luminous intensity distribution is substantially symmetrical.

[SOURCE: EN 62504:2014, 3.4 modified by note 3, added]

3.20
tuneable LED devices

device with independent channels where the spectra of the emitted light can be deliberately modified

Note 1 to entry: This means chromaticity coordinates are changeable.

Note 2 to entry: For devices with independent channels and changeable chromaticity coordinates the colorimetric figures are usually determined for the gamut corners, for changeable correlated colour temperature devices the minimum and maximum correlated colour temperature and for any additional setup (defined by applicant).

3.21
type test

conformity test on one or more LED product(s) representative of the production

[SOURCE: EN 62504:2014, 3.41]

3.22
type test sample

one or more LED product(s) submitted by the manufacturer or responsible vendor for the purpose of the type test

[SOURCE: EN 62504:2014, 3.42]

3.23
applicant

the responsible person who commissions a test

Note 1 to entry: The applicant can be for example a manufacturer, responsible vendor, customer or regulator.

Note 2 to entry: The applicant will normally provide all information required to correctly perform the test.

3.24
device under test
DUT

LED device submitted for testing

Note 1 to entry: A DUT (device under test) is not a type test sample unless it is declared so.

3.25
supply voltage (for a LED device)

voltage applied to the complete unit of LED light source or LED luminaire

[SOURCE: EN 62504:2014, 3.37]

3.26
supply power (for a LED device)

electrical power consumed by the light source(s), control gear and any control circuit in the device which includes any parasitic power when the light source is turned on

3.27
rated value

value of a quantity used for specification purposes under standard test conditions as declared by the manufacturer or responsible vendor

Note 1 to entry: The standard test conditions are given in the relevant standard

[SOURCE: EN 62504:2014, 3.33]

3.28
initial values

photometric and electrical characteristics measured at the end of the ageing period and stabilisation time

Note 1 to entry: Ageing period can be specified as zero

[SOURCE: prEN 62717:2014, 3.4]

3.29
ageing (for a LED source)

preconditioning period of LED light source before initial values are taken

Note 1 to entry: In some documents the term seasoning is used.

[SOURCE: EN 62504:2014, 3.1 modified by note 1, added]

3.30
stabilisation time (for a LED device)

time that is required for the LED light source or LED luminaire to obtain stable photometric output and electric power with constant electrical input

[SOURCE: EN 62504:2014, 3.35]

3.31
ambient temperature

t_{amb}

temperature of air or another medium in the vicinity of the device under test

Note 1 to entry: Ambient temperature is expressed in degrees Celsius (°C).

[SOURCE: EN 62504:2014, 3.38.1 modified]

3.32
ambient performance temperature

ambient temperature related to the performance of the LED light source or LED luminaire

Note 1 to entry: Ambient performance temperature is expressed in degrees Celsius (°C).

[SOURCE: EN 62504:2014, 3.38.2]

3.33
rated maximum temperature (of a component)

t_c

highest permissible safety related temperature which may occur on the outer surface of the component (LED module or control gear) (at the indicated position, if marked) under normal operating conditions and at the rated voltage/current/power or the maximum of the rated voltage/current/power range

Note 1 to entry: Rated maximum temperature is expressed in degrees Celsius (°C).

[SOURCE: EN 62504:2014, 3.38.9]

3.34
performance temperature (of a LED module)

t_p

temperature related to performance of the LED module

Note 1 to entry: Performance temperature is expressed in degrees Celsius (°C).

Note 2 to entry: Temperature is measured at a designated t_p-point.

[SOURCE: EN 62504:2014, 3.38.6]

3.35
t_p-point

the designated location of the point where to measure the performance temperatures t_p at the surface of the LED module

Note 1 to entry: The location of t_p and t_c can be different.

[SOURCE: prEN 62717:2014, 3.16, modified.by introduction of a note]

3.36
rated maximum performance temperature (of a LED module)

$t_{p,nn}$

highest temperature at t_p-point, related to a rated performance of the LED module, both as declared by the manufacturer or responsible vendor

Note 1 to entry: Rated maximum performance temperature is expressed in degrees Celsius (°C).

Note 2 to entry: For a given performance, the $t_{p,nn}$ temperature is a fixed value, not a variable, where nn, the number in the suffix indicates the related lifetime claim in khours, example: $t_{p,60}$ where nn = 60 represent 60 000 h lifetime claim.

Note 3 to entry: There can be more than one $t_{p,nn}$, depending on the performance claim.

Note 4 to entry: In some documents the symbol $t_{p,n}$, $t_{p,rated}$ or $t_{p\ max}$ is used instead of $t_{p,nn}$

[SOURCE: EN 62504:2014, 3.38.8 modified by note 4, added and omission of note 2]

3.37
rated maximum ambient performance temperature (of a luminaire)

$t_{q,nn}$

highest ambient temperature around the luminaire related to a rated performance of the luminaire under normal operating conditions, both as declared by the manufacturer or responsible vendor

Note 1 to entry: Rated maximum performance ambient temperature is expressed in degrees Celsius (°C).

Note 2 to entry: For a given life time, the $t_{q,nn}$ temperature is a fixed value, not a variable, where nn, the number in the suffix indicates the related lifetime claim in khours, example; $t_{q,60}$ where nn = 60 represent 60 000 h lifetime claim.

Note 3 to entry: There can be more than one $t_{q,nn}$ temperature, depending on the life time claim.

Note 4 to entry: In some documents the symbol $t_{q,n}$ or t_q, is used instead of $t_{q,nn}$

[SOURCE: EN 62504:2014, 3.38.7 modified by note 4, added]

3.38
luminous efficacy (of a source)

η_v, η

quotient obtained when the emitted luminous flux is divided by the power consumed by the source

Note 1 to entry: Luminous efficacy is expressed in lm·W^{-1}

Note 2 to entry: For LED applications, the source may be a LED package, module, lamp, luminaire etc.

[SOURCE: EN 62504:2014, 3.26]

3.39
light output ratio (of a luminaire)

LOR

ratio of the total flux of the luminaire, measured under specified practical conditions with its own light sources and equipment, to the sum of the individual luminous fluxes of the same light sources when operated outside the luminaire with the same equipment, under specified conditions

Note 1 to entry: LOR may be determined for LED luminaires using interchangeable sources (e.g. LED lamps) in some cases. The use of LOR is disregarded for LED luminaires with non-replaceable LED light sources. For LED luminaires with non-replaceable LED light sources, only the total flux of the luminaire can be measured, in which case, LOR is 100 % as a consequence and not significant.

[SOURCE: IEV 845-09-39, modified by note 1, added]

3.40
total spectral radiant flux (of a light source)

spectral concentration of the geometrically-total (4π steradian) radiant flux Φ of a light source:

$$\Phi_\lambda(\lambda) = \frac{\mathrm{d}\Phi}{\mathrm{d}\lambda} \tag{1}$$

Note 1 to entry: Total spectral radiant flux is expressed in Watt per nanometre (W · nm^{-1}).

3.41
partial luminous flux (of a light source, within a specified cone angle)

total luminous flux emitted from a light source within a specified cone angle α, determined from the luminous intensity distribution $I(\theta, \varphi)$ of the source:

$$\Phi_\alpha = \int_{\varphi=0}^{2\pi} \int_{\theta=0}^{\alpha/2} I(\theta,\varphi) \sin\theta \, \mathrm{d}\theta \, \mathrm{d}\varphi \tag{2}$$

Note 1 to entry: Partial luminous flux is expressed in lumen (lm)

Note 2 to entry: $(\theta, \varphi) = (0,0)$ is the direction of the cone axis

Note 3 to entry: The cone angle α is the full angle (diameter) of the cone

Note 4 to entry: “Cone luminous flux” is also used in some applications in the same meaning.

Note 5 to entry: “Useful luminous flux” is also used in a similar meaning, but is determined with the cone axis that is coincident with the observed optical beam axis of the light source, the axis about which the luminous intensity is substantially symmetrical.

3.42
absolute photometry
process for measuring photometric quantities directly in SI units

Note 1 to entry: This term is often used in goniophotometry of luminaires, in contrast with relative photometry (see 3.43).

Note 2 to entry: Absolute measurements require instruments calibrated for the appropriate SI units.

3.43
relative photometry
measurement obtained as a quotient of two photometric quantities

Note 1 to entry: This term is often used in goniophotometry of luminaires, where luminous intensity distribution is measured as relative values normalized by total luminous flux of the lamps used, and reported in the unit [cd/klm]

Note 2 to entry: This method is not applicable to LED light sources and LED luminaires with integrated LED light sources.

3.44
photometer head
combination of a detector and facilities for the spectral weighting of the detected radiation

Note 1 to entry: It may also contain facilities for directional evaluation of the light, e.g. diffusing windows, lenses, and apertures.

Note 2 to entry: In this document, a photometer head refers to an illuminance measuring unit containing a detector, a $V(\lambda)$-correction filter, and any additional components (aperture, diffuser, amplifier, etc.) within the unit.

3.45
traceability
property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty

Note 1 to entry: The International Laboratory Accreditation Cooperation (ILAC) considers the elements for confirming metrological traceability to be an unbroken metrological traceability chain to an international measurement standard or a national measurement standard, a documented measurement uncertainty, a documented measurement procedure, accredited technical competence, metrological traceability to the SI, and calibration intervals (see ILAC P10:01/2013).

Note 2 to entry: The expression “traceability to the SI” means ‘metrological traceability to a measurement unit of the International System of Units’.

[SOURCE: ISO/IEC Guide 99:2007, 2.41, modified] also [JCGM 200, 2.41, modified]

3.46
tolerance interval
interval of permissible values of a property

Note 1 to entry: Unless otherwise stated in a specification, the tolerance limits belong to the tolerance interval.

Note 2 to entry: The term `tolerance interval' as used in conformity assessment has a different meaning from the same term as it is used in statistics.

[SOURCE: ISO/IEC Guide 98-4, 3.3.5]

3.47
acceptance interval
interval of permissible measured quantity values

Note 1 to entry: Unless otherwise stated in the specification, the acceptance limits belong to the acceptance interval.

[SOURCE: ISO/IEC Guide 98-4, 3.3.9]

4 Laboratory requirements

4.1 General

4.1.1 Standard Test Conditions

Measurements of the photometric, colorimetric and electrical characteristics of a LED device shall be performed by means of appropriate equipment and procedures under defined *standard test conditions* for operation of the DUT. A standard test condition includes a *set value* and a *tolerance interval*. Ideally an operating condition parameter of a DUT (e.g. test voltage) is set exactly to the set value. In real situations, the set values cannot be set exactly and there are some deviations, and therefore a tolerance interval for each set value is specified in this test method. If necessary, a correction of results is made to adjust at the set value. Measurement results are expressed for the set value of the standard test conditions. Furthermore, test equipment shall fulfil *specific requirements*, often specified with a maximum or minimum value (or a range of values) of a performance characteristic of the instrument. The tolerance intervals and specific requirements are shown in Italic font in 4.2, 4.3, 4.4 and 4.5.

All measurements shall be traceable to the SI when instruments are used to measure absolute values of a quantity relevant to the measurement. The measurement reports shall include a statement of uncertainties of measurement (see Clause 8 for further details). All uncertainty values of instruments in Clause 4 are expressed in expanded uncertainty with a confidence interval of 95 % (typically with a coverage factor $k = 2$).

The test shall be performed with all test conditions within the tolerance intervals and all instruments meeting the specific requirements in 4.2, 4.3, 4.4 and 4.5. In this case the measurements are considered as complying with the standard conditions. To further reduce the uncertainty of measurements, the results may be corrected for the deviation within the tolerance interval, to conditions at the set value of the standard test condition. The set value is normally the centre value of the tolerance interval, though not always so.

In cases where some of the standard test conditions or requirements cannot be fulfilled, deviations outside the tolerance intervals or requirements are permitted if the related measurements are corrected to the standard test conditions. In such cases, the specific uncertainty component for the corrected parameter shall be evaluated and incorporated into the final uncertainty budget. The actual measurement condition and the fact that correction is made to the standard test condition for the parameter shall be reported in the test report.

In order to apply a correction, the sensitivity coefficients of the DUT shall be determined. The correction shall be applied only if the DUT is in steady conditions with respect to all the quantities involved for the correction parameter.

NOTE If a number of products of the same model are measured, the sensitivity coefficients measured for a DUT of that model or equivalent models may be used for correction of the other DUTs.

For the uncertainty budget, the main properties (and related sensitivity coefficients) of the DUT should be analysed. However, in practice, a detailed evaluation of all the properties of the DUT is not always possible or practical. Therefore, if there is no detailed information available, the sensitivity values for the DUT performance from Annex C may be used for evaluation of the measurement uncertainty, but these sensitivity values shall not be used for correction purposes.

The model of evaluation as the basis of the uncertainty budget and details of all correction factors used and uncertainty component evaluations made shall be kept by the laboratory and made available on demand.

Measurement equipment designs and configurations other than those explicitly described in this standard are acceptable if they are demonstrated to produce equivalent results.

Further details and examples for accounting for practical laboratory conditions are given in Annex A and guides to determining uncertainty are given in Clause 8 and Annex D.

4.1.2 Tolerance Interval

For each standard test condition, a tolerance interval for the related parameter is given for setting the operating conditions of the DUT. The measurement uncertainty of the related parameter shall be taken into account to ensure that the parameter is within the tolerance interval. For this purpose, an acceptance interval is defined as the tolerance interval reduced by the expanded uncertainty (95 % confidence) of the measurement of the parameter on both limits of the tolerance. The result of measurement of a DUT parameter shall lie within the acceptance interval. This is illustrated in Figure 1. The measurement uncertainty of the parameter includes the calibration uncertainty of the measurement instrument and additional contributions from the measurement conditions. See Annex A for additional information and some examples on tolerance interval and acceptance interval. Further information on the concept of acceptance interval is given in ISO/IEC Guide 98-4.

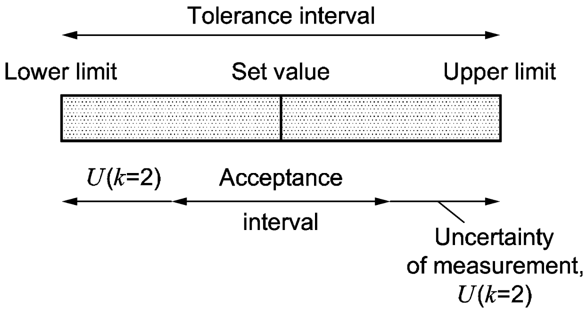


Figure 1 — Illustration of the tolerance interval and acceptance interval

4.2 Laboratory and Environmental Conditions

4.2.1 Test Room

Measurements shall be made in a room where environmental effects have negligible impacts on the measured quantities (e.g. smoke, dust, mist, vibrations).

Surroundings are arranged so that stray light is minimized and, if significant, the related error shall be corrected. More information is given in Annex B.

4.2.2 Ambient Temperature

The set ambient temperature t_{amb} shall be 25,0 °C for the measurements of LED lamps, LED light engines (designed for ambient temperature) and LED luminaires.

Tolerance interval: ± 1,2 °C.

To fulfil this requirement, the result of the temperature measurement shall lie within the acceptance interval (see 4.1.2). For example, if the uncertainty of the temperature measurement is 0,2 °C, the acceptance interval will be ± 1,0 °C. If the uncertainty is larger, the acceptance interval will be narrower.

The ambient temperature shall be measured at points representative of the near surrounding of the DUT. For an integrating sphere, the thermometer sensor should be inside the sphere and at the same height of the DUT, or at a close height (if the DUT is mounted at the top of the sphere in 2π geometry). The temperature measurement shall not be influenced by direct radiation from the DUT under test: the thermometer sensor shall be baffled to prevent the direct light reaching the sensor.

Room air conditioning and any heaters shall be arranged so that air flow and radiant heat does not directly hit either the DUT or the temperature sensor.

Care shall be taken to ensure that the thermometer and its housing do not interfere in the light measurement path.

NOTE Air temperature may be measured with a thermometer of any convenient and appropriate type (e.g. liquid-in-glass, thermocouple, and thermistor). Thermometers for this purpose are often enclosed in a metal housing polished on its outside surface so as to reflect radiation (but baffled, if necessary, to prevent reflected light reaching the detector).

Where a declared ambient air temperature other than 25,0 °C is specified for the DUT by the applicant (e.g. LED luminaire for a refrigerator show case), unless measurement is made at that temperature, measurement results at 25,0 °C are first reported, then a service conversion factor shall be established to allow converting the measured photometric value at 25,0 °C to that at the specified ambient temperature. This may be done by measuring the ratio of total luminous flux (or luminous intensity or luminance in a fixed direction) of the device in a thermal chamber or a temperature-controlled measurement system (e.g. integrating sphere with air temperature control). This service conversion factor is reported separately.

4.2.3 Surface Temperature (t_p-Point Temperature)

For LED modules, except for light engines designed for ambient temperature, all measured quantities shall be reported for the rated performance temperature t_p.

Tolerance interval: ± 2,5 °C

To fulfil this requirement, the result of the temperature measurement shall lie within the acceptance interval (see 4.1.2). For example, if the uncertainty of the surface temperature measurement is 0,5 °C, the acceptance interval will be ± 2,0 °C. If the uncertainty is larger, the acceptance interval will be narrower.

NOTE 1 The calibration uncertainty of the thermometer may be quite small e.g. 0,2 °C, however the measurement of surface temperature adds additional components like thermal contact of the thermometer to the surface, resulting in measurement uncertainty up to 2,0 °C in some cases.

NOTE 2 There can be more than one value of rated performance temperature t_p for a LED module depending on the associated rated lifetime claim.

Once the LED module is incorporated into a light engine or luminaire and its t_p-point is not accessible, the manufacturer or the applicant shall indicate a temperature monitoring point and the relationship between the temperature at this point and performance temperature (or deliver a special prepared DUT permitting access to t_p-point).

Care should be taken to ensure that the thermometer and its housing do not interfere in the light measurement path. Surface temperature measuring devices shall not influence the thermal behaviour of the DUT, while a good thermal contact between the DUT surface and thermometer is ensured.

4.2.4 Air Movement

Measurements shall be made in still air. (Set value: air velocity is zero.)

Tolerance interval: 0 m/s to 0,25 m/s

To fulfil this requirement, the result of measurement shall lie within the acceptance interval (see 4.1.2). If the uncertainty of the air movement measurement is 0,05 m/s, the acceptance interval will be 0 m/s to 0,20 m/s. If the uncertainty is larger, the acceptance interval will be narrower.

NOTE 1 The movement of air around the DUT can change its effective operating temperature, and as a consequence the luminous flux value can also change. Such movement of air can be caused by draughts, air conditioning, motion of the device in the goniophotometer, or motion of the goniophotometer frame itself.

NOTE 2 The requirement above is considered satisfied in an integrating sphere when it is closed, unless the sphere has a fan-forced air temperature control in which case it will require characterization. However, closing an integrating sphere can cause a draught on a DUT, so it is sometimes necessary to wait a short time for the DUT to stabilize after closing a sphere.

NOTE 3 For LED devices highly sensitive to temperature variations a lower air velocity (e.g. less than 0,10 m/s) may be necessary.

Air movement shall be measured in the vicinity of the device and shall ignore any effect of forced cooling or self-heating of the DUT.

In the case of a goniophotometer that moves the position of the light source during measurement, the movement speed shall be chosen adequately to meet the requirement stated above or an adequate correction shall be applied.

4.2.5 Operating Position

Specific requirement: The DUT shall remain in its designed operating condition throughout the stabilization and testing period.

NOTE This requirement is not applicable to LED modules whose temperature is set and maintained to performance temperature (see 5.3.1).

If this requirement is not met, the measurements shall be corrected to the performance in the designed operating position.

EXAMPLE: A photometric measurement can be corrected using an auxiliary photometer method that monitors the relative luminous intensity of the DUT in a fixed direction. In this method, the ratio of a reference value to the value measured by the auxiliary photometer during measurement in each different operating position serves as a measurement correction factor. The reference value is represented by the output of the auxiliary photometer measured after the stabilization procedure of the light source in the designed operating position. The relative position of the auxiliary photometer to the DUT is maintained constant during all measurements.

4.3 Electrical Test Conditions and Electrical Equipment

4.3.1 Test Voltage and Test Current

The set value is the rated supply voltage of the DUT, or rated supply current of the DUT (LED modules with DC current input), measured at the supply terminals of the DUT.

Tolerance interval: ± 0,4 % for RMS (root mean square) AC voltage; ± 0,2 % for DC voltage. For LED modules with DC current input, ± 0,2 % for DC current.

To fulfil this requirement, the measurement result shall lie within the acceptance interval (see 4.1.2). If the uncertainty of the AC voltage measurement is 0,2 %, the acceptance interval will be ± 0,2 %. Specific requirements on the calibration uncertainties of voltmeters and ammeters are specified in 4.3.2.

The test voltage shall be measured at the supply terminals of the DUT, not at the output terminals of power supply, to avoid errors due to voltage drop by the cables and connectors.

In case the rated supply voltage is specified in a range, the test voltage shall be chosen according to the appropriate IEC LED performance standard or regional specification.

NOTE The IEC LED performance standards generally relate to end-user devices which are connected to the mains power line or operated with constant voltage. For some LED modules, current control may apply instead.

4.3.2 Electrical Measurements

Measurements of AC/DC voltage, current and power shall be made with suitable measurement equipment.

Specific requirements: The calibration uncertainty of AC Voltmeters and ammeters shall be less than or equal to 0,2 %. The calibration uncertainty of DC Voltmeters and ammeters shall be less than or equal to 0,1 %.

Measurements of AC power shall be made with a suitable power meter or power analyser. The power meter shall have an appropriate bandwidth to cover the harmonic content of the electrical current.

Specific requirements: The calibration uncertainty of AC power meter or power analyser shall be less than or equal to 0,5 %. The bandwidth shall be at least 100 kHz. A lower bandwidth may be accepted (5 kHz or 30 kHz) if the absence of significant high frequency components (respectively above 5 kHz or 30 kHz) is demonstrated.

LED products may or may not show significant high frequencies components (>5 kHz) depending on the auxiliary apparatus (control gear, dimmer, etc.) used. For LED control gears generating significant high frequency components, even a bandwidth of 100 kHz may not be sufficient and the power analyser type should then be adapted to this particular situation (e.g. 1 MHz bandwidth).

All leads and connections for supply current shall be securely fastened and of sufficiently low impedance. The measurement circuits shall comply with the relevant IEC lamp standards. 4-wire measurement techniques shall be applied. For LED luminaires the connection terminals are the reference point for voltage measurement.

When LED devices of very small power consumption are measured, it should be ensured that the impedance of the volt- or power-meter is high enough to avoid error by leakage currents.

Specific requirement: The internal impedance of the voltage measurement circuit shall be at least 1 MΩ.

NOTE Some DUTs have high impedance and therefore use of equipment with a higher internal impedance may be necessary.

Measurements of DC power may be made directly by an appropriate instrument or may be obtained from the measured voltage and current.

4.3.3 Electrical Power Supply

4.3.3.1 Current Capacity

The power supply shall be of sufficient current handling capacity for the loads to be connected. In particular, the supply including ancillary transformers shall be of very low impedance.

AC Power Supply Network:

The voltage of the AC power supply shall be regulated at the supply terminals of the DUT.

Specific requirement: Any drift or fluctuation of the supply voltage during measurement of a DUT shall be within the acceptance interval of the test voltage (4.3.1).

If it exceeds the acceptance interval, correction of results shall be applied.

The supply shall have a sinusoidal voltage waveform. The total harmonic distortion (THD) of the voltage of power supply network (power supply unit, cables and connectors) shall be limited when the DUT is connected and powered.

Specific requirement: The total harmonic distortion of the voltage waveform (THDv), measured at the supply terminals of the DUT, shall not exceed 1,5 %. If measured DUTs have power factors higher than 0,9, the THDv may exceed 1,5 % but shall be less than 3 %.

NOTE 1 The total harmonic distortion, THD, is the ratio of the RMS value of the sum of the harmonic components (in this context harmonic voltage components U_h of orders 2 to 500) to the RMS value of the fundamental component U_1, as shown in the formula:

$$THD = \sqrt{\sum_{h=2}^{500}\left(\frac{U_\mathrm{h}}{U_1}\right)^2} \tag{3}$$

NOTE 2 The electrical measurement results may depend significantly on the *THD* of voltage, which depends on the source impedance of the AC power supply network and current waveform of the LED device. This effect is larger as the DUT's power factor becomes smaller (in particular if the power factor is less than 0,5) and more significant high frequency components are generated. A significant measurement error may occur if the electrical circuit presents high impedances at those frequencies. To analyse the errors and reduce uncertainties in the measurement of electrical quantities, correction procedures can be used to compensate the effects of the deviation of the power supply network impedance with the reference impedance indicated in IEC/TR 60725:2012.

The effect of the impedance of electrical circuits (length of cables, loops) on electrical measurement may be checked, separately from the photometric measurement, in a standalone, low impedance measurement circuit (short length of the electrical cables, no loops). The observed differences should be considered in the uncertainty evaluation.

The frequency of supply voltage shall be maintained at the required frequency.

Specific requirement: The frequency of the supply voltage shall be maintained within a relative tolerance interval ± 0,2 % of the required frequency.

DC Power Supply:

The voltage of the DC power supply shall be regulated at the supply terminals of the DUT.

Specific requirement: Any drift or fluctuation of supply voltage during measurement of a DUT shall be within the acceptance interval of the test voltage (4.3.1).

For LED modules with DC current input, the current shall be regulated to the acceptance interval of the current.

The supply shall be AC ripple free.

Specific requirement: The supply voltage shall not contain an AC component (as RMS value) of more than 0,5 % of the DC voltage.

4.3.3.2 Electro-magnetic Compatibility

The electric power supply and any electrical equipment in the vicinity shall not affect the electrical or photometric measurement equipment.

4.4 Stabilization before Measurement

4.4.1 General

Measurement shall be started after the DUT has achieved stable conditions. Measurement equipment shall also have achieved stable conditions.

During the stabilization, measurements of light output and electrical power are made at least at an interval of 1 min.

4.4.2 LED Lamps and LED Luminaires

This procedure applies to LED lamps (integrated, semi-integrated, non-integrated) and LED luminaires, and also to LED light engines incorporating heat sinks.

Specific requirement: The DUT shall be operated for at least 30 min and it is considered as stable if the relative difference of maximum and minimum readings of light output and electrical power observed over the last 15 min is less than 0,5 % of the minimum reading. If the DUT is pre-burned, it does not need to be operated for 30 min, and it is considered stable if the readings of the last 15 min meet above requirement.

If the DUT exhibits large fluctuations and stabilization conditions are not achieved within 45 min of operation for LED lamps or 150 min for LED luminaires, the measurement may be started and the observed fluctuations shall be reported. However if, instead of random fluctuations, a slow decrease of gradient of the measured values is still observed, then the measurements should be started only when the stabilization criteria are met.

NOTE Normally the observed stabilization process is a slow decrease in light output until thermal stability is reached. However, due to the electronics, fluctuations can still occur near thermal stability.

The stabilization is strongly related to thermal equilibrium of the components. A pre-burning (operation of the light source prior to mounting in the measurement system) may be applied to reduce the stabilization time in the measurement system. In particular for measurement of a number of products of the same type, measurement time may be reduced if it has been demonstrated that the pre-burning method produces the same stabilized condition as when using the normal procedure.

4.4.3 LED Modules

The following procedure applies to LED modules (integrated, semi-integrated, non-integrated) except LED light engines incorporating heat sinks (set for ambient temperature). The thermal condition is set by the DUT's performance temperature t_p measured at the t_p-point. The temperature of LED modules is commonly adjusted using a temperature-controlled heat sink or additional heating.

Specific requirement: When the temperature reaches and maintains the specified performance temperature t_p*, within ± 1 °C for 15 min, the LED module is considered to be stabilized in temperature.*

For LED light engines incorporating heat sink(s), the procedure in 4.4.2 is first followed at 25 °C ambient temperature, with the performance temperature t_p recorded; then the procedure in 4.4.3 is followed for measurements at additional values of t_p.

4.5 Photometric and Colorimetric Measurement Instruments

4.5.1 General

For measurement of photometric and colorimetric quantities, the following instruments are generally used:

- Integrating sphere systems:
  - sphere-photometer (photometer head as detector),

  - sphere-spectroradiometer (spectroradiometer as detector),

NOTE 1 Integrating sphere systems include integrating hemispheres. Sphere-photometers include integrating spheres with a tristimulus colourimeter head, which are used as a photometer head (Y channel) and also for relative colour measurement, but are not recommended for absolute colour measurement.

- Goniophotometer systems:
  - goniophotometer (photometer head as detector),
  - gonio-spectroradiometer (spectroradiometer as detector),
  - gonio-colourimeter (tristimulus colourimeter as detector).

NOTE 2 Goniophotometers include near-field goniophotometers. Gonio-colourimeters are used for relative colour measurement, and thus for angular colour uniformity measurement, but are not recommended for absolute colour measurement.

- Luminance meters

NOTE 3 Luminance meters include imaging luminance measurement devices (ILMD).

Other types of measurement instruments including integrating hemisphere, near-field goniophotometer and ILMD, are acceptable if they are demonstrated to produce equivalent results as a conventional integrating sphere system or conventional goniophotometer system.

Instruments are selected depending on the types of product and measurement quantities to be measured. Small-size products (e.g. LED lamps) that do not require luminous intensity distribution data can be measured with an integrating sphere system. Luminaires normally require luminous intensity distribution data, and thus a goniophotometer system is required. To measure colour quantities, a sphere-spectroradiometer, gonio-spectroradiometer, or gonio-colourimeter is required.

All measurement equipment shall be calibrated to ensure traceability to the SI. All photometric measurements shall be based on the spectral luminous efficiency function for photopic vision $V(\lambda)$ (see ISO 23539 (CIE S 010)). See ISO/CIE 19476:2014 for details on calibration, checking and description of quality indices of photometers.

4.5.2 Spectral Responsivity Requirements for Photometers

For instruments using $V(\lambda)$-corrected detectors (sphere-photometer, goniophotometer, luminance meter), the following requirements shall be fulfilled.

Specific requirement: The general $\mathrm{V}(\lambda)$ *mismatch index* f_1' of the total relative spectral responsivity (sphere plus photometer head) shall be 3 % or less.

If this requirement is fulfilled, spectral mismatch correction is not required for measurement of white light LED devices, although highly recommended. Spectral mismatch correction is required for LED devices that emit coloured light (e.g. red, green or blue single colour LED modules).

If the above requirement for f_1' is not fulfilled, it can be permitted if spectral mismatch correction is applied for each DUT measured. In this case, the actual f_1' value of the system and the fact that the correction is applied shall be reported (see also 4.1.1).

If spectral mismatch correction is not made, the uncertainty contribution from estimated spectral mismatch errors shall be evaluated, either based on the relative spectral responsivity data of the system, or if it is not available, based on the $f_1^{'}$ value (see C.3.6). When using the $f_1^{'}$ value, the uncertainty of the $f_1^{'}$ value should be considered in the measurement uncertainty budget. If spectral mismatch correction is made, there will still be remaining uncertainty contributions from those of the data used.

4.5.3 Integrating Sphere (all Types)

4.5.3.1 General

The integrating sphere shall be equipped with an auxiliary lamp to allow self-absorption measurements.

NOTE 1 Self-absorption can be significant due to the difference of shape and dimension of the DUT compared to the reference lamp and is dependent on the size of the DUT and sphere, and reflectance characteristics of the DUT and the sphere coating.

The size of the integrating sphere should be large enough relative to the size of the DUT to avoid large errors due to spatial non-uniformity of sphere responsivity caused by the baffle and DUT itself.

Specific requirement: When a DUT is mounted in the centre of the sphere (4π geometry), the total surface area (the enveloping surface) of the DUT shall not exceed 2 % of the total area of the sphere inner surface. (This corresponds to a cubic DUT with a side length of 1/10 of the sphere diameter.) When a DUT is mounted at the opening of a sphere (2π geometry), the size of the opening diameter shall not exceed 1/3 of the diameter of the sphere.

When a linear shaped DUT is mounted in the centre of the sphere (4π geometry), its long axis should coincide with the line between the detector head and the centre of the sphere so that the size of the baffle can be minimized.

The internal coating of the integrating sphere shall be diffuse, high-reflectance, non-spectrally selective and should not show fluorescence. Coating reflectances > 90 % are recommended for sphere-spectroradiometer systems.

NOTE 2 Non-uniformity of reflectance over the sphere can have significant influence if DUT and reference lamp show different intensity distributions.

The light source holder and auxiliary equipment in the sphere should have the smallest dimensions possible. All baffles inside the sphere as well as supporting structures for the DUT are coated with the coating having highest diffuse reflectance possible.

NOTE 3 The side of the baffle facing the detector may have lower reflectance and the same coating as the sphere wall may be suitable.

The detector port’s entrance optics shall be cosine corrected. It is normally achieved by using a diffuser or a satellite integrating sphere at the entrance port.

Specific requirement: The photometer head or the spectroradiometer entrance port of an integrating sphere shall have a cosine correction with a value f_2 *of 15 % or less.*

The integrating sphere system shall have sufficient mechanical repeatability so that the sphere responsivity is kept constant when DUT measurements are conducted with opening and closing of the sphere.

Specific requirement: The repeatability of the sphere for opening and closing shall be within ± 0,5 % and taken into account in the uncertainty budget.

The integrating sphere system (including measurement device) shall have sufficient stability of responsivity between recalibrations. The stability of the sphere system should be checked by first measuring a stable lamp immediately after calibration and then measuring the same lamp periodically to determine the drift or variation of the sphere responsivity.

Specific requirement: Unless the sphere is calibrated immediately before each use, the sphere shall be re-calibrated at appropriate intervals so that the drift of the sphere responsivity during the interval is less than 0,5 %.

The integrating sphere should be calibrated with reference standards having a similar intensity distribution to the DUT (e.g. omnidirectional or directional). Differences in intensity distribution between reference standards and the DUT should be considered in the uncertainty budget.

4.5.3.2 Sphere-Spectroradiometer

A sphere-spectroradiometer system shall be calibrated with or verified against a total spectral radiant flux standard traceable to the SI.

If total spectral radiant flux standard lamps are not available, the standard may be derived by the user from spectral irradiance standard lamp(s) and total luminous flux standard lamp(s), both traceable to the SI. In this case, the derivation methods and related data (e.g. angular uniformity of spectrum or that of correlated colour temperature of the standard lamp) should be reported.

It would not be acceptable if the spectroradiometer used with the integrating sphere is calibrated for spectral irradiance only without considering the relative spectral throughput of the integrating sphere. The integrating sphere and the spectroradiometer together shall be calibrated as one system for total spectral radiant flux.

The spectroradiometer used for the sphere-spectroradiometer system shall cover the visible wavelength range and have appropriate bandwidth and scanning interval for measurement of the LEDs being tested.

Specific requirements:

- The wavelength range shall cover at least 380 nm to 780 nm.
- The spectroradiometer shall have wavelength uncertainty within 0,5 nm ($k = 2$).
- The bandwidth (full width half maximum) and scanning interval shall not be greater than 5 nm.

The spectroradiometer shall have a linear response to radiation input at each wavelength over the visible range. The influence of nonlinearity shall be considered in the uncertainty budget.

The internal stray light of the spectroradiometer shall be considered in the uncertainty budget.

The auxiliary lamp for self-absorption measurement should have emission in the entire visible wavelength range.

4.5.3.3 Sphere-Photometer

A sphere-photometer shall be calibrated with a total luminous flux standard traceable to the SI. It is desirable that the standard lamp has spectral distribution similar to that of the DUT, if such standards are available.

A sphere-photometer shall have a total relative spectral responsivity (sphere plus photometer head) that matches the spectral luminous efficiency function for photopic vision $V(\lambda)$. The general $V(\lambda)$ mismatch index f_1' of the sphere-photometer system shall meet the requirements in 4.5.2.

Where necessary, a spectral mismatch correction shall be applied. For this correction, knowledge of the relative spectral distribution of the DUT and the relative spectral responsivity of the system of sphere and photometer is necessary. For spectral mismatch correction, see Annex C. The f_1' value of the sphere-photometer is determined from the relative spectral responsivity of the photometer head and the relative spectral throughput of the integrating sphere (function of $\rho(\lambda)/(1-\rho(\lambda))$, where $\rho(\lambda)$ is the spectral reflectance of the internal sphere surface). These are also needed for the spectral mismatch correction. The use of the spectral responsivity data of the photometer head alone would lead to a major error.

The relative spectral throughput of an integrating sphere changes with time, especially when the sphere is new, or when the sphere is heavily used and subject to contamination. The spectral throughput of the sphere should be measured periodically to update the $f_1^{'}$ value or spectral mismatch correction data. This is particularly important if the reflectance of the internal sphere surface is high (>95 %).

NOTE Guidance on measuring the relative spectral throughput of a sphere system is available in Annex B of IES LM-78 (2007).

It is desirable that the auxiliary lamp for self-absorption measurement has a spectral distribution similar to that of the DUT measured, especially for single colour LED modules.

4.5.4 Goniophotometer (all Types)

4.5.4.1 General

Goniophotometers shall have an angular scan range covering the entire solid angle to which the LED device emits light, especially when total luminous flux is measured.

Specific requirement: The angular aiming of the DUT shall be adjusted and maintained within ± 0,5° of the intended direction. The angular display shall have a reading resolution of 0,1° or better.

For measurement of luminous intensity distribution, procedures using conventional (far-field) goniophotometers assume that the luminous area of a light source is effectively a point source. Luminous intensity measurements derived from illuminance measurements according to the inverse square law require a sufficient photometric distance.

Specific requirements for test distance in far-field photometry:

- *For DUT having near cosine (Lambertian) distribution (beam angle ≥ 90°) in all C-planes: ≥ 5 ×* D
- *For DUT having a broad angular distribution different from a cosine distribution (beam angle ≥ 60°) in some of the C-planes: ≥ 10 ×* D
- *For DUT with narrower angular distributions, steep gradients in the luminous intensity distribution or critical glare control: ≥ 15 ×* D
- *For DUT where there are large non-luminous spaces between the luminous areas: ≥ 15 × (*D+S*)*

where D is the maximal luminous dimension of the DUT and S is the largest distance between two adjacent luminous areas.

NOTE For these test distances it may be expected that the photometric inverse square law is verified at better than 1 % in the optical axis, up to 3 % within twice of the beam angle. Other test distances verifying this rule may be applied without applying corrections (see also C.3.6.).

For some LED products where individual LEDs are effectively acting as small floodlights pointing in different directions (e.g. divergent LEDs on a linear luminaire or separate LED modules mounted within the one luminaire), the recommended test distances may be insufficient. In case of doubt it should be verified if the inverse square law applies correctly.

For near-field photometry, the test distance is theoretically considered infinite, but it should be validated.

For measurement of total luminous flux (and not for luminous intensity distribution), the far-field condition is not required, as total luminous flux can be derived by integration of illuminance distribution.

Goniophotometers in general have some angular region (called dead angle) where emission from a light source is blocked by its mechanism, e.g. an arm to hold the light source. Goniophotometers having a large dead angle exceeding a solid angle of 0,1 sr (corresponding to a cone angle of approximately 10° radius) should not be used to measure total luminous flux of omnidirectional lamps or such luminaires unless appropriate correction procedures are implemented.

4.5.4.2 Goniophotometer Using a Photometer Head

The relative spectral responsivity of the photometer head (combined with the spectral reflectance of a mirror if it is used) shall match the spectral luminous efficiency function for photopic vision $V(\lambda)$. The general $V(\lambda)$ mismatch index f_1' of the photometer head (including the mirror if used) shall meet the requirements in 4.5.2.

Where necessary, a spectral mismatch correction shall be applied. For this correction, the relative spectral distribution of the DUT and the relative spectral responsivity of the photometer head (including mirror if used) are necessary. See Annex C for spectral mismatch correction.

Goniophotometers shall be calibrated against a luminous intensity standard or illuminance standard traceable to the SI, and if total luminous flux is also measured, the measured total luminous flux value (expressed in lm) shall also be verified by measuring a total luminous flux standard traceable to the SI. Alternatively, the goniophotometer system for measurement of total luminous flux may be calibrated against a total luminous flux standard traceable to the SI, if the dead angle of the goniophotometer does not affect the measurement of the total luminous flux standard lamp.

NOTE For mirror type goniophotometers, a luminous intensity standard lamp is normally used to calibrate the photometer head, in which case, the photometric distance and the reflectance of the mirror are automatically included in the calibration.

4.5.4.3 Gonio-spectroradiometer

Gonio-spectroradiometers shall be calibrated against spectral irradiance or spectral radiant intensity standard traceable to the SI. For a mirror-type gonio-spectroradiometer, the spectral reflectance of the mirror shall be taken into account if a spectral irradiance standard is used. If total spectral radiant flux is also measured, the values (expressed in W/nm) shall also be verified by measuring a total spectral radiant flux standard lamp traceable to the SI. Alternatively, the gonio-spectroradiometer system for total luminous flux or total spectral radiant flux measurements may be calibrated against a total spectral radiant flux standard traceable to the SI, if the dead angle of the gonio-spectroradiometer does not affect the measurement of the total spectral radiant flux standard lamp.

The spectroradiometer used for the gonio-spectroradiometer system shall cover the visible wavelength range and have appropriate bandwidth and scanning interval for measurement of the LEDs being tested. The wavelength range shall cover at least 380 nm to 780 nm.

Specific requirement: The bandwidth (full width half maximum) and scanning interval shall not be greater than 5 nm. The spectroradiometer shall have a wavelength uncertainty within 0,5 nm ($k = 2$*).*

The spectroradiometer shall have a linear response to the input radiation at each wavelength over the visible range. The influence of nonlinearity shall be considered in the uncertainty budget.

The internal stray light of the spectroradiometer shall be considered in the uncertainty budget

4.5.4.4 Gonio-colourimeter

Gonio-colourimeters employ tristimulus colourimeter heads (filter-detector combinations having spectral responsivity matched to the CIE colour matching functions) to measure tristimulus values X, Y, Z. The Y-channel of a gonio-colourimeter shall meet all requirements in 4.5.4.1.

Unless otherwise demonstrated, a gonio-colourimeter alone shall not be used for absolute measurement of colour quantities, and may be used only for colour difference measurement (or relative colour measurement combined with calibration by a spectroradiometer for a particular DUT).

4.5.5 Luminance Meters

A luminance meter shall be calibrated with a luminance standard traceable to the SI. The following applies to both classical luminance meters (single point luminance measurement devices) and image luminance measurement devices (ILMD).

The relative spectral responsivity of the luminance meter shall match the spectral luminous efficiency function $V(\lambda)$ for photopic vision. The general $V(\lambda)$ mismatch index $f_1^{'}$ of the luminance meter shall meet the requirements in 4.5.2.

Where necessary, a spectral mismatch correction shall be applied. For this correction, the relative spectral distribution of the DUT and the relative spectral responsivity of the photometer are necessary, see Annex C for spectral mismatch correction.

If an ILMD is used, its measurement uncertainty shall be verified by comparing the results for luminance distribution of a typical LED device measured with a discrete luminance meter.

5 Preparation, mounting and operating conditions

5.1 Ageing

Ageing shall be according to the appropriate LED product performance standard (see Clause 2).

5.2 Test device

The applicant shall provide all necessary instructions for proper use. The optical parts of devices shall be clean, except if otherwise required by the applicant (e.g. determination of maintenance factors).

5.3 Mounting

5.3.1 Operating orientation

LED lamps shall be operated in free air in a vertical base-up position, unless other operating orientation is specified by the applicant (or regulation). If an applicant has declared that the lamp is suitable for use in a specific orientation only, the lamp shall be mounted in the declared orientation during all tests. If a different operating position is used during the test the specifications of 4.2.5 apply.

LED luminaires shall be mounted in the operating position recommended by the manufacturer for intended use so that their thermal condition due to air flow inside and outside the device will be the same as its normal use condition (in terms of operating position) and that their alignment is mechanically true and all components rigidly located in their designed positions. Adjustable parts shall be correctly set according to the manufacturer's instructions. If a different operating position is used during the test the specifications of 4.2.5 apply.

LED modules can be operated at any operating position if their temperature is set and maintained to t_p temperature.

The test device shall be mounted so that any thermal conduction through supporting elements holding the device causes negligible unintended cooling effects.

NOTE 1 For example, a luminaire may be suspended in air by wire or held by support materials that have a low heat conductivity, e.g. Teflon.

In all cases, the operating position of the device shall be reported.

NOTE 2 The light emission process of a LED is not affected by orientation (with respect to gravity). However, the orientation of a LED lamp and LED luminaire can cause changes in thermal conditions for the LEDs used in the device, and thus the light output can be affected by the orientation of the device.

5.3.2 Coordinate system

Photometric and colorimetric distributions of lighting devices are dependent on locations and directions. Therefore a coordinate system shall be linked to the DUT and the photometric/colorimetric distributions are referenced to this coordinate system. The mechanical position of the device referenced to the coordinate system shall be unique and declared. The coordinate system centre is coincident with the photometric centre of the DUT.

The provisions of EN 13032-1:2004+A1:2012, Clause 4 apply.

5.3.3 Photometric Centre

The position of the photometric centre of a device shall be at the centre of the solid figure bounded in outline by the luminous surfaces.

For LED luminaires with substantially opaque sides, where the lamp (or module) compartment is substantially white or luminous, the position shall be at the centre of the main luminaire opening, but for LED luminaires with substantially opaque sides, where the lamp compartment (or module) is substantially black or non-luminous, the position shall be at the lamp photometric centre (centre of the solid figure bounded in outline by the luminous surfaces of the lamp or module).

When using a far-field goniophotometer and measuring devices with multiple light-emitting areas that have significant separation and which do not comply with the specific requirement for test distances in 4.5.4, the devices shall be measured in several steps with each light emitting area centred accordingly. Data for each lighting emitting area shall be reported.

NOTE Light emitting areas are considered to be significantly separated when the deviation from the inverse square law when measured together, are non-negligible.

Complementary guidance for photometric centre, see EN 13032-1:2004+A1:2012, Figure 5.

5.4 Operating conditions of the LED devices

5.4.1 General

LED devices with dimming control shall be adjusted to maximum light output for all tests or to pre-defined levels if instructed by the applicant.

LED devices with internal feedback-control circuits not externally adjustable shall be tested as provided.

LED devices with adjustable colour points shall be adjusted or set to the defined settings as indicated by the manufacturer or applicant.

LED devices with a tuneable white spectrum shall be adjusted to the settings specified by the applicant or according to a relevant standard.

For multicolour LED devices e.g. RGB LED devices, each colour shall be measured individually with the full power setting and all colours together with the full power setting.

5.4.2 LED lamps

LED lamps are measured in standard test conditions and data shall be reported for t_{amb} = 25 °C. If other operating temperatures are declared by the manufacturer, the measured results at the given temperature shall be reported or a service conversion factor shall be provided by a table or graph for those temperatures.

5.4.3 LED modules

For LED modules provided without control gear the applicant shall provide the necessary specifications for the auxiliary equipment to be used.

LED modules are measured in standard test conditions at rated performance temperature. The temperature at the t_p-point shall be set at this value for the measurements. If not accessible, the manufacturer or the applicant shall indicate a temperature monitoring point. If heat sinks are needed for the correct operating of the LED module and the LED module does not have an own heat sink, a suitable temperature controlled heat sink may be used. Interpolation techniques may also be applied (see Annex C).

A LED module may show different $t_{p,nn}$ values.

Light engines that do not incorporate heat sink(s) are measured at the rated performance temperature as described above.

Light engines incorporating heat sink(s) shall be measured first in standard test conditions for t_{amb} = 25° C, with the value t_p measured and reported. Then further measurements are made at specified performance temperatures at the t_p-point. If the t_p-point is not accessible, the applicant shall indicate a related temperature monitoring point.

5.4.4 LED luminaires

LED luminaires are measured in standard test conditions at t_{amb} = 25 °C.

NOTE t_p is not relevant for the LED luminaire end-user and is often not accessible.

Data shall be reported for t_{amb} = 25 °C. If a rated maximum performance ambient temperature(s) $t_{q,nn}$ other than 25 °C is declared a service conversion factor shall be delivered for this temperature (see also 4.2.2 and C.1.2). There can be more than one rated maximum performance ambient temperature declared.

6 Measurement of photometric quantities

6.1 General

The measurement of the following photometric quantities is covered by this standard:

- total luminous flux;
- luminous efficacy;
- luminous intensity distribution and
- luminance.

Absolute photometry methods are required for all LED devices.

6.2 Measurement of total luminous flux

General guidance for luminous flux measurements is given in CIE 84:1989.

The luminous flux of a light source can be determined by different methods. The method may be chosen depending on what other measurement quantities (colour, intensity distribution) are needed to be measured or depending on the geometrical dimensions of the DUT. The following methods are available:

— Method A: Measurement with an integrating sphere (with a photometer head or a spectroradiometer). For the sphere theory, see CIE 84:1989, 6.2.

— Method B: Calculation from the luminous intensity distribution. For calculation principles, see CIE 84:1989, Clause 4. Luminous intensity can be determined from integrated luminance. See CIE 70: 1987, 2.2.

— Method C: Calculation from the illuminance distribution and photometric distance. For calculation principles, see CIE 84:1989, Clause 5.

Method A is suitable for measurement of LED lamps and LED modules. The luminous flux of LED luminaires shall be determined by appropriate integration of the luminous intensity distribution data or the illuminance distribution data (method B or C). If the LED luminaire is sufficiently small compared to the sphere, method A may also be applied. For partial luminous flux measurements (see 6.3): method B applies, or with appropriate formula, method C may also be used.

There are two possible positions to mount the DUT in an integrating sphere:

4π geometry: For all-types of LED devices, in particular devices with omnidirectional distribution, the DUT is usually mounted at the centre of the sphere in the specified operating position. If possible, the DUT is oriented in such a way that the minimum amount of direct light falls on the baffle. Linear sources should be positioned so that their axis coincides with the line between the detector head and the centre of sphere. The sphere is calibrated with a luminous flux standard lamp placed at the same location as that of the DUT.

2π geometry: For LED sources with hemispherical or directional distribution with no backward emission the DUT may be mounted at a sphere wall position where the specified operating position of the DUT is fulfilled. A small baffle shall be used to prevent direct illumination of the detector head by the light source. In this case, the sphere is calibrated with a luminous flux standard lamp with hemispherical distribution placed at the same location as that of the DUT.

NOTE 1 Examples of 4π and 2π geometries of integrating spheres are available in CIE 127:2007, Figure 9.

A self-absorption correction factor shall be applied by use of the auxiliary lamp method in CIE 84:1989 unless the DUT and luminous flux standard are similar in size and reflectance characteristics and it is demonstrated that correction is negligible for the combination of standard lamp used and the type of DUT measured. For sphere-spectroradiometers, measurement with an auxiliary lamp and self-absorption correction are applied spectrally.

NOTE 2 If multiple DUTs of the same model are measured, the same self-absorption correction factor against a particular standard lamp may be used

The differences in angular intensity distributions of the DUT and luminous flux standard reference shall be evaluated and, if significant, associated errors should be corrected.

6.3 Partial Luminous Flux

For the specified cone angle α, the partial luminous flux (see 3.40) is obtained from summation of intensity distribution data $I(\theta_i, \varphi_j)$, with scanning intervals of $\Delta\theta$ and $\Delta\varphi$.

If one of the measured points θ_k falls exactly on $\alpha/2$ (e.g. $\alpha/2 = 45°$ and $\theta_i = 40°, 45°, 50°, \ldots.$), the summation is made as

$$\Phi_{\alpha} = \sum_{j=1}^{n}\sum_{i=1}^{k} I(\theta_i,\varphi_j)\,\Omega_i \tag{4}$$

where

$$\Omega_i = \begin{cases} \frac{2\pi}{n}\left[\cos(\theta_i) - \cos(\theta_i + \frac{\Delta\theta}{2})\right] & \text{for } i = 1 \\ \frac{2\pi}{n}\left[\cos(\theta_i - \frac{\Delta\theta}{2}) - \cos(\theta_i + \frac{\Delta\theta}{2})\right] & \text{for } 1 < i < k \\ \frac{2\pi}{n}\left[\cos(\theta_i - \frac{\Delta\theta}{2}) - \cos(\theta_i)\right] & \text{for } i = k \end{cases} \tag{5}$$

n is the number of φ angles and k is the number of θ angles.

If $\alpha/2$ falls exactly between two measured θ-angle points, i.e. $\alpha/2 = \theta_k + \Delta\theta/2$, (e.g. α/2 = 45° and θ_i = …40°, 50°…)

$$\Phi_{\alpha} = \sum_{j=1}^{n}\ \sum_{i=1}^{k} I(\theta_i,\varphi_j)\,\Omega_i \tag{6}$$

where

$$\Omega_i = \begin{cases} \frac{2\pi}{n}\left[\cos(\theta_i) - \cos(\theta_i + \frac{\Delta\theta}{2})\right] & \text{for } i = 1 \\ \frac{2\pi}{n}\left[\cos(\theta_i - \frac{\Delta\theta}{2}) - \cos(\theta_i + \frac{\Delta\theta}{2})\right] & \text{for } 1 < i \leq k \end{cases} \tag{7}$$

If the goniophotometer is not calibrated in absolute scale, the ratio of total luminous flux and partial flux can be obtained from the goniophotometer, the total luminous flux can be measured with an integrating sphere, and the partial flux can be calculated as the multiplication of total flux and the ratio.

For measurement of partial luminous flux in a cone of 90° or larger, the measurement should be made with scanning intervals of 5° or less for θ angles (γ angles in C,γ coordinate system) and 45° or less for φ angles (C angles in C,γ coordinate system). Smaller angle intervals may be needed for DUTs for specific applications (e.g. street lighting luminaires).

6.4 Luminous efficacy

The luminous efficacy η_V, expressed in lm/W, is determined by the ratio of the luminous flux Φ of the LED device to the electrical power P_{tot} including all components required for the LED device operation.

$$\eta_V = \Phi / P_{tot} \tag{8}$$

The luminous flux of the LED device is measured according to 6.2. The electrical power is measured at the terminals of the LED device according to 4.3.2, or, for non-integrated and semi-integrated LED devices, as specified by the applicant or regulation.

NOTE The term “luminous efficacy” is used in this document in the meaning of luminous efficacy of a source as defined in the ILV.

6.5 Luminous intensity distribution and data presentation

6.5.1 General

Unless otherwise specified, the CIE-*C,γ* coordinate system (see 5.3 and EN 13032-1) shall apply.

The angular interval between readings of intensity within the vertical planes and the angular spacing between adjacent vertical planes should be such that luminous intensity distribution can be accurately presented and as to permit interpolation of intensity values during post-processing (lighting calculations) with an acceptable accuracy. The number of planes should also be determined by the nature of the distribution having regard to symmetry or irregularity and to the end results desired from the test. Guidance for goniophotometry of luminaires is delivered by the appropriate EN lighting application standards.

Measurements of luminous intensity distributions are usually made with goniophotometers. The provisions for goniophotometers apply: see 4.5.4. For types of goniophotometers, see also EN 13032-1.

6.5.2 LED-lamps and LED-modules

The intensity distribution of these devices shall be expressed in cd.

6.5.3 LED-luminaires

The intensity distribution of these devices shall be expressed in cd.

NOTE 1 For lighting calculation programs requiring luminous intensity distribution data in cd/klm the pro-rata luminous intensity values $I_{\text{flux-normalized}}$ may be calculated by:

$$I_{\text{flux-normalized}} = I_{\text{measured}} \times \frac{1000}{\Phi_{\text{luminaire}}} \tag{9}$$

where $\Phi_{\text{luminaire}}$ is the total luminous flux output (in lumen) of the LED luminaire and I_{measured} is the measured luminous intensity (in candela). The calculated total luminous flux output of the LED luminaire shall be stated.

NOTE 2 LOR may be determined for LED luminaires using interchangeable sources (e.g. LED lamps) in some cases. The use of LOR is disregarded for LED luminaires with non-replaceable LED light sources. For LED luminaires with non-replaceable LED light sources, only the total flux of the luminaire can be measured, in which case LOR is 100 % as a consequence and not significant.

6.6 Centre beam intensity and beam angles

The luminous intensity distributions shall be measured according to 6.5. For guidance for determining the centre beam intensity and beam angles on basis of the luminous intensity distributions, see EN 61341:2011.

For intensity distribution measurements in a goniophotometer, the direction (0,0) is usually the direction of the design optical axis (mechanical reference axis) of the light source, the axis through the photometric centre and perpendicular to the light exit plane, unless otherwise specified by the manufacturer. In EN 61341, the centre beam intensity is determined in the direction of the observed beam axis (the axis about which the luminous intensity distribution is substantially symmetrical) and the beam angle is evaluated around the observed optical beam axis. Mechanical reference axis may be used for measurement but evaluation shall be made around the observed optical beam axis. The method to determine this optical beam axis is described in EN 61341:2011, Clause 6. Mechanical reference axis and observed optical beam axis are not necessarily coincident and this should be accounted for in the evaluation of the beam angle.

6.7 Luminance Measurements

For reasonably uniform light surfaces, the following measurements may be considered:

a) Measurement of the average luminance of the whole luminaire in a stated direction, or in a series of directions: This method is often used, e.g. for the evaluation of glare. In this method the luminous intensity (distribution) is measured, usually with a goniophotometer, and the average luminance is calculated by dividing the luminous intensity by the projected luminous area.

b) Measurement of “patch luminance”: This method is often used for the evaluation of spatial non-uniformity of the luminance of large indoor luminaires – for details see CIE 121:1996, 6.5.3. The average luminance(s) of specified small areas within the luminous area of the luminaire, areas called “luminous patch” (only size and shape are specified, realized by a mask with an opening) are measured in stated direction(s). These patches are distributed over the luminous surface of the luminaire and the average luminance is determined for each patch. The maximum and minimum of these average luminances are usually reported The measurements may be made either with a goniophotometer set to the stated direction, using such a physical mask moved around over the luminous area of the luminaire (using the principle described in method a), or with a luminance meter measuring the average luminances of the luminous patches at different locations.

If the LED sources and LED luminaires have no diffusing covers and are observed as a sum of point sources sources (thus appearing as a mixture of luminous and non-luminous portions within the outer contour), method a) above for the determination of the average luminance from the luminous intensity in the viewing direction and the projected luminous area (the outer contour of the light output area) is not valid. For such LED devices, only measurements of the luminance’s of the luminous portions of the light output area are appropriate. Such measurements can be made using a luminance measurement device (LMD) or an imaging luminance measurement device (ILMD).

The luminous area can be calculated while summing up the object area of all marked pixels if the ILMD is calibrated with respect to the object space. The algorithm to divide between luminous area and background should be defined depending on the application (e.g. fixed threshold, adaptive threshold).

Further requirements for luminance measurements are under consideration.

7 Measurement of colour quantities

7.1 Colorimetric Measurements

7.1.1 General aspects

The following colorimetric quantities are covered in this standard:

- chromaticity coordinates,
- correlated colour temperature,
- distance from Planckian Locus,
- colour rendering indices and
- angular colour uniformity.

Calculations of colorimetric quantities shall take into account EN ISO 11664, all parts. Spectroradiometers are used to measure these colour quantities. Tristimulus colourimeters normally do not have sufficient accuracy for absolute colour measurement but they may be used for evaluating changes of chromaticity in different directions.

Colour rendering indices require spectral data.

The value of the colorimetric quantities of LED lamps, LED modules and LED luminaires may be angularly non-uniform.

Colorimetric or spectral measurements may basically be performed using one of the following geometries:

a) along a specific direction;

b) as a directional distribution using gonio-colorimetric or gonio-spectroradiometric measurements equipment;

c) as spatially averaged values (i.e. from the total spectral radiant flux), using an integrating sphere or numerically averaging the gonio-spectroradiometric data or the gonio-colorimetric data.

Spatially averaged colour quantities are used for all LED lamps, light engines, and LED luminaires except otherwise specified by the manufacturer or applicant.

Spatially averaged colour quantities may be obtained using one of the following methods:

1) Sphere-spectroradiometer measurements provide spatially averaged colour quantities calculated from the total spectral radiant flux;

2) If gonio-spectroradiometric data are available, total spectral radiant flux is calculated as basis for the calculation of spatially-averaged colour quantities;

3) If gonio-colorimetric data gonio-colorimetric data $X(\theta,\phi)$ $Y(\theta,\phi)$, and $Z(\theta,\phi)$ are available, the spatially integrated tristimulus values, X, Y and Z, are calculated by

$$X = \int_{\varphi=0}^{2\pi} \int_{\theta=0}^{\pi} X(\theta,\varphi)\sin\theta \mathrm{d}\theta \mathrm{d}\varphi \tag{10}$$

$$Y = \int_{\varphi=0}^{2\pi} \int_{\theta=0}^{\pi} Y(\theta,\varphi)\sin\theta \mathrm{d}\theta \mathrm{d}\varphi \tag{11}$$

$$Z = \int_{\varphi=0}^{2\pi} \int_{\theta=0}^{\pi} Z(\theta,\varphi)\sin\theta \mathrm{d}\theta \mathrm{d}\varphi \tag{12}$$

The chromaticity, correlated colour temperature and other colorimetric quantities are then calculated from the tristimulus values X, Y and Z. If chromaticity x, y, and luminous intensity at each angle is available, these can be converted to X, Y, Z to apply this method.

Colour rendering indices can only be derived using either method 1) or 2).

The chromaticity coordinates (x,y) and/or (u',v') are calculated according to CIE 15.

7.1.2 Correlated Colour Temperature (white LED light sources)

The chromaticity can also be expressed by the correlated colour temperature (T_{cp}) and the parameter D_{uv}. Correlated colour temperature is calculated according to CIE 15. D_{uv} is the signed distance from the Planckian locus on the CIE ($u', \frac{2}{3}v'$) diagram, which is positive for above and negative for below the Planckian locus.

7.1.3 Colour Rendering Indices (white LED light sources)

Calculation of colour rendering indices shall be made in accordance with CIE 13.3.

7.1.4 Angular Colour Uniformity

Angular colour uniformity is measured as the largest deviation of chromaticity (u', v') of a LED device emitted in different directions, from its spatially averaged chromaticity (u'_a,v'_a) calculated as

$$\Delta_{u',v'} = \sqrt{(u' - u'_a)^2 + (v' - v'_a)^2} \qquad (13)$$

The chromaticity coordinates (u',v') are measured with a gonio-colourimeter or gonio-spectroradiometer at a vertical angle interval of 10° or less (2,5° is recommended) and a horizontal angle interval of 90° or less (22,5° is recommended). For reflector lamps, the angle increments shall be 1/10 or less of the beam angle (diameter of the angular cone emitting more than 1/2 of the peak intensity) but no larger than 10°. The data at angle points where the luminous intensity is less than 10 % (unless otherwise specified by a relevant product standard) of the peak intensity shall be ignored in the calculation.

The average chromaticity (u'_a,v'_a) for this calculation is obtained from the gonio-colorimetric measurement points described above using the calculation procedures in 7.1.1 (3), not from a different measurement system (e.g. sphere-spectroradiometer). If data from a different measurement system is used, there may be some errors, as low intensity points may be included in other results. Also, the accuracy of chromaticity measurement for this angular colour uniformity is not as critical as that for chromaticity measurement for DUT described in 7.1.1.

NOTE General guidance on colour difference specification for light sources is available in CIE TN 001:2014

8 Measurement Uncertainties

8.1 General

The uncertainties shall be evaluated according to ISO/IEC Guide 98-3 and its supplements. Guidance is also available from CIE 198.

For all measured quantities the expanded uncertainty shall be given and expressed for a confidence level of 95 %. The expanded uncertainty is stated to at most two significant digits.

For the purposes of testing, each test report may report uncertainty values for a typical product of the similar type having similar spectral distributions and intensity distributions to the DUT (see NOTE). In this case the type of the product used in the uncertainty budget shall be stated in the test report (see NOTE). Laboratories shall have a detailed uncertainty budget for the similar type of product and keep them available on demand. If such uncertainty budget is made for a range of products (e.g. CCT from 2 700 K to 4 000 K), the largest uncertainty value within the range shall be stated.

NOTE In this context, products could be considered similar type if the following properties are the same as the DUT: phosphor type or RGB(A) type; similar geometrical shape (e.g. compact or tubular type for lamps); similar intensity distributions; omnidirectional or directional (beam angle between +50 % and −25 % of the value of the DUT); CCT within ± 15 % of the CCT value of the DUT.

An example statement in the test report: “The uncertainty values stated in this test report are those for a similar type of product: phosphor type LED lamp (compact), directional (beam angle 60°), CCT 3 500 K.” If the type of DUT does not match the type categories listed in the NOTE, the product type should be described specifically.

When corrections are applied to the measurement results, the correction shall always use the characteristics of the DUT (or product of the same model), and not of the similar type product.

For practical reasons, it is not always possible to estimate or measure the influence of the DUT repeatability between different cold-start operations; however this information shall be known from type investigations and shall be included in the uncertainty evaluation. It shall be mentioned in the uncertainty budget whether this parameter is estimated from type specific data or from individual measurements of the DUT.

For luminous intensity distributions, the measurement uncertainty shall be reported at least in one given representative direction where the luminous intensity is fairly flat.. The uncertainty on angular setting (including alignment of the DUT in the goniometer) or measurements shall be reported separately.

For luminance distributions, measurement uncertainty shall be reported at least in one representative point where the luminance distribution is fairly flat.

8.2 Guidance for Measurement uncertainty budgets

Common components of uncertainty for measurement of LED devices are listed below.

8.2.1 Common parameters to all measurements

At least the following contributions shall be considered:

- temperature setting and uncertainty on temperature measurement;
- electrical settings and uncertainty on electrical measurements (power supply, electrical measuring instruments);
- fluctuation of light output of the DUT (if significant);
- calibration standard (calibration certificate);
- operating of the calibration standard (ageing, electrical measurements, calibration process);
- linearity of measuring instruments;
- reproducibility and repeatability (if applicable, default value for the equipment and generic device type may be used if this is not evaluated for the specific DUT).

For all measurements not only the contributions from the measurement system and procedures but also the contributions from the specific characteristics of the DUT (or similar type) shall be taken into account.

8.2.2 Luminous flux

In addition to 8.2.1 at least the following contributions shall be considered (where appropriate):

Measurement (depending on the method).

a) Goniophotometer:

  - flatness of mirrors and polarization effects;
  - spectral reflectance of mirrors;
  - stray light (spatial);
  - positioning accuracy;
  - spectral matching (detector + mirror, different spectral power distributions of the calibration standard and DUT);

- detector acceptance area;
- cosine response (illuminance integration);
- uncertainty of photometric distance if the photometer head is calibrated for illuminance responsivity;
- uncertainty of the reflectance of the mirror if it is used, if the photometer head is calibrated for illuminance responsivity;

b) Sphere Photometer:

- self-absorption;
- thermal behaviour;
- spatial nonuniformity of sphere responsivity;
- sphere reflectance (influence to the spectral matching);
- spectral matching (detector + sphere, different spectral power distributions of calibration standard and DUT);
- mechanical repeatability when the sphere is opened and closed;
- stability of sphere responsivity during the period between recalibrations;
- cosine response of photometer head;
- fluorescence effects from sphere coating;

c) Sphere spectroradiometer:

- self-absorption;
- thermal behaviour;
- spatial nonuniformity of sphere responsivity;
- sphere reflectance;
- wavelength accuracy;
- stray light of the spectroradiometer;
- bandpass of the spectroradiometer;
- cosine response of the spectroradiometer entrance port;
- mechanical repeatability when the sphere is opened and closed;
- stability of the sphere responsivity during the period between recalibrations;
- fluorescence effects from sphere coating;

d) Gonio spectroradiometer:

- flatness of mirrors and polarization effects;

- spectral reflectance of mirrors;
- stray light (spatial);
- positioning accuracy;
- detector acceptance area;
- cosine response (illuminance integration);
- wavelength accuracy;
- stray light of the spectroradiometer;
- bandpass of the spectroradiometer;
- uncertainty of photometric distance if the spectroradiometer is calibrated with a spectral irradiance standard;
- uncertainty of the spectral reflectance of the mirror if it is used, if the spectroradiometer is calibrated with a spectral irradiance standard.

8.2.3 Luminous intensity and luminance

Similar parameters as in 8.2.2 shall be considered.

8.2.4 Colour quantities

This includes chromaticity coordinates, correlated colour temperature, and colour rendering indices.

In addition to 8.2.1 at least following contributions shall be considered:

- correlations due to the colour temperature uncertainty of the calibration source;
- stray light of the spectroradiometer;
- bandwidth (influence, correction);
- wavelength accuracy;
- dynamic range over the spectral range.

8.2.5 Electrical power

In addition to 8.2.1 at least the following contribution shall be considered:

- bandwidth of the AC power meter (influence, correction);
- input impedance of the AC power meter.

8.2.6 Luminous efficacy

The correlations between the luminous flux value and the electrical power measurement should be taken into account to reduce the associated measurement uncertainty. For example, if supply current affects both luminous flux output and electrical power of a DUT in the same direction with same sensitivity, the uncertainty in luminous efficacy for this component will be cancelled out.

9 Presentation of test results

9.1 Test report

9.1.1 Introduction

The following list is intended as a guide to the information which should be included in a test report covering photometric/colorimetric measurements of LED devices.

The test report shall report any tolerance intervals and specific requirements that are not met by the laboratory, with actual conditions used and, if applicable, the fact that the result is corrected to the standard test condition.

9.1.2 General information

The following information should be provided:

- testing laboratory and address, report number and date;
- identification of the applicant;
- test date(s) and types of test: descriptive title to indicate what was measured;
- identification of attached documents.

9.1.3 Information on the device(s) under test

Description of the DUT:

- identification number(s) of the DUT;
- if applicable: manufacturer's name, type, model number, rated values of electrical quantities, rated values of luminous flux, CCT, CRI, relevant dimensions and luminous area of the DUT;
- description of the DUT including its optical components such as refractors, reflectors, etc., with an option of including a photograph of the DUT;
- other essential information (e.g. the method of sample selection if it is a type test);
- for LED modules: rated maximum performance temperature $t_{p,nn}$, description of added heat-sink if used;
- for luminaires: rated maximum performance ambient temperature $t_{q,nn}$ if declared;
- for LED luminaires using interchangeable LED sources, number of LED lamps or LED modules, and if applicable, description of incorporated LED lamps or LED modules such as manufacturer's name, type, model number, rated electrical characteristics, rated maximum performance temperature $t_{p,nn}$, rated luminous flux, rated CCT and rated CRI.

Description of auxiliary equipment (LED control gear, power supply) for semi or non-integrated devices:

- manufacturer's name, type, model, (serial number if available);
- rated electrical characteristics.

9.1.4 Information on the test procedure

The following information should be provided:

- short descriptions of the photometric procedure and equipment used:
  - for a goniophotometer, type and photometric distance;
  - for a sphere, diameter, 4π or 2π geometry;
  - sphere-photometer or sphere-spectroradiometer;
  - goniophotometer or gonio-spectroradiometer;
- reference to standard test conditions of this standard or to specific service conditions;
- operating position of the DUT;
- for intensity distribution of luminaires, attitude and tilt of DUT during measurement (see EN 13032-1), relative position to the coordinate-system and photometric centre of the DUT;
- ambient test temperature, test voltage and frequency;
- ageing and stabilization time;
- traceability and references to calibration certificates of standard(s) for photometric and colorimetric (spectroradiometric) quantities as applicable.

Clear identification of all used measurement equipment shall be made available upon request.

9.1.5 Photometric and/or colorimetric data

The photometric and/or colorimetric data provided in the test report relates to the particular device(s) under test. The report shall include all useful associated electrical, temperature surfaces and environmental measurements.

The measurement uncertainties evaluated according Clause 8 shall be reported.

If the uncertainty values are stated for a typical product of the similar type, the test report shall state the type of the product used in the uncertainty budget (see Clause 8).

Annex A
(informative)

Guidance on the Application of this standard

A.1 General

This standard is designed so that laboratories following its methods can perform accurate and reproducible photometric and colorimetric tests on LED lighting products.

In order to achieve this, the DUT is tested according to the standard test conditions. Each standard test condition consists of a set value and a tolerance interval (see below). It would be ideal to perform measurement exactly at a set value, but it is normally not possible and therefore, the test condition needs to be within the tolerance interval. For best practice, however, where possible and practical, the measurement results are corrected to the set value of standard test condition. If the tolerance interval is met, correction to the standard test condition is not mandatory but highly recommended.

EXAMPLE 1 During a test, the ambient temperature is at 25,5 °C instead of 25,0 °C. and the uncertainty of the ambient temperature measurement is 0,2 °C. This meets the tolerance requirement, and it may be decided not to make the correction and instead to add in the uncertainty budget an uncertainty contribution of 0,7 °C for temperature (0,5 °C for the deviation and 0,2 °C for the uncertainty in the calibration of the thermometer). However, if the measurement uncertainty is to be reduced, a small additional test can be performed to correct the result from that measured value at 25,5 °C to what it would be at 25,0 °C.

If any of the test conditions fall outside the corresponding tolerance interval then an additional correction test shall be performed to correct the value to the standard test condition.

EXAMPLE 2 An integrating sphere test is to be conducted with a supply voltage of 230 V AC but due to the resolution of adjustment of the power supply, the voltage cannot be adjusted between 229,4 V and 230,6 V, and the uncertainty of voltage measurement is 0,2 %. This case does not meet the tolerance interval. In this case, the test can be conducted at both 229,4 V and 230,6 V and then the result for 230,0 V can be determined by interpolation.

Annex D contains examples of uncertainty estimations with components of uncertainties likely to be encountered when performing photometric measurements on LED products.

According to the demands of day-to-day testing corrections are normally not made if the standard test conditions are fulfilled or only a few corrections – for example, correction of spectral mismatch and of ambient temperature. But for calibration purpose or testing for establishing rated values (see Annex E) a laboratory may choose to take more time and perform more corrections in order to reduce the uncertainty and thereby to increase their confidence in the test result.

It is very important to have documentation to justify any changes to the uncertainty components. This may be in the form of calibration certificates, calculation spread sheets or other experimental evidence.

A laboratory may wish to use an uncertainty budget that is common to all of their testing, taking into account their equipment used to calibrate the system and perform the measurements, and use this as their own default uncertainty budget. Then for each different product type, a separate spreadsheet can be created based on this default spreadsheet and taking into account test-specific values such as the stability of the DUT and the spectral mismatch error or type-specific values.

NOTE A default uncertainty budget that covers all tests would normally have a higher uncertainty than a test-specific uncertainty budget because the intervals will need to be inflated to worst-case conditions, whereas the test-specific uncertainty budget will have DUT-specific intervals.

The standard also permits the use of new measurement techniques where specific requirements are still under consideration. In this case, besides carefully investigating the method and related uncertainties, validation of the method needs to be done by comparison with tests using well-accepted methods. In fact, for all test methods, new or well known, validation by inter-comparison with other laboratories is recommended as it helps a laboratory to detect unknown systematic errors, for example an incorrect calibration factor introduced in the measurement software.

A.2 Tolerance Interval

In this standard, the term “tolerance interval” is introduced as defined in ISO/IEC Guide 98-4. Tolerance interval is an acceptable range of the true value of the parameter (not the range of readings of instrument). Therefore, to ensure this requirement is fulfilled, measurement uncertainty of the parameter needs to be taken into account.

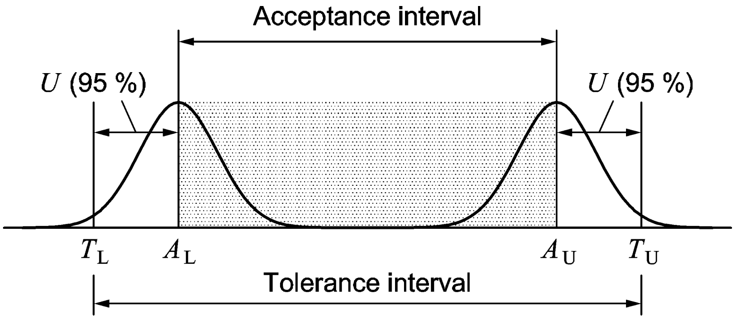


Figure A.1 — Tolerance interval and acceptance interval

To ensure that the true value of the parameter is within the tolerance interval at 95 % confidence level, the range to be accepted for the readings of instrument measuring the parameter shall be in a range smaller than the tolerance interval, reduced by the expanded uncertainty (with confidence interval of 95 %) of the measurement of the parameter on both tolerance limits. This acceptable range for the readings of instrument is called “acceptance interval”, as illustrated in Figure A.1.

For example, in this document the tolerance interval of ambient temperature is ± 1,2 °C, and if the expanded uncertainty of thermometer measurement ($k = 2$) is 0,2 °C, the acceptance interval is ± 1,0 °C. Thus, the reading of the thermometer shall lie within ± 1,0 °C from the set value.

In some other test methods previously published, the tolerance was provided and used as acceptance interval though it was not explicitly described, but at the same time, the uncertainty of the instrument to measure the tolerance parameter was specified. For example, “the tolerance of ambient temperature ± 1,0 °C” and “the uncertainty of the thermometer < 0,2 °C.” This requirement is essentially the same and compatible with the tolerance interval ± 1,2 °C, which is specified in this document, assuming that additional uncertainty contributions of the measurement of the parameter are negligible.

Annex B
(informative)

Stray light — Screening against stray light in a goniophotometer

Stray light (in a goniophotometer) is any light which reaches the entrance window of the photometer head other than directly from the source or through reflections intended to be measured. This may be due to reflections from walls, floor, ceiling or other parts of the DUT or the equipment or due to other light sources.

The entrance window of the photometer head shall be screened so that as far as possible it sees only the DUT and, where appropriate, the lower surface of the mounting board. Where a mirror goniophotometer is used the entrance window of the photometer head shall be screened to see only the image of the DUT and so as not to receive light directly from any part of the DUT itself.

All surfaces, other than the DUT (or the mirror), that are seen by the entrance window of the photometer head should be finished matt black, including the bevelled edges of mirrors. It should be noted that many 'matt' black paints have a luminance factor near the normal to the surface as high as 4 % and higher at glancing angles of incidence.

Screens should be arranged so that stray light from the DUT can only reach the entrance window of the photometer head after two or more reflections from black surfaces. Where this is not possible surfaces should be covered with a non-reflective material, for example black velvet or black carpet. Any surface such as the edges of screens which are parallel with the entrance window of the photometer head/axis of the DUT should be grooved, angled or chamfered to a sharp edge to minimize reflections onto the entrance window of the photometer head.

The background of the view of the DUT from the photometer head shall be matt black. This may include the floor and ceiling. The remainder of the room may be lighter coloured provided that precautions have been taken to eliminate stray light.

Possible paths of stray light which should not be overlooked are:

a) DUT - blackened surface (e.g. floor, screen) - mirror - entrance window of the photometer head;

b) DUT - blackened surface (e.g. floor, screen) - DUT - mirror - entrance window of the photometer head;

c) DUT - mirror - DUT - mirror - entrance window of the photometer head.

Stray light that cannot be eliminated should be measured and subtracted from the readings taking into account the variation of stray light with the position of the DUT. The amount of resultant stray light may be difficult to measure. For example, any screen placed for such a measurement between the DUT and the entrance window of the photometer head may also screen a path of stray light via the mirror to the entrance window of the photometer head.

Annex C
(informative)

Practical laboratory conditions

C.1 Correction factors

C.1.1 Measurement correction factors

Measurement correction factors are applied when measurement conditions in the laboratory do not meet the standard test conditions or when uncertainty is to be reduced. They are applied directly to the measured values to correct for the difference in operating conditions (e.g. different ambient temperature, different performance temperature t_p and operating position, etc.).

If only ambient temperature or measured performance temperature t_p differs, the measurement results shall be corrected (as required in Clause 4) based on the temperature dependence characteristics of the particular DUT and actual temperature (see also C.3).

If the mounting position of a DUT in an integrating sphere or a goniophotometer (e.g. rotating movement around the horizontal axis of the goniophotometer) differs from the standard operating position and affects the luminous flux, a correction of the measurement values is necessary. The measurement results shall be corrected (as required in Clause 4) based on the operating-position dependent characteristics of the particular DUT and actual operating position used. This can be determined with an auxiliary photometer, as long as its photometer head does not change direction and distance to the light source during movement, so that changes of the luminous flux by a change of operating position result in a proportional photocurrent.

Other errors to the measured lighting quantities can be due to the specific spectral distribution of the DUT being different from the spectral distribution of the standard lamp used for the calibration of the photometer. A spectral mismatch correction factor should be applied, if the specific spectral distribution is known (see C.3.5).

C.1.2 Service conversion factors

Service conversion factors apply when the service conditions differ intentionally from the standard test conditions. These factors are often derived by relative photometry and may relate to different ambient temperatures, different performance temperatures t_p, different electrical characteristics or different operating positions.

These factors are usually delivered in separate tables or graphs, while the measurement results are reported for the standard test conditions.

C.2 Sensitivity coefficients

An error in the measured values (output quantity) will be introduced if the practical laboratory conditions are different from the standard test conditions. The error depends on the sensitivity of the output quantity to the different influence parameters.

The measured quantity (i.e. luminous flux, luminous intensity,..) Y depends on a large number of influence parameters (i.e. ambient temperature, electrical current) $X_1, X_2, \ldots$. This can be formally expressed as a model of evaluation.

$$Y = f(X_1, X_2, \ldots) \tag{C.1}$$

It is therefore possible to quantify the influence of a specific quantity X_i through a sensitivity coefficient c_i

$$c_i = \frac{\partial F}{\partial X_i} \tag{C.2}$$

For further details, see CIE 198-2011.

Due to the large variability of the characteristics of LED products, it is difficult to provide general values. Based on today’s knowledge typical values for some of the sensitivity coefficients are given in C.3. However, if possible, the validity of these values should be checked for the DUT.

C.3 Typical Sensitivity coefficients and tolerance intervals

C.3.1 General

In the following typical values are given for LED products. The tolerances, as an example, are specified in a way that the error contribution of one specific influence parameter is smaller than ± 1 %. However, where possible, the specific influence should be reduced at a minimum.

C.3.2 Ambient temperature

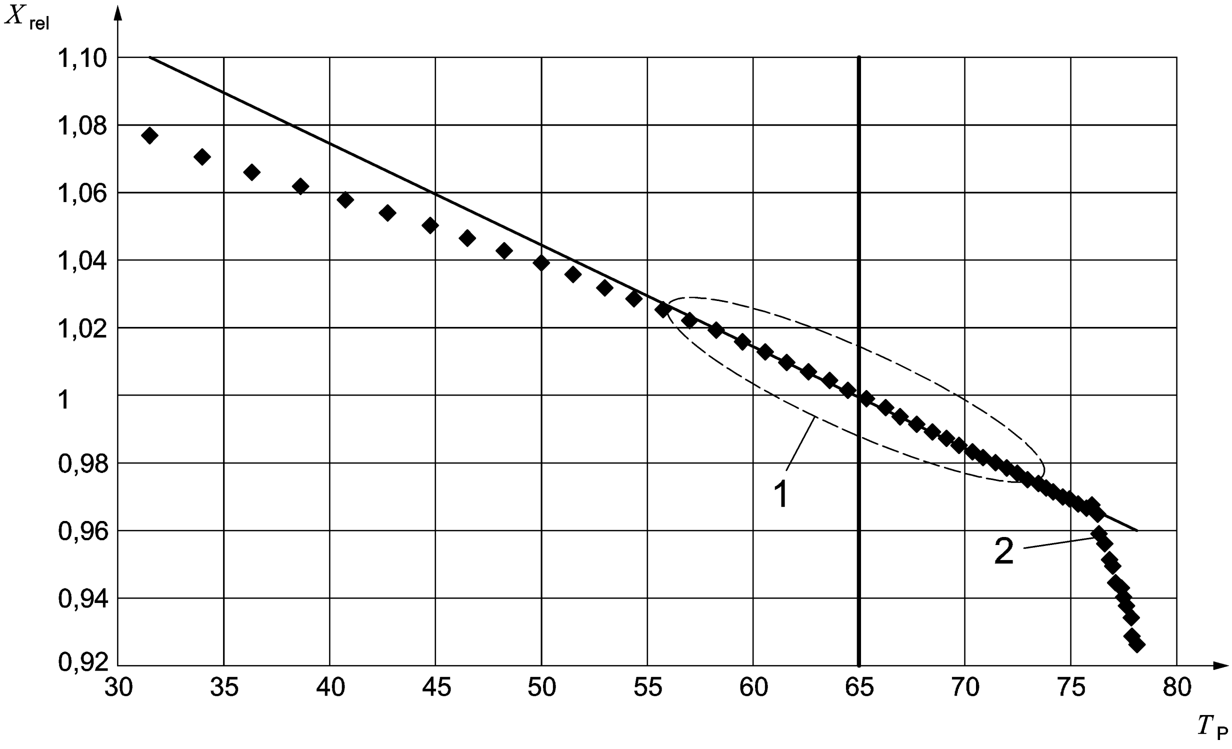
The luminous flux of a LED lamp has a typical relative sensitivity to ambient temperature of −0,5 %/°C. Hence, for a specific influence smaller than 1 %, the ambient temperature t_{amb} shall be within the tolerance interval (25,0 ± 2) °C. The recommended tolerance interval of (25,0 ± 1,2) °C should reduce the specific influence at 0,6 %.

The luminous flux of a temperature controlled LED chip has a typical relative sensitivity to ambient temperature of 0,1 %/°C. Hence, for a specific influence of 1 %, the ambient temperature t_{amb} could be within the tolerance interval (25,0 ± 10) °C However, working with such intervals could modify the electrical characteristics which have also to be reported for the standard test condition of 25°C. As a consequence the recommended ambient temperature t_{amb} should be maintained at the tolerance interval (25,0 ± 1,2) °C to guarantee correct power measurement.

C.3.3 Measurement of a LED module at Performance Temperature

As an example, two possible methods to measure a value *x* of a quantity at a given temperature will be explained. Assume the locations of test points, performance temperature t_{p} and rated maximum temperature t_{c} are identical and a series of measurement results of *x* (e.g. luminous flux) of a LED module with integrated temperature control (t_{p} = 65 °C) and/or temperature protection. (t_{c} = 75 °C) are taken and presented graphically in Figure C.1 below:

NOTE These measurements can be done during the warm-up time while logging the temperature at the measurement point for performance temperature t_{p} and a relative value (e.g. luminance or illuminance in a goniophotometer).



Key

1 forecast range

2 temperature protection

Figure C.1 — Example of measurement of a LED module

Results from the evaluation of the relative temperature coefficient $\alpha_{x,\text{rel}}$ of the quantity x with associated (absolute) standard uncertainty $u(\alpha_{x,\text{rel}})$	$\alpha_{x,\text{rel}}$ = −0,3 %/°C = −0,003/°C $u(\alpha_{x,\text{rel}})$ = 0,1 %/°C = −0,001/°C
determined with standard uncertainty $u(t_\text{p})$ of the temperature measurement	$u(t_\text{p})$ = 1 °C

Using the model for the temperature correction of CIE 198:2011-SP1.1, 1.4, one can use the following formula for the correction of the measured value x' at $t_{\text{p},1}$ to the required value x at $t_{\text{p},0} = t_{\text{p,max}}$ with $\Delta t_\text{p} = t_{\text{p},1} - t_{\text{p},0}$

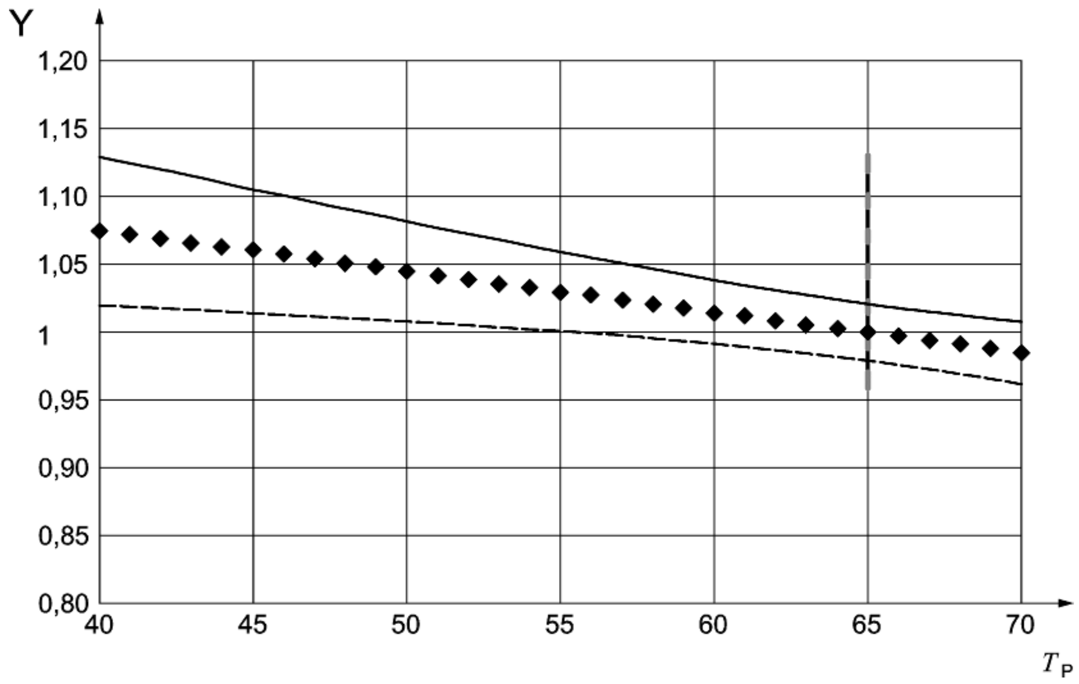
The corrected value can be calculated using a linear approach:

$$x = x' \, (1 - \alpha_{x,\text{rel}} \cdot \Delta t_\text{p}) \tag{C.3}$$

The standard uncertainty of the corrected value can be calculated using:

$$u(x) = u^2(x')(1 - \alpha_{x,rel} \cdot \Delta t_p) + x'^2 \left\{ u^2(\alpha_{x,rel}) \cdot \Delta t_p + u^2(\Delta t_p)\left[\alpha_{x,rel}^2 + u^2(\alpha_{x,rel})\right]\right\} \tag{C.4}$$

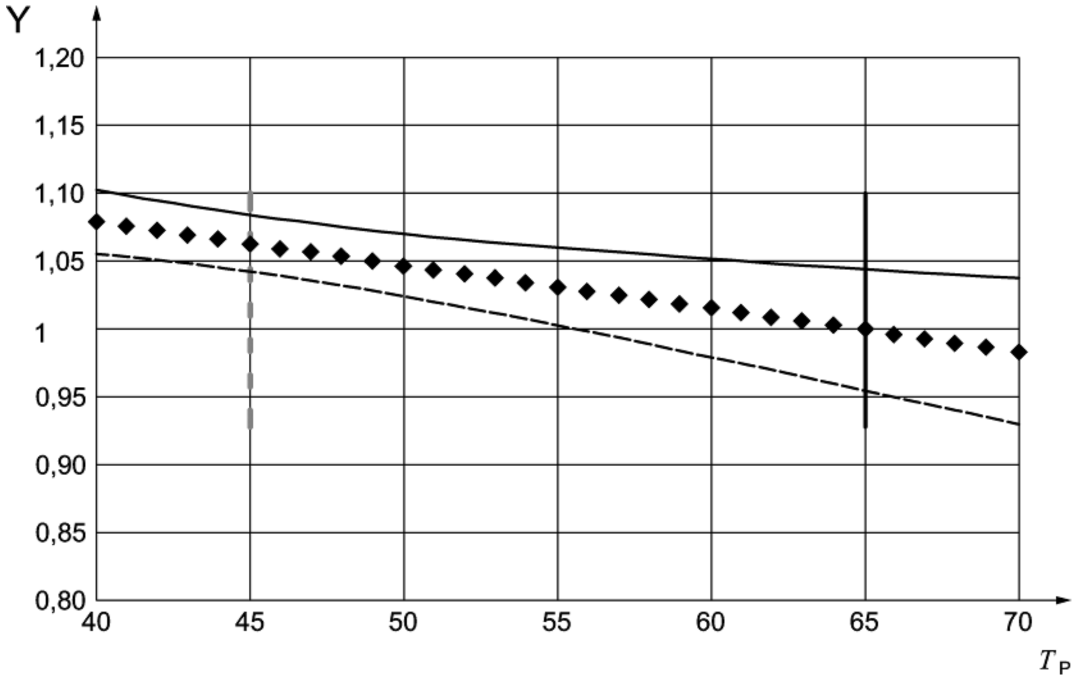
In the following the relationships are presented for the case $\Delta t_\text{p} = 0$ °C (see Figure C.2) and for $\Delta t_\text{p} = -20$ °C (see Figure C.3) to show the quadratic change of the (expanded) uncertainty interval using large temperature differences for measurement and prediction.



Key

◆	x
— — — — —	x-2*u(x)
————————	x+2*u(x)
————————	estimation point
‒ ‒ ‒ ‒ ‒	measurement point

Figure C.2 — Measurement for $\Delta t_p = 0\,°C$ (temperature is controlled for $t_p = t_{p\,max}$)



Key

◆	x
— — — — —	x-2*u(x)
————	x+2*u(x)
————	estimation point
▬ ▬ ▬ ▬ ▬	measurement point

Figure C.3 — Measurement for $\Delta t_\text{p} = -20$ °C (temperature is used as it is e.g. $t_\text{p} = 45\,°C$ in the example)

Results:

$t_{\text{p},0}$	$t_{\text{p},1}$	Correction	$u(x)$
65 °C	65 °C	1,00	1,05 %
65 °C	45 °C	0,94	2,2 %

C.3.4 Air movement

The luminous flux of a LED device has a typical relative sensitivity coefficient to air movement of ± 5 %/(m/s). Hence, for a specific influence smaller than 1 %, the air movement in the vicinity of the device should not exceed 0,2 m/s ignoring any effect of forced cooling or self-heating of the DUT.

C.3.5 Test voltage

The luminous flux of a LED device changes typically by 1 % for a voltage change of 1 %, hence the relative sensitivity being 1.

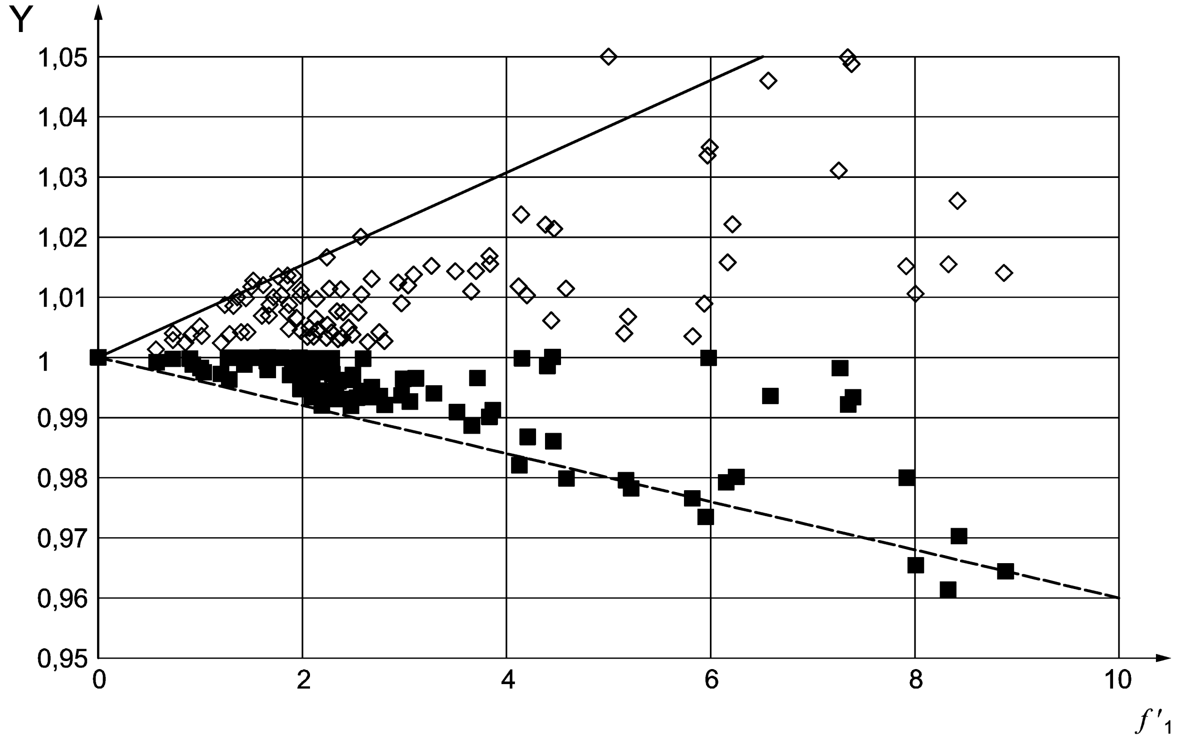
NOTE LED control gear may be voltage or current controlled. In this case mains supply voltage fluctuations are of little importance.

C.3.6 Spectral mismatch of photometer

A correction of the measured photometric value in respect to the spectral mismatch of the photometer is only possible if the relative spectral responsivity of the photometer and the relative spectral distribution of the radiation of the DUT are known (see ISO/CIE 19476:2014 for further information and calculation of the spectral mismatch correction $F^*(S_z(\lambda))$). An estimation of the uncertainty can be made based on the general $V(\lambda)$ mismatch index f_1', defined in ISO/CIE 19476:2014.

The data for phosphor-type white LED products are shown in Figure C.4. The graph is based on 200 white LEDs of different correlated colour temperatures and 120 photometers. For each photometer the maximum and minimum values of the spectral mismatch correction factors F^* are evaluated. From these data, the relative sensitivity coefficient of a photometric value with respect to the general $V(\lambda)$ mismatch index is about 0,8 at maximum. For such LEDs a photometer with f_1' < 1,3 % should therefore be used if errors are to be reduced to less than 1 %.

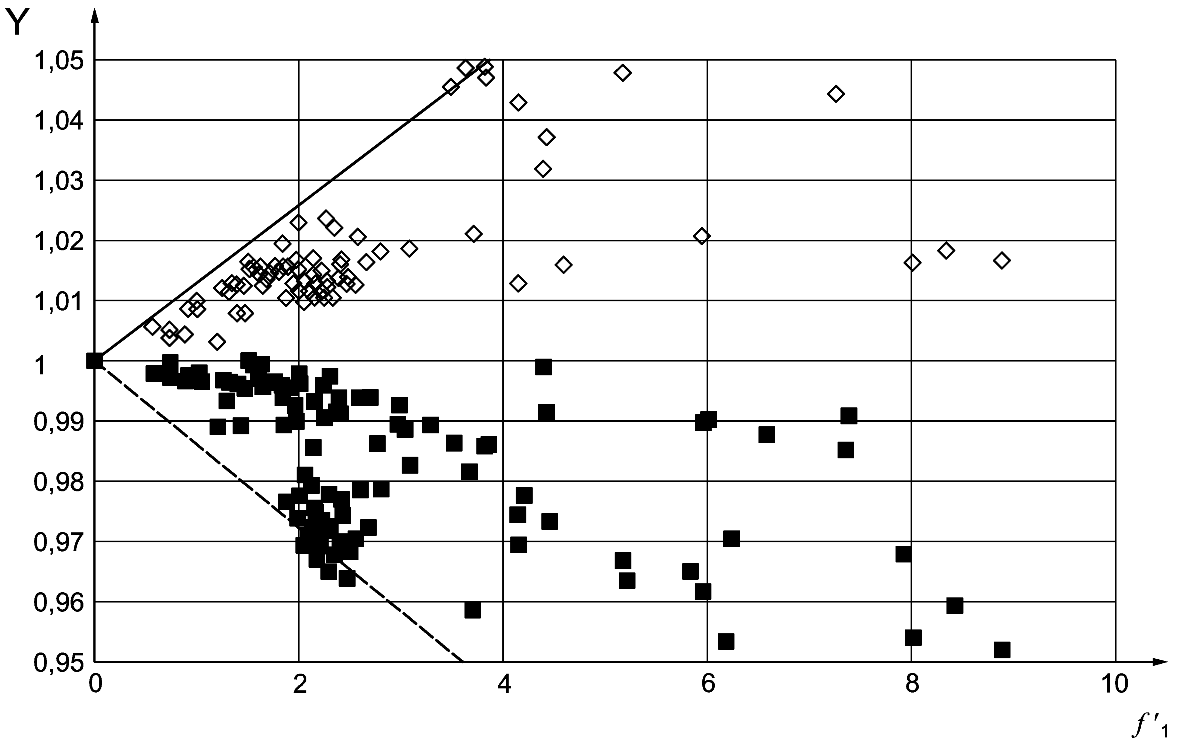
The data for RGB-type white LED products are shown in Figure C.5. The graph is based on 100 RGB type LEDs (mixed to white light) of different correlated colour temperature and 120 photometers. For each photometer the maximum and minimum values of spectral mismatch correction factors F^* is evaluated. From these data, the relative sensitivity coefficient of a photometric value with respect to the general $V(\lambda)$ mismatch index is about 1,4. For such LEDs a photometer with f_1' < 0,7 % should therefore be used if errors are to be reduced to less than 1 %.



Key

■	Min
◇	Max
————	MAX
- - - - -	MIN

Figure C.4 — Spectral mismatch correction factors (SMCF) for phosphor-type white LEDs and different f_1' -values of photometers



Key

■	Min
◇	Max
———————	MAX
– – – – – – – –	MIN

Figure C.5 — Spectral mismatch correction factors (SMCF) for RGB type white LEDs and different f_1' -values of photometers

C.3.7 Model for Luminous Intensity Distribution

For DUTs with intensity distributions significantly different from a cosine (e.g. narrow beam angle < 30°, steep gradients in the luminous intensity distribution or critical glare control): a measurement distance which allows for the application of the inverse square law needs to be chosen.

A narrow beam can be modelled by the function $I(\theta)=I_0\cdot\cos^g(\theta)$. For example, the half angle of the beam is 60° when g = 1, and 15° when g = 20. If the source is circular and has a radius a, the illuminance in the optical axis at a given distance d can be estimated by the following formula:

$$E_v \approx \frac{I_0}{d^2}\left[1-\frac{g+3}{4}\left(\frac{a}{d}\right)^2\right]\Omega_0 \tag{C.5}$$

where Ω_0 = 1 sr.

The error from the inverse square law can be evaluated in comparison to the ideal illuminance I_0/d^2.

The error from the inverse square law in far field can be evaluated using the model function above. The errors can increase significantly at larger angles from the optical axis and/or for sources with smaller beam angle. For example, the error for a circular Lambertian source at a distance of 5 × *D* is within ± 1 % in a range of ± 80° from the optical axis. For a source with 90° beam angle, the error is approximately −1 % at the optical axis, but increases to 2,5 % at 80° from the optical axis. Errors for a Lambertian linear source at a distance of 5 × *D* is −0,7 % at the optical axis and increases to approximately 2 % at 80° from the optical axis. For a linear source with a beam angle of 30°, the error at a distance of 5 × *D* on the optical axis would be close to −5 %, and the error at 30° would be close to 20 %. Increasing the distance to 15 × *D* will reduce these errors to below 3 %.

Annex D
(informative)

Guidance on calculating measurement uncertainties

D.1 General

Every measurement is subject to some uncertainty. A measurement result is only complete if it is accompanied by a statement of the uncertainty in the measurement. Evaluation of measurement uncertainties is a complicated subject, and still evolving. However, it is important to know uncertainties in order to judge the quality of the measurement and to be able to compare measurements values or to compare results between measurement laboratories. The measurement of photometric, colorimetric and electrical quantities of a LED depends usually on many parameters and an exact evaluation is demanding and time-consuming. It is possible to decrease measurement uncertainties with additional characterizations of the measurement equipment and the DUT.

It is recognized that many different categories of laboratories use this standard, including manufacturers, public testing laboratories, R&D laboratories and National Metrology Institutes. These laboratories have a wide range of levels of expertise in testing and determination of uncertainties and a wide range of sophistication and accuracies of equipment and quality of laboratory environment. The purpose of this test method standard is that, by following this test method, it is expected that the reasonable uncertainties of measurements, needed for various regulations and applications, may be achieved by all laboratories. However, this test method cannot cover all the details of measurement instruments and possible mistakes that less experienced laboratories can make. To ensure reasonable uncertainties, it is important that all laboratories using this test method have knowledge of measurement uncertainty and perform evaluation of uncertainties of their measurements.

D.2 Uncertainty budget

The uncertainty budget states the model and lists all quantities mentioned in the model and gives a specified amount of information for each entry. At minimum the following entries should be stated:

- the name of the quantity X_i and its symbol as used in the model of evaluation,
- the value x_i and associated standard uncertainty $u(x_i)$,
- the sensitivity coefficient c_i
- the absolute contribution to the output standard uncertainty $u_i(y)$
- the relative contribution to the output standard uncertainty $u_{\mathrm{rel},i}(y)$

This allows a relationship of that entry to the model and shows the individual contribution and the importance with respect to the combined uncertainty.

For more details on measurement uncertainties, see the ISO/IEC Guide 98-3 “Guide to the expression of Uncertainty in measurement” and CIE 198:2011 “Determination of measurement uncertainties in photometry”.

NOTE Measurement uncertainty evaluation of a full luminous intensity distribution is under consideration.

D.3 Example of measurement uncertainties

Due to the large variability of LED products and variations of the instruments used (even though specific requirements are given in this standard for important parameters), the uncertainties depend on many factors of individual laboratories and individual tests. It is not possible to give general values of the measurement uncertainties. In this annex some examples of uncertainty budget summaries for measurement of typical LED lighting products using the test method given in this standard are provided for information purposes.

The uncertainty values in the tables below are estimated for the condition that all the tolerance Intervals and the specific requirements in this standard are fulfilled. These tables include major components of uncertainty in general cases. There may be more components of uncertainty that can be significant in specific cases.

The values in the tables are typical values for fairly experienced laboratories (those laboratories that are accredited or interested in being accredited for testing of LED lighting products). The uncertainties of measurements by less experienced laboratories can be much larger due to unexpected or faulty settings that they may use, which are not considered in these tables. Also, the uncertainty values in the table are for typical products of given type and do not consider all the variety of products. Uncertainties may be much higher for products having very narrow beam angle or having very spiky current waveform (with low power factor) or other extreme behaviours. Thus, the values in the table are typical examples and do not cover the worst-case values. Conversely, in some cases the contributions to the uncertainty budget could be overestimated. Also, these table values are for white light LED products only, and do not include coloured LED products such as red, green or blue single colour LED modules. The uncertainties for measurement of single-colour LED devices will be much larger than the values in these tables.

The measurement uncertainties can be reduced by full characterization of the measurement equipment and the DUT. and applying corrections, and/or using higher-performance instruments (e.g. lower f_1' value for sphere-photometers and goniophotometers).

For simplification only the quantities X_i of uncertainty components and the relative contribution to the output standard uncertainty $u_{\mathrm{rel},i}(y)$ are listed in the tables. The values consider sensitivity coefficients of typical LED products.

Table D.1 — Example of uncertainty budget summary for luminous flux measurement of an LED lamp using a sphere-photometer

Name of the quantity X_i	**Relative contribution to the output standard uncertainty $u_{\mathrm{rel},i}(y)$**			
	Phosphor-type [a]		RGB-type [b]	
	Broad [c]	Narrow [d]	Broad [c]	Narrow [d]
Calibration uncertainty of SI traceable secondary luminous flux standard (case of U = 2,0 %, k = 2)	1,0 %			
Ageing of luminous flux standard lamp (gas-filled tungsten lamp)	0,6 %			
DC current uncertainty for standard lamp	0,4 %			
Ambient temperature (and uncertainty of thermometer)	0,3 %			
Supply voltage of LED (and uncertainty of volt meter)	0,2 %			
Spectral mismatch of sphere-photometer system (f_1' = 3 %)	1,7 %		3,5 %	
Linearity	0,3 %			
Self-absorption correction (residual uncertainty) [e]	0,3 %			
Spatial non-uniformity of sphere (difference in intensity distribution from the standard lamp)	0,9 %	1,8 %	0,9 %	1,8 %
Repeatability of the sphere system	0,3 %			
Stability of the sphere system (between calibrations)	0,3 %			
Near-field absorption	0,3 %			
Reproducibility of test lamp (including stabilization condition)	0,3 %			
Stability of standard lamps	0,2 %			
Relative combined standard uncertainty	2,4 %	2,8 %	3,9 %	4,1 %
Total expanded uncertainty (k = 2)	**4,9 %**	**5,7 %**	**7,7 %**	**8,3 %**

[a] Values for white LED based on phosphor technology are shown in the two left columns.

[b] Values for white LED based on RGB technology are shown in the two right columns.

[c] Values for sources having broad angular intensity distribution are shown in the first and third columns.

[d] Values for sources having narrow beam distribution where standard lamp is omni-directional and no correction is made are shown in the second and fourth columns.

[e] Value is for the case of 1,5 m sphere with 95 % reflectance measuring a typical compact LED lamp. This will change for different sphere condition and for DUTs of larger sizes.

Table D.2 — Example of uncertainty budget summary for luminous flux measurement of an LED lamp using a sphere-spectroradiometer

Name of the quantity X_i	**Relative contribution to the output standard uncertainty $u_{\mathrm{rel},i}(y)$**	
	Broad [a]	Narrow [b]
Luminous flux uncertainty of NMI traceable total spectral radiant flux standard	1,0 %	
Ageing of luminous flux standard lamp (tungsten halogen lamp)	0,3 %	
DC current uncertainty for standard lamp	0,4 %	
Ambient temperature (and uncertainty of thermometer)	0,3 %	
Supply voltage of LED (and uncertainty of volt meter)	0,2 %	
Nonlinearity of spectroradiometer	0,8 %	
Wavelength uncertainty (0,5 nm (k = 2))	0,4 %	
Stray light of spectroradiometer (2 700 K to 6 500 K source)	1,0 %	
Reproducibility of spectroradiometer	0,1 %	
Self-absorption correction (residual uncertainty) [c]	0,3 %	
Spatial non-uniformity of sphere (difference in intensity distribution from the standard lamp)	0,9 %	1,8 %
Repeatability of the sphere system	0,3 %	
Stability of the sphere system (between calibrations)	0,3 %	
Near-field absorption	0,3 %	
Reproducibility of test lamp (including stabilization condition)	0,3 %	
Stability of standard lamps	0,2 %	
Relative combined standard uncertainty	2,1 %	2,6 %
Total expanded uncertainty (k = 2)	**4,2 %**	**5,2 %**

[a] Values for sources having broad angular intensity distribution are shown in the left column.

[b] Values for sources having narrow beam distribution, and if standard lamp is omnidirectional and no correction is made, are shown in the right column.

[c] Values for the case of 1,5 m sphere with 95 % reflectance measuring a typical compact LED lamp. This will change for different sphere condition and for DUTs of larger sizes.

Table D.3 — Example of uncertainty budget summary for flux measurements of a LED lamp or LED luminaire using a goniophotometer

Name of the quantity X_i	**Relative contribution to the output standard uncertainty $u_{\mathrm{rel},i}(y)$**	
	Phosphor-type [a]	RGB-type [b]
Calibration uncertainty of SI traceable secondary luminous flux standard	1,0 %	
Ageing of luminous flux standard lamp (gas-filled)	0,6 %	
DC current uncertainty for standard lamp	0,4 %	
Ambient temperature (and uncertainty of thermometer)	0,3 %	
Supply voltage of LED (and uncertainty of volt meter)	0,2 %	
Spectral mismatch of photometer system (including the mirror), $f_1^{'}$ = 3 %	1,7 %	3,5 %
Linearity of the system	0,3 %	
Spatial stray light	0,6 %	
Polarization	0,1 %	
Stability of test lamp during scan	0,3 %	
Reproducibility of test lamp (including stabilization condition)	0,3 %	
Stability of standard lamps	0,2 %	
Relative combined standard uncertainty	2,3 %	3,8 %
Total expanded uncertainty (k = 2)	**4,6 %**	**7,5 %**

[a] Values for white LED based on phosphor technology are shown in the left column.

[b] Values for white LED based on RGB technology are shown in the right column.

Table D.4 — Example of uncertainty budget summary for luminous flux measurement of a LED lamp or LED luminaire using a gonio-spectroradiometer

Name of the quantity X_i	**Relative contribution to the output standard uncertainty $u_{\mathrm{rel},i}(y)$**
Calibration uncertainty of SI traceable secondary luminous flux standard	1,0 %
Ageing of luminous flux standard lamp (gas-filled)	0,6 %
DC current uncertainty for standard lamp	0,4 %
Ambient temperature (and uncertainty of thermometer)	0,3 %
Supply voltage of LED (and uncertainty of volt meter)	0,2 %
Nonlinearity of spectroradiometer	0,8 %
Wavelength uncertainty (0,5 nm (k = 2))	0,4 %
Stray light of spectroradiometer (2 700 K to 6 500 K source)	1,0 %
Reproducibility of spectroradiometer	0,1 %
Spatial stray light	0,6 %
Polarization	0,1 %
Stability of test lamp during scan	0,3 %
Reproducibility of test lamp (including stabilization condition)	0,3 %
Stability of standard lamps	0,2 %
Relative combined standard uncertainty	2,0 %
Total expanded uncertainty (k = 2)	**3,9 %**

Table D.5 — Example of uncertainty budget summary for colorimetric measurements of a LED lamp or LED luminaire using a sphere-spectroradiometer or gonio-spectroradiometer

(Values are shown for products with white LEDs of phosphor technology for T_{cp} = 3 000 K and 6 000 K.)

		Absolute contribution to the output standard uncertainty							
Name of the quantity X_i		$u_i(x)$	$u_i(y)$	$u_i(u')$	$u_i(v')$	$u_i(T_{cp})$ **3 000 K**	$u_i(T_{cp})$ **6 000 K**	u_i**(Duv)**	$u_i(R_a)$
Calibration uncertainty of SI traceable secondary spectral radiant flux standard or spectral irradiance standard		0,001 4	0,001 9	0,000 5	0,001 2	26,6	67,8	0,000 5	0,44
Ageing of standard lamp		0,000 1	0,000 1	0,000 0	0,000 1	2,1	5,4	0,000 0	0,00
Wavelength uncertainty		0,000 4	0,000 7	0,000 1	0,000 4	6,9	17,5	0,000 2	0,08
Reproducibility of lamp and spectroradiometer		0,000 2	0,000 3	0,000 2	0,000 2	3,7	9,4	0,000 1	0,10
Nonlinearity of spectroradiometer		0,000 7	0,000 3	0,000 5	0,000 2	11,8	30,2	0,000 1	0,23
Bandpass of spectroradiometer		0,000 1	0,000 1	0,000 0	0,000 1	1,1	2,7	0,000 0	0,03
Stray light of spectroradiometer	3 000 K	0,000 6	0,001 0	0,000 0	0,000 5	5,3	—	0,000 3	0,25
	6 000 K	0,001 9	0,002 9	0,000 3	0,001 7	—	101,5	0,000 6	0,14
Combined standard uncertainty	3 000 K	0,001 7	0,002 3	0,000 7	0,001 4	30,7	—	0,000 7	0,57
	6 000 K	0,002 5	0,003 6	0,000 8	0,002 1	—	127	0,000 8	0,53
Total expanded uncertainty (k **= 2)**	**3 000 K**	**0,003 5**	**0,004 7**	**0,001 4**	**0,002 7**	**61**	**—**	**0,001 4**	**1,1**
	6 000 K	**0,005 0**	**0,007 2**	**0,001 6**	**0,004 2**	**—**	**255**	**0,001 6**	**1,1**
For the uncertainty of chromaticity coordinates as distances from the true point on the (*x*, *y*) or (*u*',*v*') chromaticity diagram, coverage factor k = 2,45 should be used for expanded uncertainty at 95 % confidence interval.									

Annex E
(informative)

Guidance for determining rated values of photometric quantities of LED luminaires

E.1 Introduction

The published data for LED luminaires are rated data expressed for standard test conditions. Rated data are the reference for compliance in type tests (conformity test on one or more LED product(s) representative of the production). The requirements for compliance are fixed by the appropriate luminaire performance standard. Basis for photometric or colorimetric rated data are the result of measurements on a LED luminaire. The LED luminaire manufacturer should be aware that results of a measurement are not automatically the rated data of a product. The luminaire manufacturer should take into account all tolerances of components and the quality of the assembly process itself. It is advisable to correlate measured data to rated data of the LED light source.

NOTE 1 Components of a LED luminaire can be LED light sources and LED control gears but also optical components etc.

NOTE 2 Rated data are given in the appropriate luminaire performance standard. They include at least luminous flux and luminous efficacy, but may also include light intensity distribution, CRI, CCT etc.

Similar procedure as this described here for LED luminaires may be considered for other LED products.

E.2 Rating and tolerance of LED-luminaire data

In most LED luminaires the LED light sources cannot be separated from the luminaire. Therefore, LED luminaires are measured in so called “absolute photometry”. Output data of an LED luminaire measurement might be raw data at laboratory test conditions and are corrected and reported for standard test conditions (see Clause 4). Associated uncertainty is also reported.

The report pertains to the individual LED luminaire tested (i.e. the DUT) and the resulting data are influenced by the particular componentry within the sample due to the individual variations of the light sources and control gear used. As a result the data of a single sample at standard test conditions may not be sufficient to describe the product for rating and supplementary correction factors may have to be introduced.

Uncertainties of a measurement and the tolerances of a product shall be clearly distinguished.

LED luminaire manufacturers should evaluate whether the relevant components used in the measured LED luminaire are representative for the component independent from the luminaire. Particular attention should be paid to the main components LED light sources and the control gear. These components should be checked to see if they are conform to the data delivered by the manufacturer.

The data of the single components evaluation should also be linked to the photometric measurement data as incorporation in the LED luminaire affects the working conditions of the component. This requires that the same parameters have to be measured during the photometric measurement as for the component evaluation. By comparing the relevant data correction factors can be calculated (optical or electrical efficiency etc.).

NOTE 1 Parameters could be LED Light source current, temperature of LED light source, LED control gear etc.

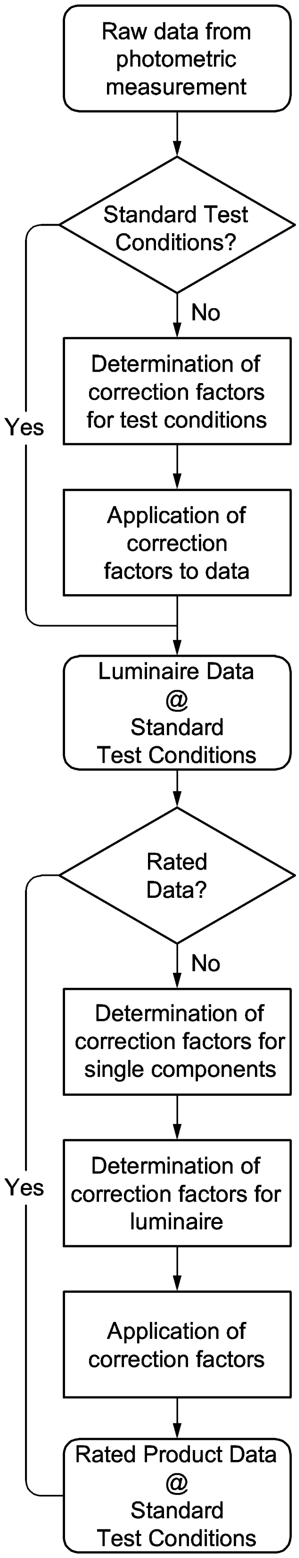
NOTE 2 Data of components delivered by manufacturer or responsible vendors can be rated data, tolerances, statistical distributions, typical values et cetera.

NOTE 3 Special care has to be taken if data are to be interpolated or extrapolated.

The model of determining the rated data and tolerances has also to take into account the tolerances of the assembly process (e.g. Performance of thermal management between LED light source and heat sinks).

If no correction factors can be derived to determine rated data, tolerances have to be increased.

A detailed step-by-step procedure has to be developed by the LED luminaire manufacturer individually for each system (see Figure E.1).



See Chapter 4

Record relates only to the single LED Luminaire.
Data record for comparison between laboratories.

Record relates to all similar equipped LED luminaire.

Figure E.1 — Flow chart of a step-by-step procedure delivering rated photometric quantities of LED luminaires

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