ZVEI: Die Elektroindustrie

Guide to

Reliable Planning with LED Lighting

Terminology, Definitions and Measurement Methods: Basis for Comparison

2nd Edition

Lighting Division

Imprint

Guide to
Reliable Planning with LED Lighting
Terminology, Definitions and Measurement Methods:
Basis for Comparison

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Introduction

The use of LEDs for lighting is rapidly moving forward. In Germany today, every second outdoor luminaire and around a third of the luminaires for indoor use in the commercial, industrial and municipal sector are sold with LED modules (as of Q1 2015).

Over the past three to four years, the transformation of the market towards LED lighting has proceeded considerably faster than predicted by studies. The development of new electronic and lighting standards can hardly keep pace. Accordingly, many decision-makers and users still feel the need for more information about LED luminaire technology and performance. At the same time, the opportunities the technology presents are increasing. Because of the growing complexity, it is becoming increasingly difficult for the industry's customers to define their requirements and ensure that the new lighting solutions selected will match or even improve on the high quality currently achieved by observing relevant standards.

In view of this rapid technological development, the ZVEI has decided to update and upgrade its successful guide so that manufacturers and users of lighting continue to speak the same language. This second edition of the guide takes account of the latest technical standards.

Anyone seeking to develop a tailored lighting design is advised to consider the parameters described in this guide for the application in question. The information available on the www.licht.de website is also very useful.

On behalf of the management of the Lighting Division, I ask you to bear in mind the content of this guide in your daily work and communication.

Manfred Diez
Lighting Division Chairman

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I LED Lighting – A New Technology has Arrived in the Market

LED technology is now well established in many areas of lighting. Every second euro spent on professional lighting in Germany goes on ground-breaking LED solutions. Potential energy savings of well over 50 percent, together with the longevity of LED luminaires, make for considerably lower operating and maintenance costs. The resulting short payback times facilitate the switch to this eco-friendly lighting technology. LED luminaires dramatically increase the scope for lighting design. LED technology permits millions of colours and dynamic effects that conventional light sources cannot offer, e.g. for design, scene and mood lighting. What is more, the targeted use of dynamic colour lighting impacts positively on sense of wellbeing and even enhances performance. LED luminaires lend themselves easily to analogue and digital control, so they are programmable and thus offer endless opportunities for creative use.

Nevertheless, there are still a large number of new market players from outside the lighting technology sector marketing products that fail to live up to their technical specifications and thus cause uncertainty among consumers. To promote the continued spread and acceptance of LED technology, standard definitions and rating procedures are therefore needed so that specifications can be relativised and application-based comparisons made.

All those involved – manufacturers, lighting planners and designers, procurers and users – need to know what is meant by different specifications and what can be expected for a particular application.

The 2nd edition of this guide takes account of current IEC standards and considers additional quality features. By clarifying key terms and describing methods of measurement, it sets out to provide market partners with a standard vocabulary and guidance on the parameters used. It is absolutely essential to use a uniform set of standardised – and thus comparable – quality criteria when assessing technical specifications.

The Lighting Division set up a working group to develop and document a uniform nomenclature. Its task was to identify and explain the major parameters describing LED luminaires within the context of LED lighting. This guide was produced by that working group. Its content should be taken into account when using and declaring LED luminaire data.

More on the subject of assessing LED lighting system quality is found in the German-language ZVEI checklist "Arbeits- und Entscheidungshilfe zur Auswahl von LED-Leuchten", which is available for download at www.zvei.org.

II EU Regulations

It is a general rule in the EU that electrical equipment may only be placed on the market if the basic requirements of the relevant European directives (transposed into national law) are observed.

Light sources (lamps, modules) and luminaires for lighting purposes are governed by the Low Voltage Directive, the EMC Directive, the ErP Directive and the General Product Safety Directive. Accordingly, the products need to satisfy and document the safety, EMC, EMF, ecodesign and other requirements contained therein. This guide does not comment on those requirements; it only describes and explains the nomenclature used.

The regulations cited above refer to the "state of the art", which is essentially defined by the relevant standards listed in the Official Journal of the EU.

III LED Luminaire Performance Standards

The International Electrotechnical Commission (IEC) has developed performance standards for LED luminaires and LED modules. The IEC standards have now been published. The performance standards for LED products define quality criteria and set out agreed general conditions for measurement.

All those active in this field thus have a basis for comparative assessment. This guide is based on the following standards for LED luminaires and LED modules.

LED luminaire performance standards:

- IEC 62722-1:2014-09;
  Luminaire performance – Part 1:
  General requirements
- IEC 62722-2-1:2014-11;
  Luminaire performance – Part 2-1:
  Particular requirements for LED luminaires

LED module performance standards:

- IEC 62717:2014-12+AMD:2015;
  LED modules for general lighting –
  Performance requirements

LED luminaire performance requirements are directly connected with the stipulations contained in the standard for LED modules; that norm thus also needs to be considered when assessing LED lighting systems.

A data resource based on standard parameters is absolutely essential for manufacturers to be able to generate confidence and guarantee reliability in an environment of fair competition – especially in the fast-growing LED market segment. It helps give all market partners security for realising LED lighting systems.

The following have been identified as major parameters:

1. rated input power
2. rated luminous flux
3. luminaire efficacy
4. luminous intensity distribution
5. colour quality
    a. correlated colour temperature
    b. colour rendering index
    c. colour tolerance
6. rated ambient temperature
7. longevity criteria (useful life of the LED luminaire in hours and the associated rated lumen maintenance)

Without the disclosure of this data (established in compliance with the IEC performance standards), it is not possible to perform a technical comparison of luminaires based on objective criteria.

Attention should also be paid to the documentation obligations for CE product marking (under COMMISSION REGULATION (EU) No. 1194/2012 of 12 December 2012 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for directional lamps, light emitting diode lamps and related equipment). In many cases, the performance requirements set out in the standards IEC 62722-1 and IEC 62722-2-1 form the basis for assessment.

The individual technical parameters are described in detail below.

IV Rated Values and their Use

Certain thermal, electrical and photometric data for light sources and luminaires are published as rated values. A rated value is a quantitative value established for a particular characteristic under specified operating conditions. Values and conditions for the declaration of rated values are set out in the relevant standards. In order to permit a meaningful comparison of manufacturers' product specifications, it is vital that rated values should be established in compliance with the relevant rules.

To take account of possible differences in manufacturers' product designs or differences in components and tolerances in manufacturing processes, rated values should be published with limits. This generally ensures reliable operating conditions and optimal information about the relevant characteristics of light sources and luminaires. Typical examples of rated values for LED luminaires are rated input power and rated luminous flux, which need to be declared for compliance with standards IEC 62722-1 and IEC 62722-2-1.

Different power parameters are not new. The connection between the different values can be explained by taking an EB-operated double-ended 58 W linear fluorescent lamp as an example:

- **The lamp has a nominal input power of 58 W** – practically the name of the lamp (nominal value).
- **In EB operation, however, the lamp has a rated input power of only 50 W** – the power for which the lamp was designed for EB operation (rated value).
- **The measured input power of the lamp may be 49 W** – actual input power tolerances are shown in lamp data sheets.

1. Rated Input Power P of LED Luminaires (in W)

In the case of luminaires with replaceable LED lamps, the nominal input power and the number of lamps are declared.

For luminaires with LED modules, however, the rated input power of the luminaires needs to be declared in the luminaire specifications.

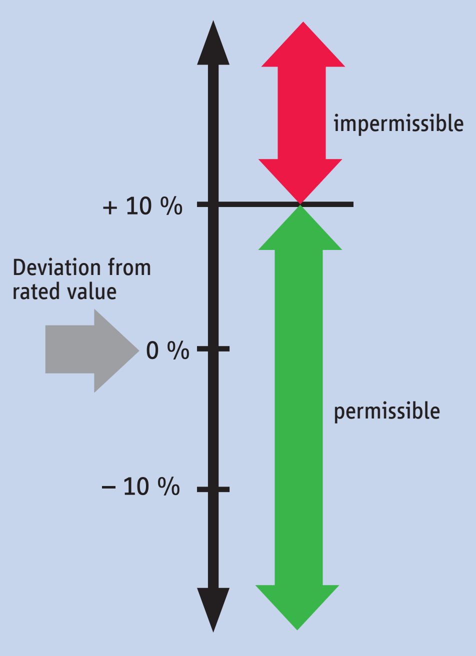
The measured input power of an LED luminaire (in W) must not exceed the declared rated input power by more than 10 percent when operated on rated voltage, at rated ambient temperature t_q and 100 percent luminous flux (light output) after thermal stabilisation.

Owing to component tolerances, input power in LED modules and EBs may be subject to fluctuations that impact on luminaire input power values. So, to ensure observance of the +10 percent tolerance limit, component tolerances need to be taken into account when rated power is established. Rated input power is a typical value for all manufacturing variants of the product.

Where rated input power is < 10 W, it needs to be stated to one decimal place (provided that permissible tolerances are observed, many manufacturers round values to x.0 or x.5). Where rated input power is ≥ 10 W, it needs to be declared as a whole number.

For luminaires with constant luminous flux technology, rated input power needs to be declared at the beginning and end of the luminaires' useful life L_xB_y or on the basis of their median useful life L_x (see Chapter 7a).

Fig. 1: Tolerance range for rated input power



2. Rated Luminous Flux Φ_v of LED Luminaires (in lm)

In the case of LED luminaires, the rated luminous flux in lumen (lm) needs to be declared in the product documentation. This always refers to the initial luminous flux of the new luminaire under specified operating conditions and is a typical value for all manufacturing variants of the product.

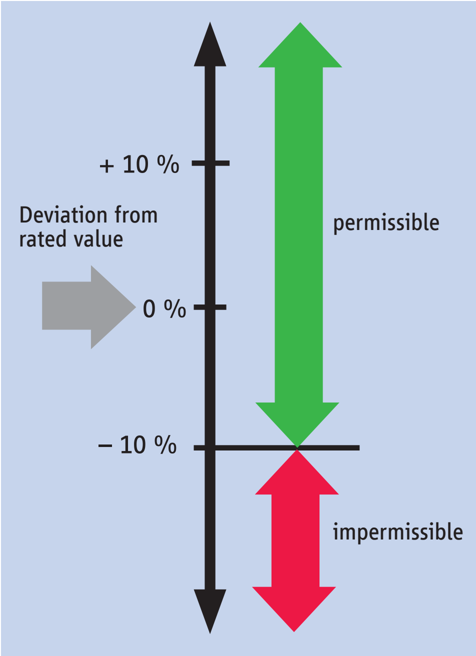
The rated luminous flux of a luminaire can be established by an appropriate calculation method.

The measured initial luminous flux values of luminaires must be no more than ten percent lower than the rated luminous flux published. Unless stated otherwise, the luminous flux value declared for the LED luminaire as a whole is based on an ambient temperature t_q of 25 °C.

Note: It is not customary for luminaire luminous flux to be measured and published for luminaires incorporating traditional light sources (base/lampholder system lamps). In such cases, the lamp luminous flux (of the lamps used) is normally multiplied by the luminaire light output ratio (LOR or η_{LB}). For luminaires with LED modules, declaring luminaire light output ratio separately becomes less relevant. It is set by many luminaire manufacturers at a theoretical 100 percent.

Further information about establishing luminous flux values (so-called absolute photometry) can be found in the standard DIN EN 13032-4.

Fig. 2: Tolerance range for rated luminous flux



3. Luminous Efficacy η_v of LED Luminaires (in lm/W)

The luminous efficacy of an LED luminaire is the quotient of the luminous flux emitted and the power consumed by the luminaire in lumen per watt. For the presentation of product data for a whole batch of LED luminaires, the quotient of the rated luminous flux and the rated input power shown in the luminaire data sheet should be used to establish luminous efficacy.

Note: To rate the energy efficiency of a luminaire, it is generally not enough to consider luminous efficacy alone. This is because luminous efficacy also includes stray light, which does not contribute to the illumination of the target area. This applies particularly to narrow beam luminaires and streetlights, for example.

4. Luminous Intensity Distribution of LED Luminaires

Luminous intensity distribution is established with a goniophotometer and recorded in the lighting design documents.

The spatial distribution of the luminous intensity of a light source or luminaire is indicated by intensity distribution curves. Fig. 3 shows the luminous intensity distribution of an interior luminaire and Fig. 4 that of a streetlight.

Sections through the vertical axis are represented by intensity distribution curves (IDCs) for C planes with the relevant light emission angle γ on those planes, which need to be plotted on polar coordinates for compliance with the standard DIN EN 13032-2. They are based on luminous intensity values under standard luminaire operating conditions (e.g. normal position of use). The values are expressed in cd (candela) or in cd/klm (candela per kilolumen). For more details about interpreting intensity distribution curves, please refer to chapter IX.

Fig. 3: Example of the luminous intensity distribution of an indoor luminaire

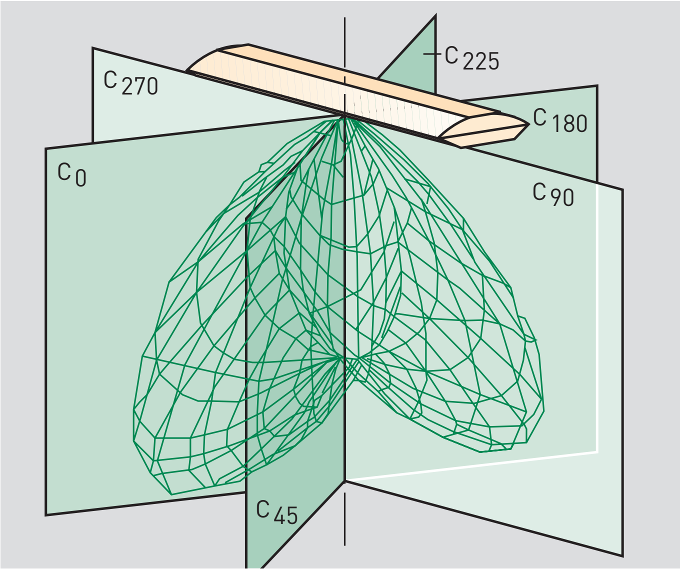
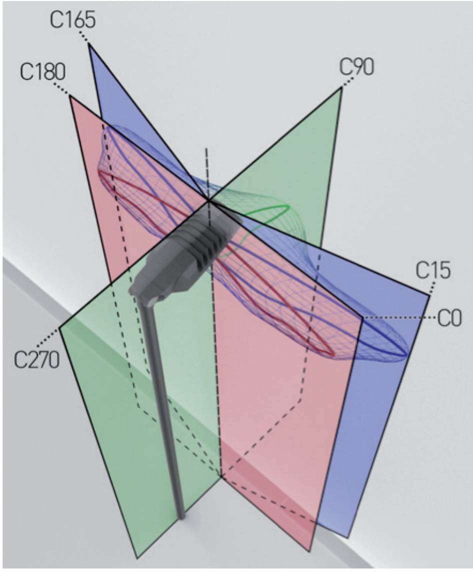


Fig. 4: Example of the luminous intensity distribution of a streetlight



5. Colour Quality

The colour quality of white light is defined by the following characteristics:

- **a** light colour, expressed as a correlated colour temperature
- **b** colour rendering, expressed as a colour rendering index
- **c** colour tolerance, expressed by MacAdam ellipses

5a. Light Colour, Expressed as Correlated Colour Temperature T_{cp} (in K)

White light occurs in various colours both in nature and when light is generated by artificial light sources. For example, at around noon on an overcast day, daylight tends to be bluish, whereas in the morning and evening it tends to be reddish.

For the precise definition of light colours, a variable known as "correlated colour temperature T_{cp}" is used.

Correlated colour temperatures are found in light source data sheets, expressed in Kelvin (K). It is recommended, though not required, that they should be rounded to 100 K. It should be noted that different light sources can produce a different coloured light even if they have the same correlated colour temperature (hence the qualifier "correlated").

Figure 5 shows the CIE Norm Valent System (also frequently referred to as the CIE colour triangle), a coordinate system that enables all of the colours perceptible to the human eye to be expressed as xy coordinates. The curved line is also known as the "Planckian Locus". The straight lines that intersect it contain all the coordinates of the relevant correlated colour temperature declared.

This explains why two light sources with the same correlated colour temperature can produce light of different colours. Light colours are often classed as "warm white" (ww), "neutral white" (nw) or "daylight white" (dw). Warm white covers light sources with a colour temperature up to 3,300 K, neutral white refers to colour temperatures from 3,300 K to 5,300 K and daylight white groups colour temperatures higher than 5,300 K.

Fig. 5: The CIE Norm Valent System – a coordinate system for defining all colours perceptible to the human eye

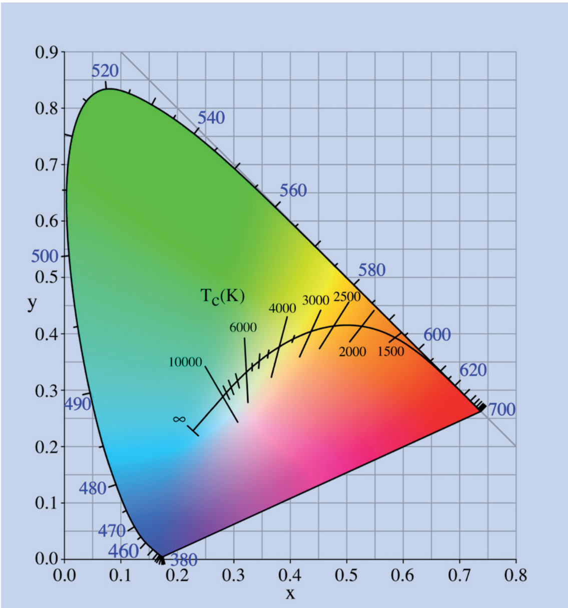


Fig. 6: Example of good colour rendering

Fig. 7: Example of poor colour rendering

5b. Colour Rendering, Expressed by Colour Rendering Index (R_a)

Despite producing an identical light colour, light sources can have different colour rendering characteristics because of the different spectral composition of their beam. The general colour rendering index R_a was introduced to provide a yardstick for objectively identifying the colour rendering characteristics of a light source. It indicates how closely the perceived colour of an object matches its appearance under a particular reference light source. According to EN 12464-1, light sources with a colour rendering index lower than 80 should not be used on work premises in rooms where people spend a significant length of time.

The colour rendering achieved with R_a values higher than 90 is referred to as very good, that achieved with values between 80 and 90 is described as good.

In addition to manufacturers' descriptions, a manufacturer-neutral three-digit colour code has been introduced internationally (see Table 1) to identify clearly the light colour and colour rendering characteristics of light sources. The code number 840, for instance, denotes a colour rendering index of 80 to 89 and a colour temperature of 4,000 K, which is within the neutral-white light colour range.

Table 1: Identification of LED light sources in terms of R_a range and colour temperature

1st numeral indicates colour rendering		2nd and 3rd numerals indicate light colour	
1st digit	R_a-range	2nd and 3rd digit	Colour temperature
9	90 – 100	27	2.700 K
8	80 – 89	30	3.000 K
7	70 – 79	40	4.000 K
6	60 – 69	50	5.000 K
5	50 – 59	60	6.000 K
4	40 – 49	65	6.500 K

5c. Colour Tolerance, Expressed by MacAdam Ellipses

The chromatic coordinates of a particular colour can be defined precisely by x and y coordinates in the CIE Chromaticity Diagram (according to the 1931 CIE Colour Space; DIN 5033). The coordinates of the achromatic locus (white), for example, are x = 0.333 and y = 0.333.

When LED chips are manufactured, tolerances occur which can result, among other things, in differences in light colour. LEDs are therefore tested after they are manufactured and sorted into tolerance classes. This process is called "colour binning". A colour bin corresponds to a particular (rectangular) area of the CIE colour triangle. A standard binning structure was proposed by the ANSI (American National Standards Institute) in 2008.

In many cases, ANSI classification is found too crude. Hence the development of a system of ellipses based on the research of David MacAdam, which enables colour deviations to be described more precisely.

MacAdam ellipses refer to regions on the CIE Chromaticity Diagram which contain colours that the human eye cannot distinguish from the colour at the centre of the ellipse. The contour of the ellipse indicates the colours that can just be distinguished.

MacAdam ellipses are often extended, e.g. to three, five or seven times their original diameter. These 3, 5 or 7-step MacAdam ellipses are used to distinguish two light sources, the steps representing the range of colour difference. Light sources with a 3-step MacAdam ellipse colour difference will show less marked differences than light sources with a colour difference spanning a 5-step MacAdam ellipse. Care should be taken to ensure small colour differences – especially for lighting applications where individual light sources are not far apart and can be seen simultaneously.

Fig. 8: Standard binning structure according to ANSI C78.377A as a section of the CIE colour triangle

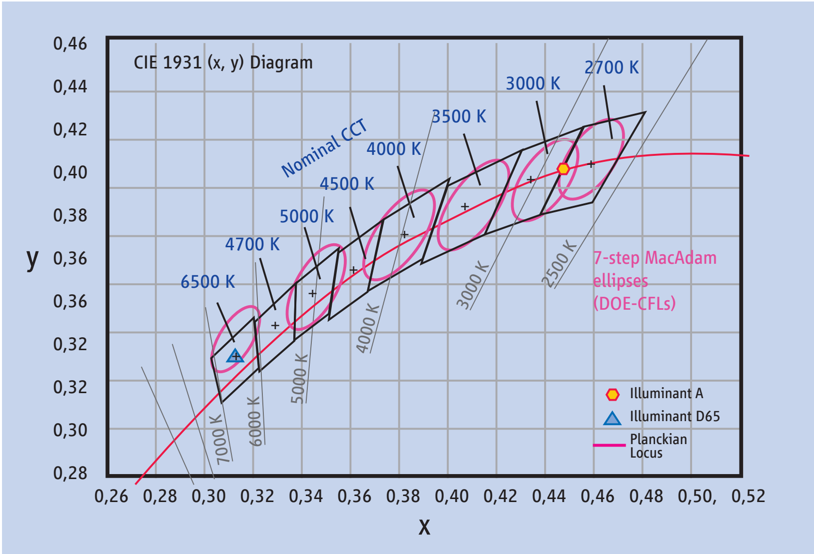


Abb. 9: CIE Norm Valent System with MacAdam ellipses (magnified 10 times for greater clarity)

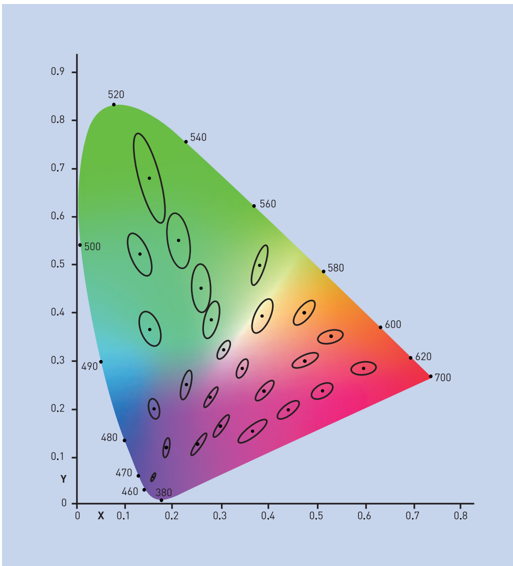
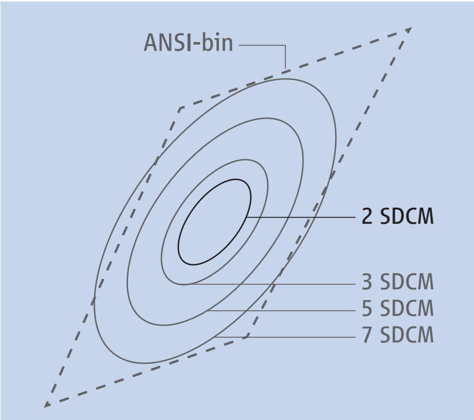


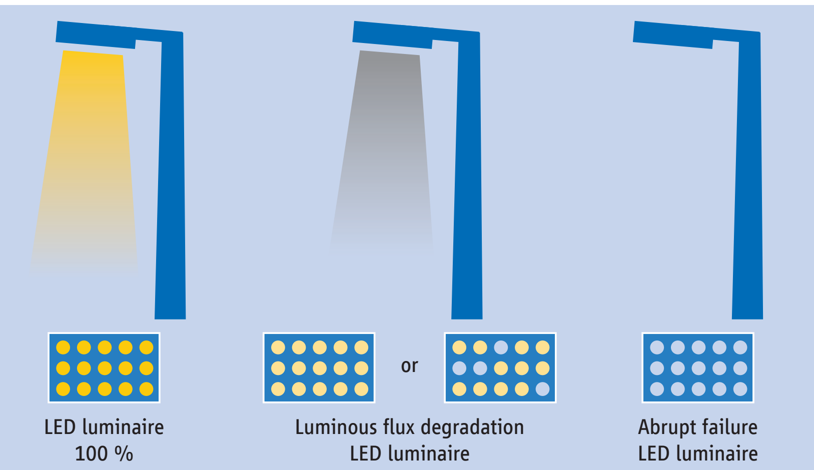
Fig. 10: MacAdam ellipses within an ANSI bin



The colour coordinate tolerance of light sources is thus assessed using the steps of MacAdam ellipses (also referred to as SDCMs – Standard Deviations of Colour Matching). For compact fluorescent lamps, for example, international standards recommend a tolerance of at most a 7-step MacAdam ellipse (synonymous with 7 SDCM). From 3 SDCM upwards, differences are perceptible between colours at the edge of the ellipse and the colour at its centre.

The colour coordinates of LED light change in the course of time as chips and the phosphors used in them age. This is why colour coordinate tolerances are declared at two points: when the luminaire is first put into operation and after a certain number of operating hours (e.g. < 3 SDCM initial and < 5 SDCM after 50,000 hrs).

Fig. 11: Failure of a luminaire (original state, degradation and abrupt failure)



6. Rated Ambient Temperature for Luminaires

Luminaire performance is influenced by ambient temperature. The rated ambient temperature t_a is the highest sustained temperature at which the luminaire may be operated under normal operating conditions (the value may be exceeded briefly during operation by 10 K). Where t_a = 25 °C, no declaration is required for the luminaire; any other rated ambient temperature value needs to be declared (same rule applies to t_q).

Temperature t_q (quality) is a new parameter indicating the highest rated ambient temperature permitted for a defined level of performance (incl. life expectancy, lighting characteristics). More than one t_q value can be declared for different performance characteristics.

7. Longevity Criteria for LED Luminaires

LED luminaire lifespans are not defined only by the point of abrupt failure. Up to a certain number of operating hours, the majority of luminaires do not actually fail at all; their luminosity decreases over time (degradation). The lifespan of LED luminaires is thus limited essentially by the luminous flux falling below a predefined minimum level "x [%]"and by abrupt failure. LED control gear failure is not taken into account here.

Apart from LED degradation, the decrease or degradation of luminous flux may be due to the failure of individual LEDs or LED modules, which may be incorporated in a luminaire in large numbers, depending on its design.

Figure 11 shows the original state, degradation and abrupt failure of a luminaire (terminology from IEC 62717:2014-12+AMD:2015). The two longevity criteria "luminous flux degradation" and "abrupt failure" are among the terms defined in the current IEC standard 62722-2-1:2014-11. The longevity criteria shown in Figs. 12a and 12b are presented on that basis, highlighting the distinction currently made between useful life (L_xB_y) and median useful life (L_x).

The useful life and failure figures declared are prognoses. Useful life and LED luminaire failure times are very long, so LED luminaires cannot be monitored over their full lifespan before they are placed on the market. Instead, monitoring is conducted over a shorter period and the results are extrapolated by precisely defined methods to obtain the relevant prognoses.

The constructive design of an LED luminaire has a significant influence on its performance and declared useful life. So unless the technical operating parameters of the LEDs or LED modules used are observed, LED and LED module longevity figures cannot be taken one-to-one as figures for LED luminaire longevity declarations.

In the case of **LED luminaires**, luminous flux degradation and abrupt failure depend on the electrical and thermal operational specifications of the integrated LED modules, the ambient temperature of the luminaires in use and other luminaire environment parameters. The luminaire manufacturer must make the relevant data available to the user or designer of a lighting installation so that a maintenance plan can be created for the lighting design (see Chapter V).

Fig. 12a: General longevity criteria for LED luminaires

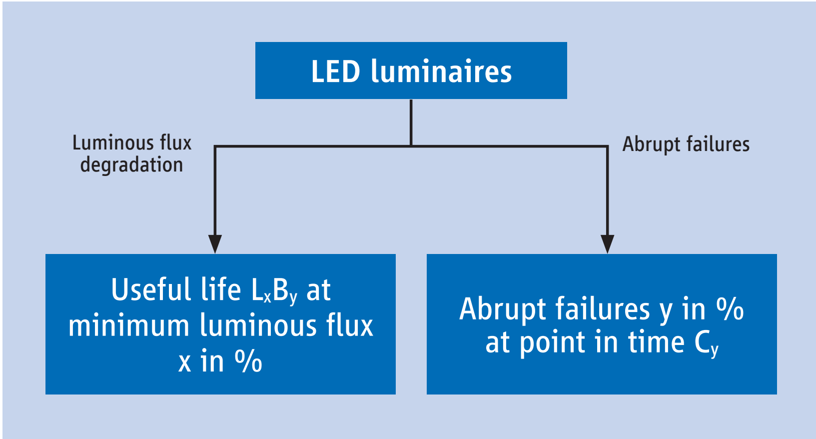
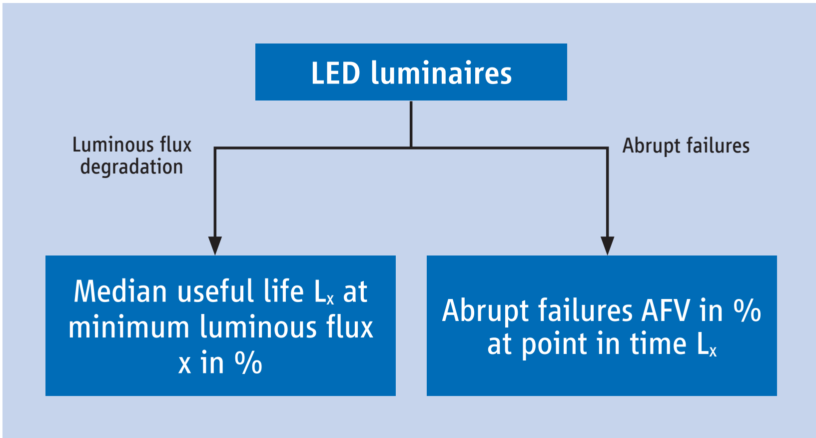


Fig. 12b: Longevity criteria of LED luminaires for median useful life



7a. Useful Life (L_xB_y), Median useful life (L_x)

Useful life is based on the percentage of luminaires subject to elevated luminous flux degradation B_y and is expressed as L_xB_y.

The luminous flux degradation permitted over the life of LED luminaires is indicated by the variable "x", which is a percentage of the luminaires' rated luminous flux.

Typical values of "x" are 70 or 80 percent (L_{70} or L_{80}) for a useful life of e.g. 50,000 hours at an ambient luminaire temperature of 25 °C.

Median useful life L_x (without modifier) is based on $B_y = B_{50}$. It is recommended that median useful life should be declared as represented in Figure 12b.

7b. Gradual Failure Fraction (B_y)

The gradual failure fraction indicates the percentage y of LED luminaires that fall below the target luminous flux of x percent (see x of L_x) but are still functional at the designated end of their life.

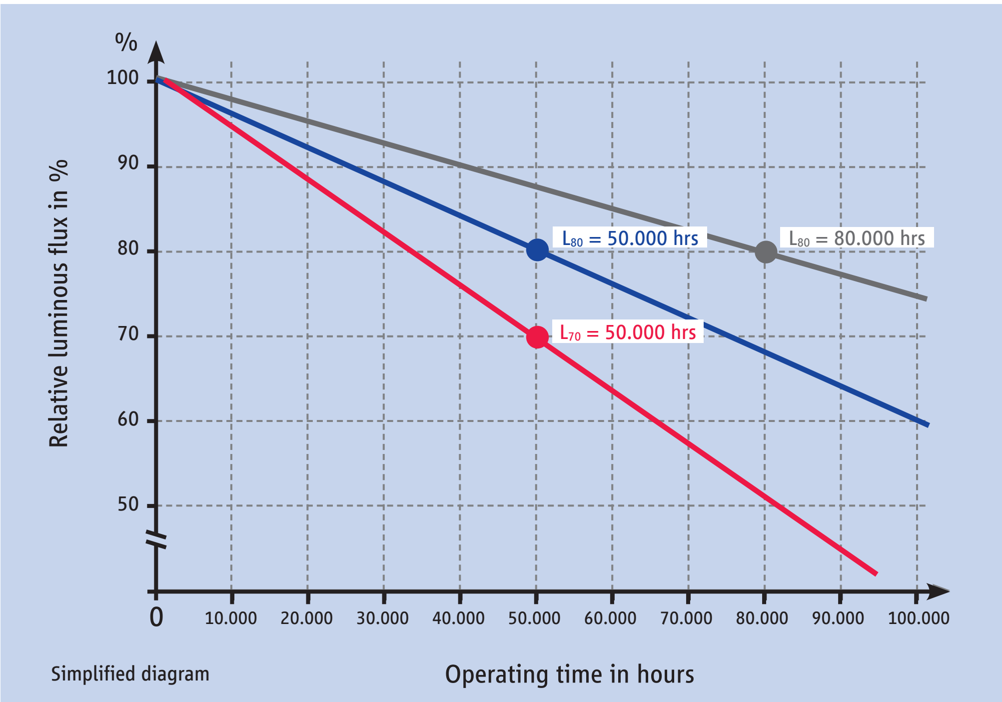
The value B_{50} thus means that 50 percent of a population of LED luminaires of the same type deliver less than the declared percentage "x" of luminous flux at the end of the median useful life "L_x" and 50 percent deliver more.

The B_{50} criterion (median value) is used to indicate the average luminous flux of LED luminaires functioning at the designated end of the median useful life L_x (rated median useful life).

For certain applications, B_{10} may be of interest. This is the point in time when only ten percent of the LED luminaires fail to deliver the declared percentage "x" of their initial luminous flux.

The B_y criterion indicates nothing, however, about the luminous flux of the individual LED luminaires or their precise distribution.

Fig. 13: Schematic representation of the change in luminous flux over operating time



7c. Taking Account of Abrupt Failures (AFV and C_y)

The term Abrupt Failure Value (AFV) denotes the percentage of LED luminaires that fail abruptly before reaching the median useful life L_x.

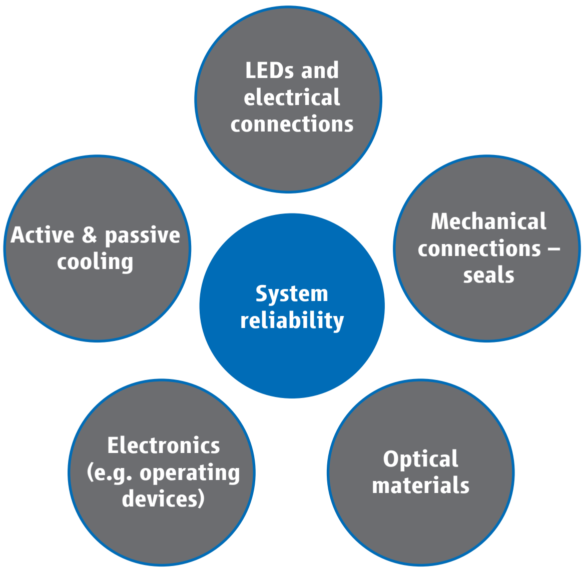
LED luminaires with only individual failed LEDs and LED luminaires in which only one of several LED modules fails are not classed as abrupt failures.

AFV is thus the failure rate at the median useful life L_x (in the case of B_{50}). In the case of B_y values other than B_{50}, C_y is used. C_y is the time to abrupt failure of y percent of the LED luminaires.

7d. System Reliability

The life expectancy of an LED luminaire is influenced by the reliability of all the components used in the system and by the ambient conditions at the location where the luminaire is used. The failure of one luminaire component can cause the abrupt failure of the luminaire as a whole. Examples of component-based factors influencing LED luminaire system reliability are shown in Figure 14.

Fig. 14: Factors influencing system reliability



Ways of calculating abrupt failure that take account of all system components are currently being discussed. The outcomes will flow into future standardisation work.

In practice, the failure of electronic components (e.g. control gear failure) can only be considered separately at present and declared by the manufacturer.

8. ZVEI Recommendations

The ZVEI Lighting Division recommends that the parameters described in this guide should be used as indicated.

The luminaire data sheet should include the following information:

Luminaire designation:	Type description
Luminaire input power:	P [W]
Luminaire luminous flux:	Φ_v [lm]
Luminaire luminous efficacy:	η_v [lm/W]
Colour rendering:	CRI or R_a (min. or ≥)
Correlated colour temperature:	T_{cp} oder CCT [K]
Colour coordinate tolerance (initial value):	(number of MacAdam ellipses)
Median useful life L_x:	L_{80} [h]
Ambient temperature:	t_q [°C] (unless specified, t_q = 25°C)
Luminous intensity distribution	

All the values shown are rated values

LED luminaire longevity declarations must always be specified together with the specific ambient temperature and the number of burning hours.

If data are declared in the recommended form and obtained by the methods stipulated in this guide, manufacturers may make the following voluntary statement on their own responsibility:

"The terminology used and the underlying technical calculation methods are all as recommended in the ZVEI guide to "Reliable Planning for LED Lighting" (2nd edition, March 2016)."

V Notes on Lighting Planning

Maintenance factors are an important consideration in the planning of lighting installations. For compliance with the DIN EN 12464 series of standards, for example, the planner needs to establish and document how much the luminous flux of a lighting installation will decrease by a certain point in time and recommend appropriate maintenance action.

The following maintenance factors are defined in the publications CIE 97 (Indoor lighting) and CIE 154 (Outdoor lighting):

- **MF:** Maintenance Factor
- **LLMF:** Lamp Lumen Maintenance Factor
- **LSF:** Lamp Survival Factor
- **LMF:** Luminaire Maintenance Factor
- **RMF:** Room Maintenance Factor
- **SMF:** Surface Maintenance Factor

The maintenance factor MF of the lighting installation is the product of the individual maintenance factors.

Indoor lighting:

MF = LLMF x LSF x LMF x RMF

Outdoor lighting:

MF = LLMF x LSF x LMF (x SMF)*

*** Note:** SMF is used where appropriate, e.g. as the surface maintenance factor of an illuminated surface or for pedestrian subways.

LLMF is obtained from manufacturers' luminous flux degradation curves for the relevant observation period.

LSF is obtained from the number of LED luminaires that have failed abruptly over the time up to the monitoring point.

For lighting designs incorporating LED luminaires, LLMF and LSF form a basis for rating LED luminaires and can be determined for different luminous flux classes on the basis of operating times (in hours). This method is in line with the declaration of LLMF and LSF for conventional lamps.

The relevant LED luminaire assessment parameters are derived from useful life. "L_xB_y" and "L_x" declarations are made in the following form: L_xB_y = ii.iii hours (alternatively hrs) and L_x = ii.iii hours (alternatively hrs). For example: L_{80} = 50.000 hours

Table 2 shows an example of how LED luminaire maintenance factors LLMF and LSF can be represented. The first column contains the rated values. These are found in manufacturers' product data sheets (e.g. L_{80} = 50.000 hrs). The table shows the lumen loss LLMF and lamp survival factor LSF for any time specified by the designer. Lumen loss is assumed to be linear.

Even for LED luminaires, the designer needs to apply a luminaire maintenance factor LMF to take account of lumen loss due to luminaire soiling.

The abrupt failure of an LED luminaire (not counting operating device failure) can be represented by LSF. Within a luminaire's specified useful life, LSF = 1 is the norm, which corresponds to AFV = 0 or y = 0 (of C_y). In such cases, this factor is negligible for planning purposes. Where a large number of luminaires (> 100) is considered, individual failures are statistically insignificant, so even where LSF = 1, individual LED luminaires may have failed.

A similar table can be created for other rated values.

This tabular method cannot be used for LED luminaire warranty statements.

The German lighting society (Deutsche Lichttechnische Gesellschaft – LiTG) is planning a publication of its own on "LED Maintenance Factors".

Table 2: **Possible representation of LED luminaire maintenance factors LLMF and LSF**

Useful life			Operating time in 1,000 hrs																				
Parameters			1	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	...
L_{90}	ii.iii h	LLMF																					
		LSF																					
L_{80}	ii.iii h	LLMF																					
		LSF																					
L_{70}	ii.iii h	LLMF																					
		LSF																					
L_{60}	ii.iii h	LLMF																					
		LSF																					
L_{50}	ii.iii h	LLMF																					
		LSF																					

VI Photobiological Safety of LED Luminaires

For the assessment of photobiological risk from optical radiation, a distinction is made between different wavelength ranges (UV, visible and IR radiation). The main focus here is on the depth of penetration in human tissue. Because optical radiation does not penetrate deep into tissue, only skin and eyes are affected.

UV and IR rays are absorbed as soon as they enter superficial tissue layers. The risk they present and the limits that apply depend on the illuminance that a light source or luminaire produces and not on its dimensions. Broadly speaking, this means that the risk changes as a function of the luminous intensity distribution and the square of the distance (i.e. half the distance from the source means four times the risk).

Blue light risk is a different matter. Blue light rays penetrate the cornea of the eye and are directed onto the retina by the lens, so the risk depends on the size of the light source.

In DIN EN 62471 "Photobiological safety of lamps and lamp systems", a distinction is made between two types of measurement. For lamps for general illumination, risk classification should be performed at the distance where illuminance is 500 lx (200 mm minimum).

For all other lamp applications, a distance of 200 mm is recommended.

Further information on blue light risk (in German) can be found in the ZVEI publication "Fotobiologische Sicherheit der Beleuchtung" (www.zvei.de) and the LiTG publication "Beurteilung der photobiologischen Sicherheit von Lampen und Leuchten" (www.litg.de).

For more about the biological effects of light, go to www.licht.de.

VII Other Quality Features in LED Lighting

Flicker

Luminaires that constantly flicker can cause physiological problems, giving rise to complaints such as headaches. Stroboscopic effects can also lead to hazards. They can interfere with our perception of rotating or reciprocating machine parts, even to the extent that the movement is no longer visible.

To prevent such impacts, coordinated measures should be taken. This may mean assigning the luminaires to different current phases or selecting LED luminaires with sufficiently high LED operating frequencies.

VIII LED Retrofit Lamps in Professional Lighting

Double-ended LED lamps are available as retrofit or conversion lamps for existing lampholder systems.

The retrofit variant is an LED lamp that replaces a fluorescent lamp. The existing starter needs to be replaced or removed, according to the manufacturer's instructions. However, the luminaire is not modified, so an electrician is not required.

With the conversion variant, not only is the fluorescent lamp replaced and the starter removed or replaced but the luminaire also needs to undergo technical modification, e.g. in the form of replacement or modification of operating devices and/or internal wiring. These alterations to the luminaire need to be performed by an electrician, ensuring that they comply with the relevant safety and operating standards and meet the necessary electromagnetic compatibility requirements.

G13 or G5 base LED lamps for direct line voltage operation are a special type of conversion lamp. New luminaires are being launched on the market for these lamps.

Whether luminaires are modified or whether they are new for operating G13 and G5 base LED lamps, safety precautions need to be taken to ensure that the use of fluorescent lamps (G13 and G5 base) does not present a hazard.

Because a lighting installation's lighting characteristics may be changed by the use of LED lamps, it is recommended that a technical inspection should be carried out.

Apart from safety and lighting aspects, the requirements of European directives also need to be observed. For example, they do not allow marked differences in beam characteristics when an LED lamp is used to replace a fluorescent lamp.

When an existing installation is converted to LED, questions arise about responsibility for the conformity of the retrofit luminaires and for the technical and especially safety-related consequences.

Conformity assessments, CE marking and any test marks awarded to the original luminaires apply to the state of the products at the time they are placed on the market and thus to the form of use intended by the luminaire manufacturer and the types of lamp intended for use in the luminaire. Both are normally described in luminaire data sheets or operating instructions.

In the course of conformity assessment, manufacturers of retrofit or conversion solutions ensure the suitability of their products for the intended and declared purpose and accept responsibility for it. The CE mark on retrofit lamps or conversion components documents this externally, signalling compliance with the relevant EU directives. That includes compliance with safety standards and electromagnetic compatibility. When installations are modified by conversion solutions, the luminaires undergo a significant change and become a "new product".

In the case of conversion (as with the use of retrofit lamps) the obligation to ensure professional execution compliant with state-of-the-art safety and EMC standards rests with the operator and converter, who may need to present corroborating documentation.

More details can be found in publications on the ZVEI website www.zvei.org.

IX Addenda to Chapter IV.4

Measurement and representation of the luminous intensity distribution curves of narrow-angle LED luminaires

Depending on the form and symmetry characteristics of a luminaire's intensity distribution curve, a distinction is made between narrow, wide, symmetrical and asymmetrical luminous intensity distribution.

For LED luminaires with very narrow intensity distribution curves, C planes should be shown in 5° steps and γ angles in 2.5° steps. If intensity distribution curves are extremely narrow, an even greater number of angles may be needed, e.g. in 1° steps for the area in which 90 percent of the luminous flux is radiated. Such cases need to be taken into account in lighting design by increasing the number of calculation points. More details can be found in the EN 13032 standards series.

X Appendix: Definitions of Quality Criteria Performance Requirements

Term	Definition	Standard	Remarks
Rated input power (in W)	**input power** ***P*** electrical power from the mains supply consumed by the luminaire including the operation of all electrical components necessary for its intended functioning **Unit:** W **rated value** quantitative value for a characteristic of a product for specific operating conditions specified in this standard , or in applicable standards, or assigned by the manufacturer or responsible vendor **Source:** IEC 62722-1:2014	**IEC 62722-1:2014-09;** **IEC 62722-2-1:2014-11:** The provisions of Clause 7 of IEC 62717 apply to the LED luminaire. **IEC 62717:2014-12+AMD:2015 – Performance standard for LED modules:** The initial power consumed by each individual LED module in the measured sample shall not exceed the rated power by more than 10 %.	Emergency lighting charging power should be deleted – Ad-hoc remarks (see also item 3, LED luminaire efficacy (lm/W)).
Rated luminous flux (in lm)	**luminous flux** ϕ_v, ϕ quantity derived from radiant flux, Φ_e, by evaluating the radiation according to its action upon the CIE standard photometric observer **Unit:** lm **Note 1:** For photopic vision $$\Phi_v = K_m \int_0^\infty \frac{d\,\Phi_e(\lambda)}{d\,\lambda} V(\lambda) d\,\lambda$$ where $$\frac{d\,\Phi_e(\lambda)}{d\,\lambda}$$ is the spectral distribution of the radiant flux and $V(\lambda)$ is the spectral luminous efficiency. **Note 2:** For the values of Km (photopic vision) and K'm (scotopic vision), see IEC 60050-845, 845-01-56. **Note 3:** The luminous flux of LED dies is usually expressed in groups into which they are sorted. **Source:** CIE 084:1989	**IEC 62722-1:2014-09;** **IEC 62722-2-1:2014-11:** The provisions of 8.1 of IEC 62717 apply to the LED luminaire. In addition the provisions in Clause A.1, paragraph 2 of IEC 62722-2-1 apply where a rated ambient temperature related to performance other than 25 °C is advised by the manufacturer. **IEC 62717:2014-12+AMD:2015 – Performance standard for LED modules** he initial luminous flux of each individual LED module in the measured sample shall not be less than the rated luminous flux by more than 10 %.	
LED luminaire efficacy (in lm/W)	**Luminaire efficacy** η_v, η ratio of the luminaires total luminous flux versus its rated input power at rated supply voltages, excluding any emergency lighting charging power **Note:** Luminaire efficacy is expressed in lumen per watt. **Unit:** $lm \cdot W^{-1}$ **Source:** EN 13032-4:2015 oder CIE S 017/E:2011	**IEC 62722-1:2014-09;** **IEC 62722-2-1:2014-11:** The provisions of Clause 8.1 of IEC 62717 apply to the LED luminaire. **IEC 62717:2014-12+AMD:2015 – Performance standard for LED modules:** LED module (luminaire) efficacy shall be calculated from the measured initial luminous flux of the individual LED module (luminaire) divided by the measured initial input power of the same individual LED module (luminaire). For measurement of luminous flux see Annex A.3.2.	
Luminous intensity distribution	**luminous intensity** (of a source, in a given direction) **I_v; I** quotient of the luminous flux $d\Phi V$ leaving the source and propagated in the element of solid angle $d\Omega$ containing the given direction, by the element of solid angle $IV = d\Phi V/d\Omega$ **Unit:** $cd = lm \cdot sr^{-1}$ **Note 1:** The definition holds strictly only a point of source. **Note 2:** The luminous intensity of LED is expressed according to CIE 127:2007 measurement procedure. [IEC 60050-845:1987, 845-01-31] and [CIE S 017/E:2011 ILV, 17-739 modified] **Source:** (CIE S 017/E:2011) CIE 127:2007, Abschnitt 4.2 EN 13032-4:2015, Abschnitt 6.4 = luminous efficacy CIE 84:1989, Abschnitt 4	**IEC 62722-1:2014-09;** **IEC 62722-2-1:2014-11:** The provisions of Clause 8.2.3 of IEC 62717 apply to the LED luminaire. **IEC 62717:2014-12+AMD:2015 – Performance standard for LED modules:** The distribution of luminous intensity shall be in accordance with that declared by the manufacturer. The measurement is conducted according to A.3.3.	

Term	Definition	Standard	Remarks
Correlated Colour Temperature (CCT in K)	**Correlated colour temperature** T_{cp} temperature of the Planckian radiator having the chromaticity nearest the chromaticity associated with the given spectral distribution on a diagram where the (CIE 1931 standard observer based) $u', \frac{2}{3}v'$ coordinates of the Planckian locus and the test stimulus are depicted **Unit:** K **Note 1:** The concept of correlated colour temperature should not be used if the chromaticity of the test source differs more than from the Planckian radiator $\Delta C = \left[(u'_t - u'_p)^2 + \frac{4}{9}(v'_t - v'_p)^2\right]^{1/2} = 5 \cdot 10^{-2}$ where (u'_t, v'_t) refer to the test source, (u'_p, v'_p) to the Planckian radiator. **Note 2:** Correlated colour temperature can be calculated by a simple minimum search computer program that searches for that Planckian temperature that provides the smallest chromaticity difference between the test chromaticity and the Planckian locus, or e.g. by a method recommended by Robertson, A. R. "Computation of correlated colour temperature and distribution temperature", J. Opt. Soc. Am. 58, 1528-1535, 1968. (Note that the values in some of the tables in this reference are not up-to-date). **Abbreviation:** "CCT" **Source:** ISO 11664	**IEC 62722-1:2014-09;** **IEC 62722-2-1:2014-11:** The provisions of Clause 9.2. of IEC 62717 apply to the LED luminaire. **IEC 62717:2014-12+AMD:2015 –** **Performance standard for LED modules:** Preferred values to ensure interchangeability are under consideration. The four-digit CCT value is divided by 100 and the resulting figure is rounded off to the next integer number, when using the photometric code in Annex D.	
Rated Colour Rendering Index (CRI)	**colour rendering index** ***R*** measure of the degree to which the psychophysical colour of an object illuminated by the test illuminant conforms to that of the same object illuminated by the reference illuminant, suitable allowance having been made for the state of chromatic adaptation See also CIE 13 Method of Measuring and Specifying Colour Rendering of Light Sources **Abbreviation:** "CRI" **Source:** CIE 13	**IEC 62722-1:2014-09;** **IEC 62722-2-1:2014-11:** The provisions of Clause 9.3. of IEC 62717 apply to the LED luminaire. Where suitable component reliability data is available the test duration may be reduced from 6 000 h to 2 000 h. **IEC 62717:2014-12+AMD:2015 –** **Performance standard for LED modules:** The initial Colour Rendering Index (CRI) of a LED module is measured. A second measurement is made at an operational time as stated in 6.1. (= 6000 h / 25 % rated life) **Compliance:** For all tested items in a sample the measured CRI values shall not have decreased by more than • 3 points from the rated CRI value (see Table 1) for initial CRI values and • 5 points from the rated CRI value (see Table 1) for maintained CRI values.	
Rated chromaticity coordinate values (initial and maintained)	**chromaticity coordinates** ratio of each of a set of 3 tristimulus values to their sum **Unit:** 1 **Note 1:** As the sum of the 3 chromaticity coordinates is equal to 1, 2 of them are sufficient to define a chromaticity. **Note 1:** In the CIE standard colorimetric systems, the chromaticity coordinates are represented by the symbols x, y, z and x10, y10, z10. **Source:** ISO 11664 and LM-80 for maintained	**IEC 62722-1:2014-09;** **IEC 62722-2-1:2014-11:** The provisions of Clause 9.1 of IEC 62717 apply to he LED luminaire. Where suitable component reliability data is available the test duration may be reduced from 6.000 h to 2.000 h and the measured chromaticity value coordinate value for initial and 2.000 h shall not exceed the rated colour variation category for initial and 6.000 h respectively. **IEC 62717:2014-12+AMD:2015 –** **Performance standard for LED modules:** The initial chromaticity coordinates are measured. A second measurement of maintained chromaticity coordinates is made at an operational time as stated in 6.1 (= 6.000 h / 25 % rated life). The measured actual chromaticity coordinate values (both initial and maintained) shall fit within one of 4 categories (see Table 5), which correspond to a particular MacAdams ellipse around the rated chromaticity coordinate value, whereby the size of the ellipse (expressed in n-steps) is a measure for the tolerance or deviation of an individual LED module.	

Term	Definition	Standard	Remarks
Maintained luminous flux	**luminous flux maintenance factor** **lumen maintenance factor** ratio, expressed as a percentage x, of the luminous flux emitted by the light source at a given time in its life to its initial luminous flux emitted **Unit:** % **Note:** The lumen maintenance factor of LED light source includes optical parts degradation, the effect of decrease of the luminous flux output of the led package and failure(s) of individual LED packages if the LED light source contains more than one LED package. **Abbreviation: "LLMF"** **Source:** IEC 61717	**IEC 62722-1:2014-09;** **IEC 62722-2-1:2014-11:** The provisions of Clause 10.2 of IEC 62717 apply to the LED luminaire except that the maintenance test shall be conducted at the ambient temperature in the temperature interval (rated t_q, rated t_q – 2). The provisions of 10.2 of IEC 62717 apply to the LED luminaire, except that the maximum rated temperature t_p of the LED module is not exceeded in the luminaire during testing as long as the interval (rated t_p – 5, rated t_p) is maintained. **Compliance criteria** The measured luminous flux value shall not be less than the luminous flux value given by the rated lumen maintenance factor related to rated median useful life.	fLLM is not used in IEC standards (at least LED module) as the shape of the lumen depreciation curve as function of time between LED modules varies among manufacturers and is depending on the specific LED technology used. Specified in IEC 62504 is 'life', as time period at a specified performance temperature at which x % of the measured initial luminous flux value is reached.
Ambient temperature (t_q) for a luminaire	**temperature, rated ambient performance (rated ambient performance temperature)** **t_q** 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 **Unit:** °C **Note 1:** Rated ambient performance temperature is expressed in °C. **Note 2:** For a given life time, the t_q temperature is a fixed value, not a variable. **Note 3:** There can be more than one t_q temperature, depending on the life time claim, .3.4. **Source:** IEC 62722-2-1:2014	**IEC 62722-1:2014-09;** **IEC 62722-2-1:2014-11:** **General** The provisions of Subclause A.1 of IEC 62717 apply to the LED luminaire. Where a rated ambient performance temperature t_q other than 25 °C is advised by the manufacturer a correction factor will need to be established to correct the measured luminous flux value at 25 °C to the luminous flux value at the declared ambient. This shall be done using relative photometry in a temperature controlled cabinet.	
Useful life (of LED modules and Luminaires) – Bemessungs-lebensdauer	**useful life (of LED modules)** **L_xB_y** length of time until a percentage y of a population of operating LED modules of the same type have parametrically failed to provide at least percentage x of the initial luminous flux **Note:** The useful life includes operating LED modules only. **Source:** 34A/1864/DC – proposal for amendment to IEC 62717	**IEC 62722-1:2014-09;** **IEC 62722-2-1:2014-11:** **General** The provisions of 10.1 of IEC 62717 apply to the LED luminaire. The length of time until a percentage y of a population of operating LED modules reaches gradual light output degradation of a percentage x is called the useful life (or "By life") and expressed in general as L_xB_y. Light output lower than the lumen maintenance factor x is called a parametric failure because the product produces less light but still operates. "B_{10}" life is the age at which 10 % of products have failed parametrically. The age at which 50 % of the LED modules parametric fail, the "B_{50} life", is called median useful life. The population includes operating LED modules only; non-operative modules are excluded.	
Median useful life (of LED modules and Luminaires) – Mittlere Bemessungs-lebensdauer	**median useful life (of LED modules)** **L_x** length of time during which 50 % (B50) of a population of operating LED modules of the same type have parametrically failed to provide at least percentage x of the initial luminous flux **Note 1:** The median useful life includes operating LED modules only. **Note 2:** In common language the expression "life of LED modules" without any modifiers is understood to mean the median useful life. [SOURCE: IEC 60050-845:1987, 845-07-61, modified – new definition] **Source:** 34A/1864/DC – proposal for amendment to IEC 62717	**IEC 62722-1:2014-09;** **IEC 62722-2-1:2014-11:** **General** The provisions of 10.1 of IEC 62717 apply to the LED luminaire. The length of time until a percentage y of a population of operating LED modules reaches gradual light output degradation of a percentage x is called the useful life (or "By life") and expressed in general as L_xB_y. Light output lower than the lumen maintenance factor x is called a parametric failure because the product produces less light but still operates. "B_{10}" life is the age at which 10 % of products have failed parametrically. The age at which 50 % of the LED modules parametric fail, the "B_{50} life", is called median useful life. The population includes operating LED modules only; non-operative modules are excluded.	

Term	Definition	Standard	Remarks
Abrupt failure fraction of LED-module and LED-Luminaire	**abrupt failure** failure of a LED product to operate or to produce luminous flux **Note 1:** For the purpose of this standards , the LED product is a LED module **Note 2:** The term "complete Failure" is commonly used for the same purpose. **Note 3:** For illustration of abrupt failure mode see Figure C1 (hier Bild 11). **Source:** IEC 62717:2014	**IEC 62717:2014+AMD:2015** **Life time specification for abrupt light output degradation:** The abrupt light output degradation of a population of LED Luminaires at a certain point in time is called time to abrupt failure and expressed as C_y. The recommended life time metrics for specifying LED module life is explained in Annex C of IEC 62717 and apply to the LED luminaire. For compliance criteria see 10.2 of the standard.	
Time to abrupt failure of LED-module and LED-Luminaire	**time to abrupt failure** **C_y** length of time during which y % of a population of initially operating LED modules of the same type fail to produce any luminous flux **Unit:** h **Note 1:** The time to abrupt failure includes inoperative LED modules only. **Note 2:** $C_{AFV} = L_x$. **Source:** IEC 62717:2014+AMD:2015	**IEC 62717:2014+AMD:2015** **Life time specification for abrupt light output degradation:** The abrupt light output degradation of a population of LED Luminaires at a certain point in time is called time to abrupt failure and expressed as C_y. The recommended life time metrics for specifying LED module life is explained in Annex C of IEC 62717 and apply to the LED luminaire. For compliance criteria see 10.2 of the standard.	
Abrupt failure value, corresponding to the median useful file of LED modules and luminaires	**abrupt failure value** **AFV** percentile of LED modules failing to operate at median useful life, L_x **Note 1:** AFV = $F(L_x) \times 100$ %; $LSF(L_x) = 1 - F(L_x)$ **Note 2:** Example: Given L_x=20 000 h and AFV = F(20 000 h) × 100 % = 7 % results in LSF(20 000 h) = 1 – 0,07 = 0,93. **Source:** IEC 62717:2014+AMD:2015	**IEC 62717:2014+AMD:2015** **Life time specification for abrupt light output degradation:** The abrupt light output degradation of a population of LED Luminaires at a certain point in time is called time to abrupt failure and expressed as C_y. The recommended life time metrics for specifying LED module life is explained in Annex C of IEC 62717 and apply to the LED luminaire. For compliance criteria see 10.2 of the standard.	

XI References

Performance Standards for LED Luminaires

- IEC 62722-1:2014-09;
  Luminaire performance – Part 1:
  General requirements
- IEC 62722-2-1:2014-11;
  Luminaire performance – Part 2-1:
  Particular requirements for LED luminaires

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