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Incorporating corrigendum July 2014

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Application of IEC 62471 for the assessment of blue light hazard to light sources and luminaires

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National foreword

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The UK participation in its preparation was entrusted by Technical Committee CPL/34, Lamps and Related Equipment, to Subcommittee CPL/34/1, Electric lamps.

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TECHNICAL REPORT

colour inside

Application of IEC 62471 for the assessment of blue light hazard to light sources and luminaires

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

APPLICATION OF IEC 62471 FOR THE ASSESSMENT OF BLUE LIGHT HAZARD TO LIGHT SOURCES AND LUMINAIRES

FOREWORD

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IEC TR 62778, which is a technical report, has been prepared by subcommittee 34A: Lamps, of IEC technical committee 34: Lamps and related equipment.

This second edition cancels and replaces the first edition published in 2012. This edition constitutes a technical revision.

This edition includes the following significant technical change with respect to the previous edition: inclusion of the photobiological assessment of LED arrays (Annex D).

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
34A/1737/DTR	34A/1758/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

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APPLICATION OF IEC 62471 FOR THE ASSESSMENT OF BLUE LIGHT HAZARD TO LIGHT SOURCES AND LUMINAIRES

1 Scope

This Technical Report brings clarification and guidance concerning the assessment of blue light hazard of all lighting products which have the main emission in the visible spectrum (380 nm to 780 nm). By optical and spectral calculations, it is shown what the photobiological safety measurements as described in IEC 62471 tell us about the product and, if this product is intended to be a component in a higher level lighting product, how this information can be transferred from the component product (e.g. the LED package, the LED module, or the lamp) to the higher level lighting product (e.g. the luminaire).

A summary of recommendations to assist the consistent application of IEC 62471 to light sources and luminaires for the assessment of blue light hazard is given in Annex C.

NOTE It is expected that HID and LED product safety standards will make reference to this Technical Report.

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.

IEC 60050 (all parts), *International Electrotechnical Vocabulary* (available at <http://www.electropedia.org>).

IEC 62471:2006, *Photobiological safety of lamps and lamp systems*

CIE S 017/E:2011, *ILV: International Lighting Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 62471:2006, CIE S 017/E:2011 and IEC 60050-845 as well as the following apply.

3.1
blue light hazard efficacy of luminous radiation
$K_{B,v}$
quotient of blue light hazard quantity to the corresponding photometric quantity

Note 1 to entry: Blue light hazard efficacy of luminous radiation is expressed in W/lm.

Note 2 to entry: The quantity $\Phi_\lambda(\lambda)$ in the formula below can be replaced by $L_\lambda(\lambda)$ or $E_\lambda(\lambda)$.

$$K_{B,v} = \frac{\int \Phi_\lambda(\lambda) \cdot B(\lambda) \cdot d\lambda}{K_m \cdot \int \Phi_\lambda(\lambda) \cdot V(\lambda) \cdot d\lambda}$$

where K_m = 683 lm/W.

Note 3 to entry: $K_{B,v} = L_B/L = E_B/E$.

3.2
blue light hazard efficiency of radiation
η_B
ratio of blue light hazard quantity to the corresponding radiometric quantity

Note 1 to entry: The quantity $\Phi_\lambda(\lambda)$ in the formula below can be replaced by $L_\lambda(\lambda)$ or $E_\lambda(\lambda)$.

$$\eta_B = \frac{\int \Phi_\lambda(\lambda) \cdot B(\lambda) \cdot d\lambda}{\int \Phi_\lambda(\lambda) \cdot d\lambda}$$

3.3
correlated colour temperature
CCT
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*', 2/3 *v*' coordinates of the Planckian locus and the test stimulus are depicted

Note 1 to entry: Correlated colour temperature is expressed in kelvin (K).

Note 2 to entry: The concept of correlated colour temperature should not be used if the chromaticity of the test source differs more than $\Delta C = [(u'_t - u'_p)^2 + \frac{4}{9}(v'_t - v'_p)^2]^{1/2} = 5 \times 10^{-2}$ from the Planckian radiator, where

u'_t, v'_t refer to the test source, u'_p, v'_p to the Planckian radiator.

Note 3 to entry: 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 color 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).

[SOURCE: CIE S 017/E:2011, 17-258, modified — T_{cp} is not referenced.]

3.4
illuminance <at a point of a surface>
E
quotient of the luminous flux dΦ incident on an element of the surface containing the point, by the area dA of that element

Note 1 to entry: Illuminance is expressed in lm/m^2 or lx.

[SOURCE: IEC 60050-845:1987, 845.01.38, modified — The second half of the definition is omitted.]

3.5
blue light weighted irradiance
E_B
irradiance spectrally weighted with the blue light spectral weighting function as defined in IEC 62471

Note 1 to entry: Blue light weighted irradiance is expressed in W/m^2.

3.6
threshold illuminance
E_{thr}
threshold illuminance value, below which the light source can never give rise to an exposure time t_{max} < 100 s, regardless of the light source's L_B value

Note 1 to entry: The threshold illuminance can be calculated by taking the E_B value for t_{max} = 100 s, which is E_B = 1 W/m^2, and dividing E_B by the $K_{B,v}$ value corresponding to the spectrum of the light source.

Note 2 to entry: Threshold illuminance is expressed in lm/m^2 or lx.

3.7
etendue
geometrical property of a collection of light rays in an optical system, given by the integral over all positions in a plane that these light rays pass through and over all directions into which they travel

Note 1 to entry: It takes the form of a product of area and solid angle. It can be seen as a volume in phase space. Basic physical conservation laws, related to the ‘second law of thermodynamics’, dictate that optical components that change only the direction of light (lenses, reflectors, all beam shaping optics) can never decrease the etendue for a given packet of flux.

Note 2 to entry: Etendue is expressed in m^{2}sr.

3.8
irradiance <at a point of a surface>
E_e
quotient of the radiant flux dΦ_e incident on an element of the surface containing the point, by the area dA of that element

Note 1 to entry: Irradiance (at a point of a surface) is expressed in W/m^2.

Note 2 to entry: The spectral power distribution of the irradiance, as a function of wavelength, is denoted by $E_\lambda(\lambda)$.

Note 3 to entry: For the purposes of this Technical Report, it is important to mention that when $E_\lambda(\lambda)$ is known, it can be converted to illuminance (E) when weighted with the CIE 1924 photopic eye sensitivity spectrum $V(\lambda)$, and to blue light weighted irradiance (E_B) when weighted with the blue light spectral weighting function as defined in IEC 62471.

[SOURCE: IEC 60050-845:1987, 845.01.37, modified — Notes 2 and 3 to entry are introduced.]

3.9
luminance <in a given direction, at a given point of a real or imaginary surface>
L
quantity defined by the formula

$$L = \frac{\mathrm{d}\,\Phi}{\mathrm{d}A \cdot \cos\theta \cdot \mathrm{d}\Omega}$$

where dΦ is the luminous flux transmitted by an elementary beam passing through the given point and propagating in the solid angle dΩ containing the given direction; dA is the area of a section of that beam containing the given point; θ is the angle between the normal to that section and the direction of the beam

Note 1 to entry: Luminance (in a given direction, at a given point of a real or imaginary surface) is expressed in cd/m^2.

[SOURCE: IEC 60050-845:1987, 845.01.35, modified — “L” instead of “L_V” is used. The note is deleted.]

3.10
blue light weighted radiance
L_B
radiance spectrally weighted with the blue light spectral weighting function as defined in IEC 62471

Note 1 to entry: Blue light weighted radiance is expressed in W/(m^2·sr).

3.11
light source
any product that produces light

EXAMPLE LED package, LED module, lamp, luminaire

3.12
luminaire
apparatus which distributes, filters or transforms the light transmitted from one or more lamps and which includes, except the lamps themselves, all the parts necessary for fixing and protecting the lamps and, where necessary, circuit auxiliaries together with the means for connecting them to the electric supply

[SOURCE: IEC 60050-845:1987, 845.10.01, modified — Notes 1 and 2 are deleted.]

3.13
luminaire optics
all luminaire components that modify the spatial and directional characteristics of the radiation emitted by the primary light source inside the luminaire

3.14
primary light source
surface or object emitting light produced by a transformation of energy

Note 1 to entry: For the purpose of this Technical Report, it may refer to an LED package, an LED module, or a lamp.

[SOURCE: IEC 60050-845:1987, 845.07.01, modified — A new note to entry is added.]

3.15
radiance <in a given direction, at a given point of a real or imaginary surface>
$\boldsymbol{L_e}$
quantity defined by the formula

$$L_e = \frac{d\Phi_e}{dA \cdot \cos\theta \cdot d\Omega}$$

where $d\Phi_e$ is the radiant flux transmitted by an elementary beam passing through the given point and propagating in the solid angle $d\Omega$ containing the given direction; dA is the area of a section of that beam containing the given point; θ is the angle between the normal to that section and the direction of the beam.

Note 1 to entry: Radiance (in a given direction, at a given point of real or imaginary surface) is expressed in $W/(m^2 \cdot sr)$.

Note 2 to entry: The spectral power distribution of the radiance, as a function of wavelength, is denoted by $L_\lambda(\lambda)$.

Note 3 to entry: For the purposes of this document, it is important to mention, that when $L_\lambda(\lambda)$ is known, it can be converted to luminance (L) when weighted with the CIE 1924 photopic eye sensitivity spectrum $V(\lambda)$, and to blue light weighted radiance (L_B) when weighted with the blue light spectral weighting function as defined in IEC 62471.

[SOURCE: IEC 60050-845:1987, 845.01.34, modified — Notes to entry 1 to 5 are deleted and new notes to entry are introduced.]

3.16
risk group
RG
risk classification when the product, at the relevant evaluation position, gives rise to a certain t_{max} value, according to Table 1, as defined in IEC 62471

Table 1 – Correlation between exposure time and risk group

Risk group number	Risk group name	Corresponding t_{max} range s
RG0	Exempt	> 10 000
RG1	Low risk	100 to10 000
RG2	Moderate risk	0,25 to100
RG3	High risk	< 0,25

3.17
maximum permissible exposure time
t_{max}
maximum permissible exposure time as calculated using the relevant formulae in 4.3.3 and 4.3.4 of IEC 62471:2006

3.18
true luminance
luminance value as obtained by integrating the equation as given in the definition of luminance, over a certain area of a light source, such that only the light emitting surface (or part of it) is included in the integration, and no dark surface area surrounding the light emitting part of the light source

Note 1 to entry: When a luminance measurement is performed over a certain field of view, it will only give a true luminance value when the field of view underfills the light emitting part of the light source.

3.19
true radiance
radiance value as obtained by integrating the equation as given in the definition of radiance , over a certain area of a light source, such that only the light emitting surface (or part of it) is included in the integration, and no dark surface area surrounding the light emitting part of the light source

Note 1 to entry: When a radiance measurement is performed over a certain field of view, it will only give a true radiance value when the field of view underfills the light emitting part of the light source.

3.20
LED package
one single electrical component encapsulating principally one or more LED dies, possibly with optical elements and thermal, mechanical, and electrical interfaces

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

Note 2 to entry: An LED package is a discrete component and part of the LED module. For a schematic build-up of an LED package, see Annex A of IEC 62504[1].

3.21
secondary optics
optics that are not part of the LED package itself

3.22
threshold distance
d_{thr}
distance from the light source at which the illuminance produced by that light source is equal to the E_{thr} value for that light source

1 To be published.

4 General

IEC 62471 is a comprehensive horizontal standard, describing all potential health hazards associated with artificial optical radiation, from the ultraviolet, visible, and infrared portions of the spectrum. This Technical Report deals exclusively with the hazard described in 4.3.3 and 4.3.4 of IEC 62471:2006. This hazard is called the retinal blue light hazard, as it is an effect mainly induced by the blue portion of the visible spectrum, which has its potentially damaging effects on the retina. The effects are described in Clause A.3 of the same standard.

Because the effect takes place on the retina, it is a function not only of the total amount of light that reaches the eye, but also of the size of the light source that produced this light. Larger light sources are imaged onto a larger portion of the retina, and therefore produce a lower irradiance on the retina than smaller light sources producing the same amount of light in the direction of the viewer's eye. Subclause 4.3.3 of IEC 62471:2006 takes this into account by relating the maximum permissible exposure time, t_{max}, to the radiance of the light source. Radiance (unit: W/($m^2 \cdot$sr)) is a quantity describing the radiometric intensity, which is the radiation power emitted into a certain direction, divided by the apparent area of the light source when viewed from that same direction. In an imaging system, such as the eye, the local irradiance on the image plane (which for the eye is on the retina) is proportional to the radiance of the source.

Only when the light source is too small to be imaged sharply, or when it is so small that it will never be fixated on the same portion of the retina for so long that it can produce any damage, the radiance value is not the appropriate value. In this case, 4.3.4 of IEC 62471:2006 shall be applied, where the irradiance on the pupil is used as a value proportional to the effective irradiance on the retina.

The question whether a light source is "large", such that 4.3.3 shall be applied, or "small", such that 4.3.4 shall be applied, depends on the size of the light source as well as on the viewing distance. The subtended angle of the light source is used as discriminating quantity. When the time needed to produce damage is longer than 10 s, IEC 62471 states that the limiting subtended angle for a light source to be large or small is 0,011 rad. For light sources just on the edge between large and small, t_{max} can be calculated either way (using its radiance according to 4.3.3 and using the irradiance according to 4.3.4), which will produce the same result within about 5 %. The deviation of 5 % is caused by rounding of the conversion factors used to convert the radiometric quantity to t_{max}.

In the context of IEC 62471, "light source" means any product used to produce light. In real life, there is a hierarchy of lighting products, where light source is generally used to describe the constituent component of the lighting product that actually produces the light. Since some of the other components of the lighting product, most notably the luminaire optics, may change the radiation characteristics of the primary light source, it is important to know whether and how a photobiological assessment of the primary light source can be transferred to the product using this primary light source as light generating component.

Next to this, IEC 62471 makes a statement about risk classification of products. Because the t_{max} values as calculated in 4.3 of IEC 62471:2006 are determined both by the product itself and by the distance from which it is viewed, these cannot in themselves be used to determine a unique risk classification for a product. For this reason, IEC 62471:2006, Clause 6 states the standard conditions where photobiological safety shall be evaluated to determine risk classification of the products. For lamps intended for general lighting service (GLS), as defined in 3.11 of the same standard, the hazard values shall be reported at a distance which produces an illuminance of 500 lx, but not at a distance less than 200 mm. For all other light sources, including pulsed lamp sources, the hazard values shall be reported at a distance of 200 mm. Examples of these non-GLS light sources are given in the same 3.11 and include lamps for such uses as film projection, sun-tanning, and industrial processes. In some cases, the same lamp may be used in both GLS and special applications and in such cases should be evaluated and rated for the intended applications. At the evaluation distance, t_{max} is determined, and when it falls below 100 s, the product is classified as risk group 2 (RG2) and a cautionary labelling is required.

It is important to assess carefully what information these two different evaluation conditions can give that are relevant to the assessment of the risk in the actual application. While 500 lx is a typical value for illuminance in a wide range of lighting applications, there are undeniably some applications where the illuminance at the viewer's position is higher than 500 lx. What then does a risk classification at 500 lx tell us? On the other hand, setting the evaluation distance to 200 mm for all light sources will lead to exaggerated risk assessment for high-power light sources used in applications where people will never be within short range of the operating light sources; examples are road lighting and stadium lighting; this aside from the practical problems of measuring such a light source at this short distance, which will damage any standard optical measurement equipment.

Although IEC 62471 guides towards the 500 lx measurement for GLS situations, in practice illumination to a level of 500 lx does not necessarily represent an appropriate exposure scenario, illumination levels both above and below 500 lx being very common. Therefore this Technical Report recommends measurements at 200 mm, 0,011 rad, with determination of the RG1/2 boundary condition where appropriate.

This report will investigate the following two matters: (a) transferring the photobiological safety information from a light source component to a higher level lighting product based on this component; (b) making recommendations about measurement distance and risk group classification. It will base these recommendations on an analysis of the quantities relevant to blue light hazard, through spectral calculations and optical considerations.

5 Spectrum, colour temperature, and blue light hazard

5.1 Calculation of blue light hazard quantities and photometric quantities from emission spectra

In order to determine blue light hazard, a measurement of either radiance or irradiance is performed on the light source.

In a radiance measurement, care is taken that the detector measures a signal proportional to the radiance of the source. This can be accomplished by making an image of the source using imaging optics, and placing a detector or detector array in the image plane. Alternatively, it can be performed by placing a diaphragm with a specified opening close to the light source, such that only the light from a known portion of the surface area of the source hits the detector. The radiance can then be calculated from the detector signal when all relevant geometrical parameters are known (diaphragm size, diaphragm distance to the light source and to the detector).

In an irradiance measurement, no imaging optics or diaphragms are placed between light source and detector, and the total amount of radiation that was emitted from the source into the reception aperture of the detector is measured.

In order to determine the blue light weighted radiance or irradiance, both measurements shall record not just the total radiation power, but also the spectral power distribution of the radiation falling on the detector. The spectral power distribution is then multiplied with the blue light spectral weighting function, as defined by Table 4.2 and Figure 4.2 of IEC 62471:2006. If the original measurement is a radiance measurement, the resulting quantity is the blue light weighted radiance L_B. If the original measurement is an irradiance measurement, the resulting quantity is the blue light weighted irradiance E_B.

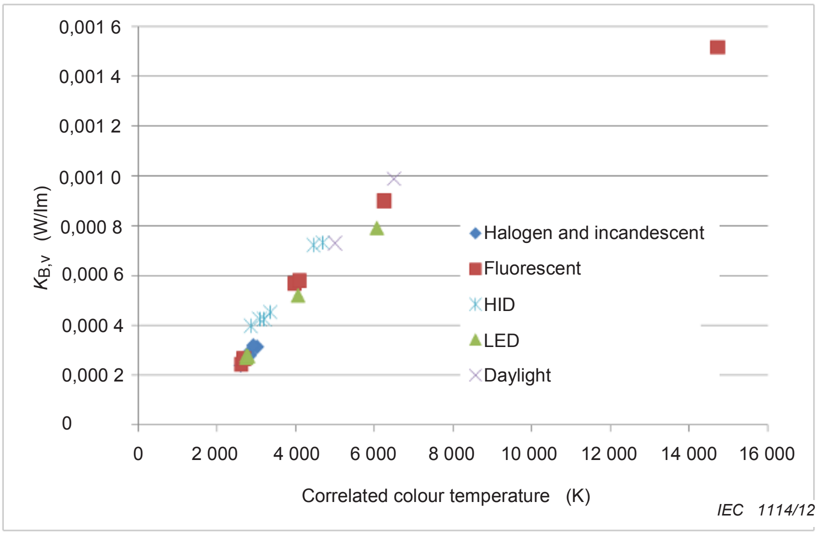
It is important to note that there is a close relationship between these blue light weighted quantities and two corresponding photometric quantities with which many lighting designers and lighting product engineers are familiar with. The blue light weighted radiance L_B is closely related to the luminance L (unit: cd/m^2). The blue light weighted irradiance E_B is closely related to the illuminance E (unit: lx).

Luminance L is in principle determined from the same spectral radiance measurement that produced the L_B value, but in the case of L the spectrum is multiplied with the CIE 1924 photopic eye sensitivity curve $V(\lambda)$. For any given spectrum, L_B will be proportional to L.

In a similar way, the illuminance E is determined from a spectral irradiance measurement, and so for any given spectrum, E_B will be proportional to E.

It is important to realize that the calculations are numerically the same, regardless of whether the spectrum was determined by an irradiance measurement or a radiance measurement. Therefore, for any given spectrum, the proportionality factor between L_B and L is equal to the proportionality factor between E_B and E. This proportionality factor is called the blue light hazard efficacy of luminous radiation, and is denoted by the symbol $K_{B,v}$. It is given in units of W/lm.

When $K_{B,v}$ is determined for a range of different light source spectra, an interesting observation occurs, see Figure 1. For all white light sources, regardless of whether they are based on incandescent, high-intensity discharge, fluorescent, or LED technology, a strong correlation is seen between $K_{B,v}$ and the correlated colour temperature (CCT) of the spectrum. Even daylight, though strictly speaking not subject to IEC 62471, which deals only with artificial light sources, follows the same trend.



NOTE $K_{B,v}$ is displayed against the correlated colour temperature of the light source spectrum to reveal the strong correlation between CCT and $K_{B,v}$.

Figure 1 – Blue light hazard efficacy of luminous radiation, $K_{B,v}$, for a range of light sources from different technologies, and for a few typical daylight spectra

This can be understood from the following observation (see Figure 2). The photopic eye sensitivity curve is, by definition, equal to the CIE 1931 Y curve. The blue light spectral weighting function has good congruence with the CIE 1931 Z curve. These are two of the curves used to determine the colour point (x, y) of a certain spectrum. Because of this it is expected that $K_{B,v}$ correlates with Z/Y. From the definition of the CIE 1931 x, y coordinates through

$$x = \frac{X}{X+Y+Z} \quad (1)$$

and

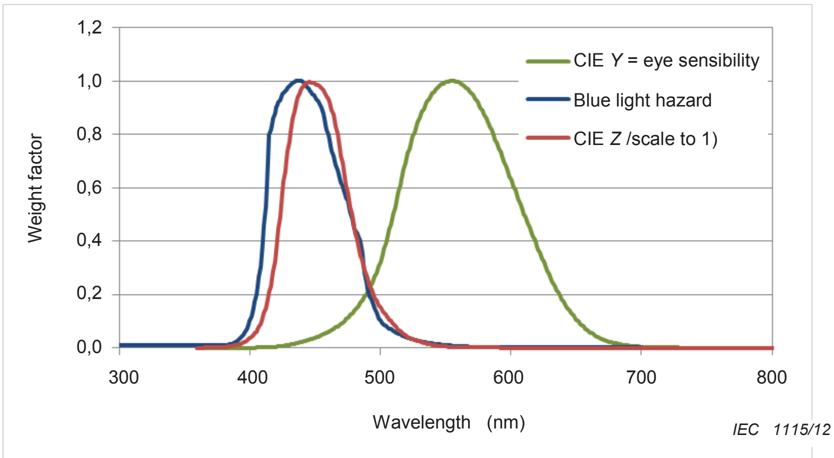
$$y = \frac{Y}{X + Y + Z} \tag{2}$$

it can easily be derived that

$$\frac{Z}{Y} = \frac{1 - x - y}{y} \tag{3}$$

Figure 3 shows for all the studied spectra the correlation between $K_{B,v}$ and $(1 - x - y)/y$. Although not perfect, the quantity $(1 - x - y)/y$ which can be calculated from the colour coordinates alone, without knowing the details of the spectrum, can give an estimate of the $K_{B,v}$ value to within 15 % accuracy.

It should be pointed out that this 15 % accuracy does not reflect a measurement accuracy, but it is the expected uncertainty when correlating colour point to the value of $K_{B,v}$ without knowing any other details of the spectrum. A full spectral measurement will always produce an accurate value of $K_{B,v}$.



NOTE All curves scaled to maximum 1.

Figure 2 – Comparison between the curves involved in calculating $K_{B,v}$ (the photopic eye sensitivity curve and the blue light spectral weighting function) and the CIE 1931 *Y* and *Z* curves involved in calculating the CIE 1931 *x*, *y* colour coordinates

The blue light hazard efficacy of luminous radiation ($K_{B,v}$) is a useful value for calculations involving white light sources. For coloured sources, e.g. blue LED packages, that have their flux specified in watts rather than lumens, it is more useful to use the blue light hazard efficiency of radiation (η_B), which is a dimensionless number.

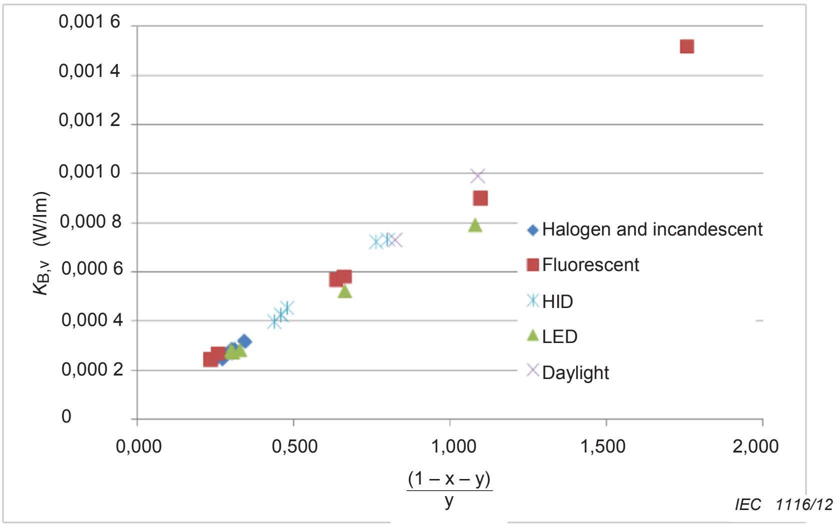


Figure 3 – Correlation plot between the quantity (1 – *x* – *y*)/*y*, calculated from the CIE 1931 *x*, *y* colour coordinates, and the value of $K_{B,v}$, for all the spectra analysed to generate Figure 1

5.2 Luminance and illuminance regimes that give rise to t_{max} values below 100 s

Using the quantity $K_{B,v}$, one can now investigate what luminance and illuminance values possibly give rise to t_{max} values that would require labelling, according to IEC 62471. For blue light hazard, the threshold value from where labelling is required is 100 s. The label should state a cautionary warning not to stare into the light source.

Note that this threshold value still does not give rise to any sizeable risk of eye injury, because of the innate aversion response that causes people and animals alike to close or avert the eyes away from a bright light source, which evolved to prevent eye damage from direct viewing of the sun. For comparison, t_{max} for the sun, if it should fall under IEC 62471, would be around 1 s.

t_{max} = 100 s is reached:

– in the case of a large source, for L_B = 10 000 W/(m^2·sr) (4.3.3 of IEC 62471:2006);
– in the case of a small source, for E_B = 1 W/m^2 (4.3.4 of IEC 62471:2006).

Using the estimated $K_{B,v}$ values for all CCTs, the curves as shown in Figure 4 and Figure 5 can be generated. With these two curves, an estimate can be made if a certain situation (combination of light source and viewing distance) is above or below the 100 s mark for t_{max}, based on the luminance and the CCT of the light source and on the local illuminance level at the eye position of the viewer of the light source. As said before, the estimate is only accurate to about ± 15 %, therefore a more detailed spectral measurement is required to determine the true $K_{B,v}$ value for the spectrum of the source.

First, it shall be determined if the light source at the viewer's eye position is large or small. If it is large, one only needs the light source's luminance, and Figure 4 shall be used. If it is small, the illuminance at the viewer's eye position shall be evaluated, and Figure 5 shall be used. The two curves look very similar, since they were both derived from the same $K_{B,v}$ values as a function of CCT.

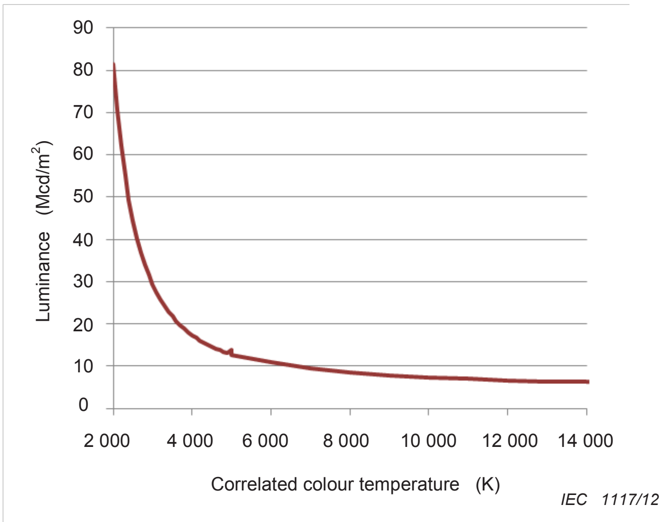


Figure 4 – Estimate of the luminance level where L_B = 10 000 W/(m²·sr), border between RG1 (t_{max} > 100 s) and RG2 (t_{max} < 100 s) in the large source regime, as a function of CCT

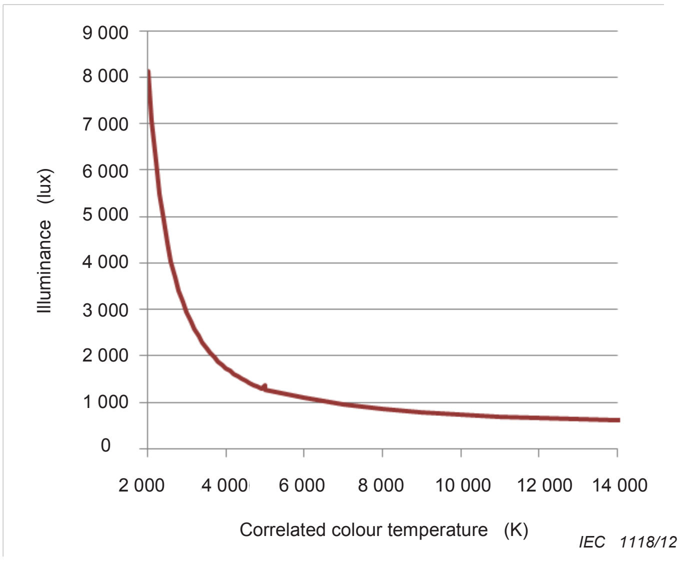


Figure 5 – Estimate of the illuminance level where E_B = 1 W/m², border between RG1 (t_{max} > 100 s) and RG2 (t_{max} < 100 s) in the small source regime, as a function of CCT

Note that the small source regime presents a sort of "worst case" in terms of source luminance. From basic geometrical relations between the involved optical quantities, as explained in Annex A, it can be derived that illuminance at a certain position is equal to the luminance of the source, multiplied by the subtended angle of the source. For a range of situations with the same illuminance value, sources with small subtended angles shall have higher luminance values than sources with large subtended angles.

Knowing the E_B value at a certain illuminance level essentially gives the t_{max} maximum limit regardless of which luminance. This leads to an important simplification of the discussion. It means that if the illuminance level at the viewer's eye position is well below the illuminance where E_B = 1 W/m² (the curve of Figure 5), t_{max} cannot be below 100 s, regardless of the luminance of the light source. Note that the 500 lx mark is below the curve throughout the CCT range relevant for general lighting. In other words, the 500 lx criterion can never generate an RG2 classification for white light.

Another simplification of the discussion can be inferred from Figure 4. The large source regime is valid at short distances, and luminance is a light source property independent of viewing distance. If a light source has L_B < 10 000 W/(m^2·sr), it will have t_{max} > 100 s even at the shortest viewing distances. At longer distances, where it would pass from the large source to the small source regime, t_{max} can only increase and never decrease. An example for an idealized, but in all other ways unspecified light source is given in Annex B. Therefore, if a light source has an L_B value below 10 000 W/(m^2·sr) (i.e. when its luminance lies below the curve in Figure 4), it cannot be in RG2 no matter at what distance it is evaluated.

From the two statements marked in the paragraphs above ("…if the illuminance level at the viewer's eye position…" and "…if a light source has an L_B value below…"), it follows that whenever either of the two conditions is fulfilled, then a classification greater than RG1 is not possible. In order to give rise to a RG2 situation, both the luminance of the light source and the illuminance at the viewer's eye position have to be above a limiting value. In this case, the luminance of the light source is above the curve in Figure 4, and the illuminance at the viewer's position is above the curve in Figure 5. In all other situations, the risk group is RG1 maximum.

The reasoning as given above is not only valid for white light sources, but to all light sources that have their main emission in the 380 nm to 780 nm range. For white light sources in the CCT range as displayed, Figure 4 and Figure 5 can be used to obtain an estimate of the limiting values of luminance and illuminance.

For all other light sources with their main emission in the 380 nm to 780 nm range, the $K_{B,v}$ value can be calculated from a spectral measurement, and the limiting values for luminance and illuminance can be determined from that $K_{B,v}$ value.

NOTE RG3 for blue light hazard is highly unlikely for white light sources. RG3 is defined by IEC 62471 for t_{max} < 0,25 s. This occurs when the blue light level is a factor of 400 higher than at the RG2 lower limit. Along the same line of thinking as above for RG2, RG3 for blue light hazard at e.g. 6 000 K is only reached when the light source luminance is above 4 Gcd/m^2 and when the illuminance is above 400 000 lx. RG3 can still be reached for hazards other than the blue light hazard.

6 LED packages, LED modules, lamps and luminaires

In the lighting business, a hierarchy of products exists based on level of integration. Products on different integration levels are often produced by different manufacturers. There is a need to pass photobiological safety information down the chain, to avoid reassessment at each next level as much as possible. This is especially desired since each next level is generally associated with a steep increase in product diversity.

For all the lighting technologies that existed before the advent of LED technology, there are two levels: the lamp and the luminaire. The lamp is the primary light source, which is placed into a luminaire using an open industry standard for the mechanical and electrical interface. Luminaires are designed with a certain lamp type in mind, but since the interface standard is open, the end user of the luminaire has the possibility to replace this lamp by a lamp of another lamp type, as long as it conforms to the same interface standard.

For LED technology, the situation is more diverse. A chain of product levels exists, where there is a convention in the industry to number them in the following way.

– Level 0: the LED chip or die.
– Level 1: the LED package, allowing soldering and handling outside a clean room environment. For white LED packages, the phosphor material that converts the blue light of the chip into the other wavelengths that together produce white light is contained in the package.
– Level 2: basic LED module, consisting of one or more LED packages on a printed circuit board.

– Level 3: LED module with extended functionality, usually consisting of a level 2 board with additional features to allow mechanical mounting, electrical connection or an optical function. The actual additional features present depend on the type of product and may include some or all of the electronic control gear needed to operate the LED module.
– Level 4: the luminaire, the LED product as it is used in the application.

Not all levels exist for all products; some products may use a level 2 board that was made directly from level 0 chips ("chip on board"), and many level 4 products are directly based on a level 2 LED module without any additional level 3 LED module in between. It depends, next to technical considerations, on the industrial competences of the various players in the chain.

Usually, the lower level LED modules and LED packages in the level 4 product are not designed to be easily replaceable by the end user. Interfaces between the levels are rarely based on open industry standards.

LED replacement lamps present a special case. They are LED products, sold to the open market, designed to the open interface standards of the previously existing lamp technologies. They will be placed in the luminaire by the end user, as a replacement of the lamp that the luminaire was originally designed for.

An important point to notice is that product diversity sharply increases with each next level in the chain. It makes sense to perform the photobiological safety measurements at the lowest product level possible, and to hand on all relevant information along the chain in a way to be able to assess the risk group at the luminaire level or level 4, where it is needed, if possible without any additional measurement effort at this level, where diversity is huge.

Clause 7 details a recommended measurement information flow from one level to the next. It makes use of an optical law, which states that passive optical components can never increase radiance in any way whatsoever, generally known as the 'law of conservation of luminance'.

7 Measurement information flow

7.1 Basic flow

The considerations enabling the flow of information from one level to the next are based on

– the 'law of conservation of luminance';
– the findings as explained in Clause 5 of this Technical Report.

The 'law of conservation of luminance' states that if the luminance (or radiance) of the primary light source is known, this also gives the upper limit for the luminance (or radiance) of any product that contains this primary light source. It is actually a combination of two fundamental conservation laws: the conservation of flux and the conservation of etendue. Radiance, though usually described as intensity per surface area, can also be written as the quotient of flux and etendue. Increasing radiance would amount to either increasing flux or decreasing etendue, and both are forbidden by the basic conservation laws. While it is easy to explain why flux does not increase in a passive optical system, it is less easy to grasp why decreasing etendue is not possible. Nevertheless, the etendue conservation law is just as forbidding; when investigated more deeply, the underlying reasoning is similar to the 'second law of thermodynamics'.

When making use of the 'law of conservation of luminance', one shall take care to use only luminance/radiance values that are obtained as true luminance/radiance values.

Because of the 'law of conservation of luminance', the best starting point of the information flow is a radiance measurement. This radiance value can be handed on along the chain from primary light source to luminaire, without additional measurements required, provided the light source is operated in the luminaire under similar conditions as when tested as a component.

Only when optical measures are taken in the luminaire to reduce the radiance (such as a diffusing cover and/or operation at lower current), an additional measurement can be performed to verify the reduced radiance value. If this measurement is not performed, the original radiance value remains a worst case estimate which is always on the safe side.

If the radiance measurement on the primary light source gives an L_B value in the RG0 (0 W/(m^2·sr) to 100 W/(m^2·sr)) or RG1 (100 W/(m^2·sr) to 10 000 W/(m^2·sr)) region, this information can pass to all products based on this primary light source. They can never be in RG2, regardless of the type of optics (including beam shaping optics that produce directional light output) and regardless of viewing distance in the application.

If the radiance measurement on the primary light source gives an L_B value in the RG2 region (10 000 W/(m^2·sr) to 4 000 000 W/(m^2·sr)), there is a possibility that the final product will also be in the RG2 region, depending on the situation in the application. To find out if this is the case, the findings described in Clause 5 of this Technical Report can be applied. In the application, there will only be a RG2 situation when the illuminance at the viewing position is above a threshold value E_{thr}, which can be calculated using the RG1 upper limit for E_B (1 W/m^2) and the $K_{B,v}$ value. This value can be calculated using the spectrum acquired in the radiance measurement.

Note that, as discussed in 5.2 of this Technical Report, an estimate of E_{thr} can already be made if only the CCT of the primary light source is known, as shown by the curve in Figure 5.

Passive optical components, such as lenses and reflectors, will not change E_{thr}. If the radiance of the primary light source is above 10 000 W/(m^2·sr), the value of E_{thr} can be handed on along the chain, in order to determine the true risk group classification in the application.

Note that in this context, all components that substantially change the colour, such as dichroic reflectors, phosphor containing components, and therefore the spectrum, of the light source, are not considered to be passive. When the spectrum changes, the $K_{B,v}$ value changes, and therefore E_{thr} obtains a different value.

Summarizing the above, the radiance measurement of the primary light source can give three possible outcomes:

a) RG0 unlimited: the primary light source gives rise to maximum RG0 in all luminaires at all distances;
b) RG1 unlimited: the primary light source gives rise to maximum RG1 in all luminaires at all distances;
c) E_{thr} for RG2: the primary light source gives rise to RG2 at distances where the luminaire containing the light source produces an illuminance above E_{thr}, RG1 at distances where the luminaire containing the light source produces an illuminance below E_{thr}.

NOTE 1 RG3 situations for blue light hazard are extremely unlikely. Therefore they are not considered in this Technical Report.

If the third outcome is produced, the risk group classification depends on the use conditions. At the minimum distance where people are very likely to view the luminaire, is the illuminance above or below the E_{thr} value? This distance depends on the luminaire optics and can therefore not be transferred from primary light source to luminaire. It can be calculated when the peak of the angular light distribution from the luminaire optics is known, both in magnitude and direction. For many beam shaping optics, these light distributions are already known, as the distributions are needed for professional lighting design.

In order to find the maximum direction of the beam, i.e. direction of the maximum intensity, a goniophotometer should be used for the evaluation of the distribution of the intensities.

NOTE 2 For the calculation of the distance from the light distribution curve and the E_{thr} value, the following formula is applicable, see Figure 6:

$$E_{thr} = \frac{I \cdot \cos\alpha}{d^2} \tag{4}$$

where

I is the intensity of the source into the direction of the position where E_{thr} is evaluated;

d is the distance for the light source to this position;

α is the angle between the direction of the light and the normal of the plane in which E_{thr} is determined.

The plane on which E_{thr} is determined is perpendicular to the direction of the light and the cosine of the angle α equals 1. This represents the condition when the eye looks directly at the light source.

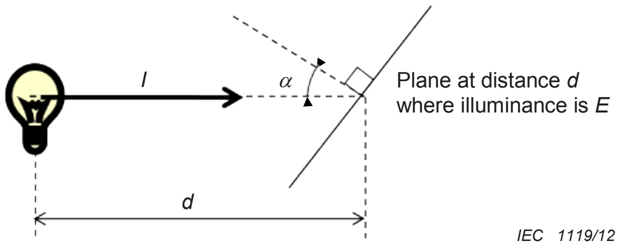


Figure 6 – Relation of illuminance *E*, distance *d* and intensity *I*

NOTE 3 In the case when a white light source is covered by a coloured filter, e.g. for safety lighting, the following approach can be followed if the effect of the coloured filter on $K_{B,v}$ is not known. One can take the white light source, determine the E_{thr} (if applicable) and then calculate the d_{thr}. When the source is now covered with a filter, the conservative approach is to keep the d_{thr} as in the uncovered situation. As this could lead to an over restrictive assessment, the alternative would be to measure the luminaire with the filter in place.

7.2 Conditions for the radiance measurement

For practical implementation of the measurement information flow described in 7.1, it shall be established what the standard measurement conditions are for the radiance measurement on the primary light source. These conditions shall at least specify a measurement distance and a field of view over which the radiance is averaged. In line with the existing practice as given in IEC 62471, 200 mm distance and 0,011 rad field of view gives a good starting point. These conditions give a true radiance value if the field of view underfills the emitting area of the source. As this corresponds to a diameter of only 2,2 mm, this is the case for many light sources.

As mentioned before, the result can be transferred only when the test conditions of the primary light source are identical to the test conditions for the luminaire. Since the manufacturer of the primary light source will in general not know the test conditions for the luminaire, at least the result for the worst case test conditions should be reported (e.g. for LED packages at the maximum rated current), leaving the possibility to additionally report the result for other specified test conditions (e.g. for LED packages at specified current levels below the maximum rated current).

NOTE The worst case field of view of 0,001 7 rad is proposed for the true radiance measurement. In the case of a homogeneous light source, there will be no difference between the 0,001 7 rad value and the 0,011 rad value. However, in the case of a light source with high luminance hot spots, the 0,001 7 rad measurement will produce a higher value. This value would only be relevant to risk group classification if the high luminance hot spot is enlarged by the luminaire optics to such an extent that it covers a field of view of 0,011 rad at the distance relevant for the application. This would only be the case for very narrow beam optics, without any faceting or segmenting to even out irregularities in the light source, viewed from a distance not much larger than 200 mm, and can be considered an unlikely scenario.

If the field of view of 0,011 rad overfills the light source even at a distance of 200 mm, the measurement does not give a true radiance value. In that case, two routes can be taken.

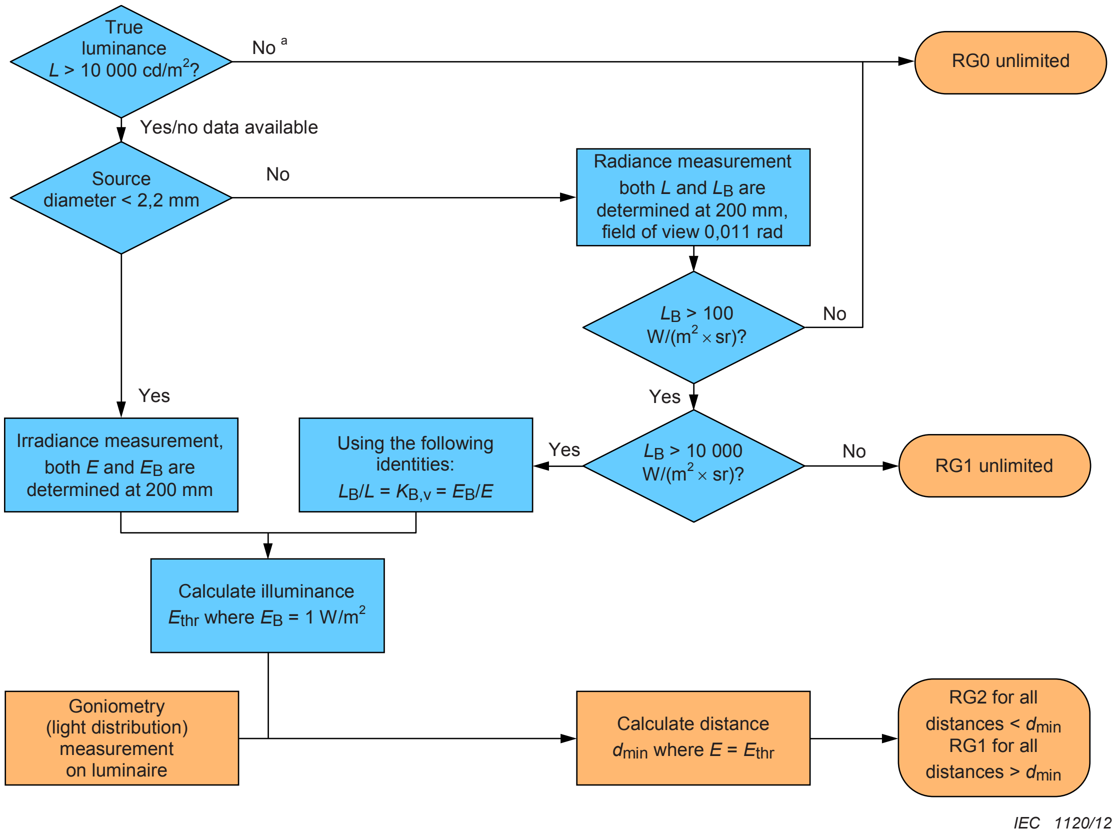
a) The field of view of the measurement can be reduced such that it underfills the light source. In that case, a radiance value L_B is determined, and one of the three outcomes given in 7.1 can be assigned to the light source.

b) The measurement is performed as an irradiance measurement. This gives the data to calculate E_{thr}. Since no radiance measurement is performed, worst case is assumed, and only outcome c) of 7.1 can be generated: the E_{thr} value for RG2.

Some light sources may generate so much light that it is technically impossible to produce the measurement at 200 mm, due to overheating or saturation of the measurement equipment. In these cases, the measurement distance can be increased to the lowest value where a measurement becomes possible. Again, it will have to be evaluated if the field of view overfills or underfills the light source. If it underfills the light source, the measurement will produce a true radiance value, as desired. If it overfills the light source, there is again the choice to either reduce the viewing angle, or to perform an irradiance measurement and assume worst case: outcome c) of 7.1, E_{thr} value for RG2.

Figure 7 shows the flow diagram that summarizes the required measurements and the information that needs to be handed down the chain from the primary light source, in order to make the right risk group classification of the luminaire in the application.

Measurements on the primary light source are always made at 200 mm and 0,011 rad field of view. In case RG0 is required for a certain application of the final product, a second measurement could be made on the final product at 200 mm and 0,1 rad field of view. In this case the result will not be “RG0 unlimited”, and the results of the assessment cannot be transferred to other products using the same source.



[a] The RG0 result following from the ≤ 10 000 cd/m² condition is only valid for white light sources.

Figure 7 – Flow chart from the primary light source (in blue) to the luminaire based on this light source (in amber)

The product safety standard applicable to the luminaire shall give guidelines as to what distance or at what illuminance level the risk group shall be evaluated. This is not relevant for all RG0 and RG1 unlimited primary light sources, but is needed in case of a primary light source with an E_{thr} value for RG2.

7.3 Special cases (I): Replacement by a lamp or LED module of another type

Subclause 7.3 gives a recommendation for the following case: when a lamp or LED module in a luminaire can be replaced by a lamp or LED module of another type, including LED replacement lamps, for which the luminaire was not designed.

The analysis detailed in 7.1 and 7.2 assumes that the luminaire manufacturer knows exactly what light source will be used in the luminaire. In practice, this is often only partly true. While the luminaire is obviously designed with a certain primary light source in mind, open industry standards generally make replacement with a lamp of another type possible.

It is recommended that the luminaire manufacturer assesses the luminaire risk group making use of the data for the worst case primary light source (lamp or LED module) that fits the interface standard. This will generally be the light source with the highest luminance (not necessarily the highest luminous flux output) and the highest CCT value.

7.4 Special cases (II): Arrays and clusters of primary light sources

Subclause 7.4 describes a case that is more common in LED lighting technology than in the other lighting technologies. Many LED modules consist of an array of individual LED packages. Because one does not, in general, know beforehand what the effects of the geometrical arrangement and/or luminaire optics will be on the average luminance of the array, it is advised to follow a conservative approach to produce a result that is valid for all applications. To be conservative, the luminance of the single LED package is taken as the average luminance of the entire array.

In general, one should then take the outcome of the measurement of a single LED package as a basis for the evaluation of the array of LED packages. This means that if the outcome of a single LED package is either RG0 unlimited or RG1 unlimited, this classification directly applies to the array as well.

In the case of an E_{thr} result, the E_{thr} of the LED package also directly applies to the array. In other words, the E_{thr} of the array is the same as for the LED package. The distance that corresponds to this E_{thr} is then determined using the peak intensity of the full array.

For a more detailed assessment, reference is made to Annex D. The assessment, making use of geometrical and optical parameters of the LED array, will never result in a higher risk group classification at a certain distance than the approach as outlined above but may, in some specific cases, lead to a shorter threshold distance for RG2.

8 Risk group classification

It is very important to note that, for the above to be implemented in a meaningful way, there shall be a clear distinction between the conditions for the measurement and the conditions under which the risk is evaluated and the risk group classification is made. While it is recommended that primary light sources are measured at short distance to perform a true radiance measurement, the risk group classification shall still depend on the actual use conditions. Since these may vary between different applications, it is recommended to define the evaluation conditions in the relevant product safety standard, whenever they are different from the evaluation conditions (500 lx for general lighting service products, 200 mm for other and unknown applications) as specified by the horizontal standard, IEC 62471.

Annex A
(informative)

Geometrical relations between radiance, irradiance and radiant intensity

The simplified geometrical situation as shown in Figure A.1 is considered. In the limit of small subtended angles (where the cosine of the subtended angle is approximately equal to 1) the following relations between optical and geometrical quantities are valid:

$$I = L \cdot A \tag{A.1}$$

where

I is the intensity of the light source in the direction considered;

L is the luminance of the light source;

A is the apparent area of the light source, which is the true area projected onto a plane perpendicular to the considered direction.

NOTE Here it is defined in terms of photometric quantities. The relations look exactly the same for corresponding radiometric and blue light hazard quantities.

This relation follows from the definition of luminance. It assumes a constant luminance over the surface area; if not, the formula can still be applied, but then L denotes the average luminance over the surface area.

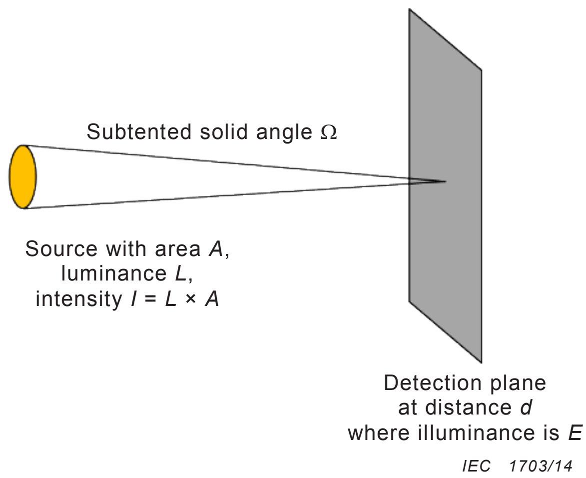


Figure A.1 – Schematic image of the situation considered in Annex A

$$\Omega = \frac{A}{d^2} \tag{A.2}$$

where

Ω is the subtended solid angle;

A is the apparent area of the light source as defined above;

d is the distance from light source to detection plane.

The formula follows from the basic definition of solid angle. In the exact definition, A is defined as the area on a sphere with radius d that intersects with the cone that describes Ω. When Ω is small, this area is nearly equal to the area of a plane that intersects with the cone that described Ω. Ω can be considered small when cos $\alpha \approx 1$, where α is the apex angle of the cone that encompasses Ω. For α = 0,011 rad, this is the case, since cos α = 0,999 94.

$$E = \frac{I}{d^2} \tag{A.3}$$

where

E is the illuminance in the detection plane;

I is the intensity in the direction from light source to detection plane;

d is the distance from light source to detection plane.

This is a well-known relation to lighting designers, valid in the case of one single source with a small solid angle.

Combining Formula (A.1) with Formula (A.3) gives:

$$E = \frac{L \cdot A}{d^2} \tag{A.4}$$

And then, combining Formula (A.4) with Formula (A.2) gives:

$$E = L \cdot \Omega \tag{A.5}$$

This relation means that, when the illuminance level is constant, there is an inverse proportional relation between luminance and solid angle. Larger solid angle means lower luminance, and vice versa.

Annex B
(informative)

Distance dependence of t_{max} for a certain light source

A general picture of what happens with t_{max} as a function of viewing distance can be achieved in the following way.

For a light source with blue light weighted radiance L_B and diameter D, the following expressions for t_{max} hold.

Large source regime: viewing distance d where the subtended angle is larger than 0,011 rad; this is the case when $d < D$ / 0,011. In this regime, t_{max} is determined by the L_B value through

$$t_{max} = \frac{10^6 \left[\mathrm{J/(m^2 sr)} \right]}{L_B [\mathrm{W/(m^2 sr)}]} \tag{B.1}$$

where

L_B is the blue light weighted radiance; and
t_{max} is, apart from the boundary condition $d < D$ / 0,011, independent of distance.

Small source regime: subtended angle is smaller than 0,011 rad, so t_{max} is determined by the E_B value, through

$$t_{max} = \frac{100 \left[\mathrm{J/m^2} \right]}{E_B [\mathrm{W/m^2}]} \tag{B.2}$$

where

E_B is the blue light weighted irradiance.

The E_B value can be calculated from the L_B value and from the apparent surface A of the light source, using Formula (A.4):

$$E_B = \frac{L_B \cdot A}{d^2} \tag{B.3}$$

where

E_B is the blue light weighted irradiance;

L_B is the blue light weighted radiance;

A is the apparent area of the light source; and

d is the viewing distance.

The result is that t_{max} has a quadratic dependence of viewing distance:

$$t_{max} = \frac{d^2 \cdot 100 \ \mathrm{s}}{A \cdot L_B / [\mathrm{W/(m^2 sr)}]} \tag{B.4}$$

When $d = D$ / 0,011, the two regimes meet; when calculated according to the large source definition, $t_{max} = 10^6$ s / (L_B/[W/(m$^2\cdot$sr)]) still holds (as it is independent of distance). When evaluated according to the small source definition, one substitutes $d = D$ / 0,011 and $A = \pi(D/2)^2 = (\pi/4)D^2$ (assuming a circular or spherical source) and obtains

$$t_{max} = \frac{(D/0{,}011)^2 \cdot 100\text{s}}{\pi/4 \cdot D^2 \cdot L_B/[\text{W}/(\text{m}^2\text{sr})]} = \frac{1{,}05 \cdot 10^6 \text{s}}{L_B/[\text{W}/(\text{m}^2\text{sr})]} \tag{B.5}$$

where

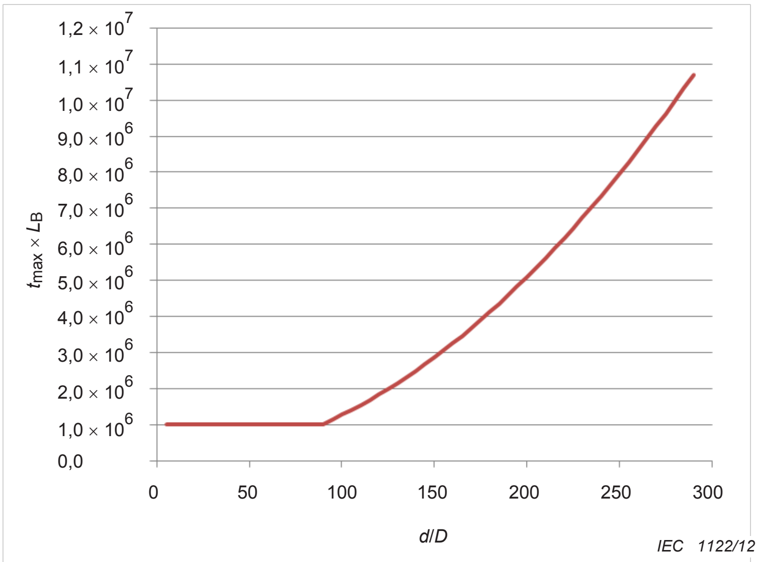
L_B is the blue light weighted radiance; and

D is the diameter of the light source.

The result deviates only a few per cent from the large source value at this distance. The exact deviation depends on the shape of the source.

From this point on towards longer distances, t_{max} will increase proportional to d^2. For the sake of the discussion, this implies that any light source will have its shortest t_{max} at short distances in the large source regime. At larger distances, in the small source regime, t_{max} will always be longer.

Figure B.1 shows the general behaviour of t_{max} as a function of distance, as given by the formulae derived above. In order to obtain a general curve, independent of L_B and D, the horizontal axis is scaled to D and the vertical axis is multiplied by L_B, to give $t_{max} \times L_B = 10^6$ for all light sources in the large source regime.



NOTE The tipping point from large source regime (flat line, no dependence of d) to small source regime (quadratic dependence of d) lies at $d = D/0{,}011 = 91D$.

Figure B.1 – General appearance of t_{max} as a function of viewing distance d, for any light source with homogeneous luminance L and diameter D

Annex C
(informative)

Summary of recommendations to assist the consistent application of IEC 62471 for the assessment of blue light hazard to light sources and luminaires

C.1 General

Annex C provides a summary of the recommendations of this Technical Report to assist the consistent application of IEC 62471 to light sources and luminaires for the assessment of blue light hazard. Clause C.2 describes the situations where risk group assessment can be made without detailed spectral measurements. For all other situations, Clauses C.3 to C.5 give guidance as to what measurements to perform and what information to pass on to determine the risk group classification.

C.2 Situation of RG0 or RG1 classification not requiring radiance or irradiance measurement

C.2.1 Boundary conditions

If, for white light only, the true luminance of the light source is less than 10 000 cd/m^2, it is classified RG0.

In addition, for white light only, the light source and any luminaire using the light source are considered RG0 or RG1, without further spectral assessment, where any one of the conditions given in C.2.2 and C.2.3 apply.

The values mentioned in Table C.1 (see Figure C.1) and Table C.2 (see Figure C.2) are intended as an upper limit where measurements are not necessary. When a light source or a luminaire has luminance or illuminance values below the mentioned values, one can predict that any measurement will always give at most RG1 unlimited as an answer; therefore one does not have to make the measurement. When a light source or a luminaire has luminance or illuminance values above these mentioned values, it may still be RG1 unlimited, but a measurement is required to prove this.

NOTE The mentioned luminance and illuminance values in Table C.1 and Table C.2 are based on an estimate of blue light hazard related to CCT, where a safety margin of a factor of 2 is included to account for the uncertainty in this estimation. The use of this safety factor of 2 is due to the use of photometric data instead of radiometric data.

C.2.2 True luminance values giving risk group not greater than RG1

If the true luminance of the light source complies with the following values for the given correlated colour temperatures (CCT) its classification will not be greater than RG1.

Table C.1 – Luminance values giving risk group not greater than RG1

Rated CCT K	Luminance *L* Mcd/m^2
CCT ≤ 2 350	40
2 350 < CCT ≤ 2 850	18,5
2 850 < CCT ≤ 3 250	14,5
3 250 < CCT ≤ 3 750	11
3 750 < CCT ≤ 4 500	8,5
4 500 < CCT ≤ 5 750	6,5
5 750 < CCT ≤ 8 000	5
The manufacturer's rated data for CCT and luminance may be used as a basis for this assessment.	

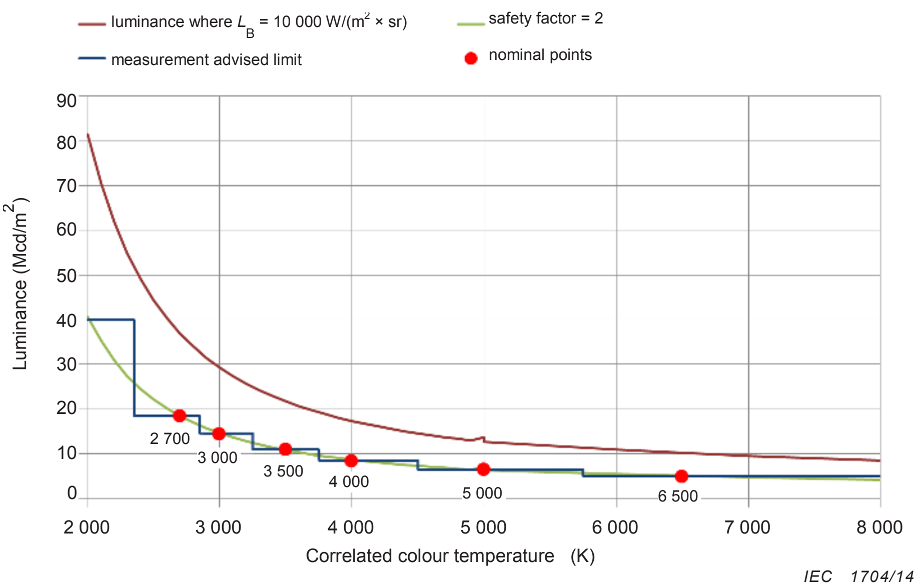


Figure C.1 – Luminance values from Table C.1 in relation to the RG1/RG2 border as function of correlated colour temperature

C.2.3 Illuminance values giving risk group not greater than RG1

If the true luminance of the light source does not comply with the values in C.2.2, but the illuminance from the luminaire in the direction of the maximum intensity, at the specified distance, complies with the following values for the given correlated colour temperatures (CCT), its classification will not be greater than RG1.

Table C.2 – Illuminance values giving risk group not greater than RG1

Rated CCT K	Illuminance *E* lx
CCT ≤ 2 350	4 000
2 350 < CCT ≤ 2 850	1 850
2 850 < CCT ≤ 3 250	1 450
3 250 < CCT ≤ 3 750	1 100
3 750 < CCT ≤ 4 500	850
4 500 < CCT ≤ 5 750	650
5 750 < CCT ≤ 8 000	500

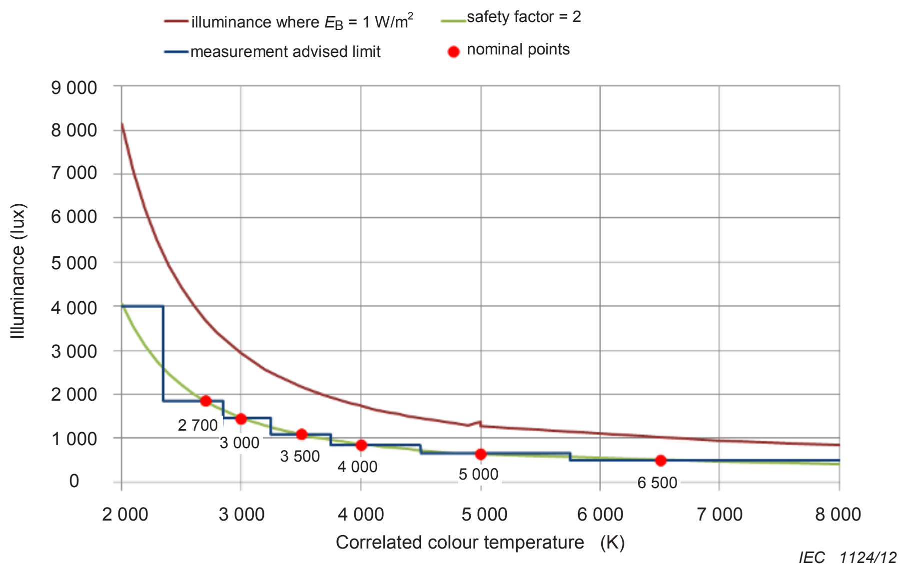


Figure C.2 – Illuminance values from Table C.2 in relation to the RG1/RG2 border as function of correlated colour temperature

C.3 Situation for the classification of light sources larger than 2,2 mm and luminaires using these light sources

For the situation of light sources with a diameter > 2,2 mm, the following should be applied.

a) The IEC 62471 radiance measurement is made at a distance of 200 mm with a field of view of 0,011 rad at current(s) as defined in 7.2.

b) If L_B < 100 W/(m²·sr), the light source is classified RG0.

c) If L_B < 10 000 W/(m²·sr) and > 100 W/(m²·sr), the light source is classified RG1.

d) Where L_B > 10 000 W/(m²·sr) the maximum illuminance E_{thr} appropriate to an RG1/RG2 border classification (E_B = 1 W/m²) should be calculated.

e) The light source manufacturer should provide information regarding the RG0, RG1, or E_{thr} classification of the light source as appropriate.

f) For luminaires using large light sources classified as RG0 or RG1, the RG classification of the source is directly transferrable to the luminaire, regardless of any optical systems that the luminaire may use.

g) For luminaires using large light sources classified with an E_{thr} value (RG1/RG2 border condition), a warning not to stare into the luminaire, or the distance from the luminaire that the blue light risk is attenuated to RG1, should be reported.

NOTE Updating of IEC 60598-1 to specify precisely the safety requirements for luminaires in this respect is expected.

C.4 Situation for the classification of light sources smaller than 2,2 mm and luminaires using these light sources

For the situation of small light sources with a diameter < 2,2 mm, the following should be applied: The measurement may be performed as detailed by either item a) or item b) of 7.2 to establish the RG0, RG1 rating or E_{thr} value of the light source.

C.5 Situation for the classification of light sources that pose practical difficulties in measurements at 200 mm

The measurement may be performed at the lowest distance value where it is practically possible to perform it. If, at this distance, and at a field of view of 0,011 rad, this light source is large (i.e. its subtended angle is larger than 0,011 rad), follow the procedure as outlined in Clause C.3. If, at this distance, and at a field of view of 0,011 rad, this light source is small (i.e. its subtended angle is smaller than 0,011 rad), follow the procedure as outlined in Clause C.4.

Annex D
(informative)

Detailed assessment of arrays and clusters of primary light sources, comprised of LED packages

D.1 General

This annex covers the assessment of arrays and clusters of primary light sources. It shows a step-by-step approach to come to a more detailed assessment of the blue light hazard of LED arrays or clusters. LED modules, LED luminaires and/or LED lamps are very often comprised of multiple LED packages. This annex gives a detailed evaluation for those products with a well-defined distribution of the individual LED packages, with or without a secondary optic. In those cases it can be verified by calculations and additional measurements that the conservative approach as detailed in 7.4 can be over restrictive. For the less defined cases the reader is still referred to the main text 7.4 where the conservative approach is explained.

D.2 Approach

D.2.1 Step by step assessment

The following step-by step approach may be considered for transferring data from the single LED package to the entire final array or cluster. Here the first 4 steps are in common for every type of array:

Applicability of the steps 1 to 6 is given in Table D.1.

Table D.1 – Applicability of steps 1 to 6

Case 1: LED package data[a] available	Case 2: LED package data[a] not available but can be measured	Case 3: LED package data[a] neither available nor measurable
Approach: Take the single LED package assessment and assess[b] the array.	Approach: Assess[b] the single LED package and then assess[b] the array.	Approach: Assess[b] the array as a whole.
Steps 1 to 5 apply. Step 6 is optional.	Steps 1 to 5 apply. Step 6 is optional.	Subclause 7.4 and steps 3 to 4 apply.

[a] The LED package data is the results of the photobiological assessment according to IEC TR 62778 for the single LED package.

[b] Assess means photobiological assessment according to IEC TR 62778.

Below the different steps are described in more detail.

- Step 1:
  - Take the assessment of the single LED package that is used to build up the array or cluster. The array or cluster cannot have a higher classification than its components.
  - If the LED package is RG0 unlimited then the array or cluster is RG0 unlimited.
  - The assessment can end here.
  - If the LED package is RG1 unlimited then the array or cluster is RG1 unlimited.
  - The assessment can end here.
  - If the LED package is assessed having an E_{thr}, then the array or cluster will need an additional analysis given in the next steps.

- Step 2:
  - Using the E_{thr} illuminance value of the single LED package, it is possible to determine the distance d_N where the entire array, considered with a full field of view, reaches this illuminance. The distance at which the array reaches the threshold illuminance is determined by the peak intensity of the full array and using the inverse square law.
  - The assessment for the single LED package is usually made without secondary optics. In case of arrays or clusters made of LED packages coupled with a secondary optic, d_N needs to be determined with the optics in place (resulting in a different light distribution than in the single LED package measurement). The illuminance value is found in the direction of the maximum intensity.
- Step 3:
  - At this distance d_N the average blue-weighted radiance of the full array can be calculated using the following formula: $L_{B,array} = (1\ W/m^2 \cdot d_N^2) / A_{array}$, where A_{array} is the smallest area that just includes all of the light emitting surface of the array. This formula is derived in Clause D.3.
- Step 4:
  - In case the average blue-weighted radiance is larger than 10 000 W/(m^2·sr), then the full array has a boundary condition at the distance d_N. In this case, the conservative approach as outlined in 7.4 is legitimate and not overrestrictive.

The assessment ends here

– When the array as a whole does not have an average blue-weighted radiance larger than 10 000 W/(m^2·sr), the threshold distance of the array for the boundary condition is shorter than d_N. In this case, the conservative approach can be considered to be overrestrictive and additional analysis and measurements can verify a shorter distance for the boundary condition. The array still has a threshold distance, because the single LED package from which it is built up has a threshold illuminance.

At this point, after step 4, the assessment is completed with the additional steps detailed in D.2.2.

D.2.2 Type of arrays and additional steps

Arrays can be built in different configurations and with or without secondary optic. Arrays provided with secondary optics are commonly used for directional light, searchlight, wall-wash application and/or when an illumination of a specific task is required. Figure D.1 shows some type of secondary lenses used for these kinds of applications.

IEC 1705/14

Figure D.1 – Examples of secondary lenses with identical light distribution and alignment

As shown in Figure D.1, the design of these kinds of lenses can be very diverse. Here only lenses that have a clear boundary for the single LED package are considered. When this is not the case, the assessment of the array is done considering the conservative approach explained in 7.4.

Other types of arrays are shown in Figure D.2. This type of array is commonly used for general lighting applications where several LED packages are placed together to get more luminous flux in a wider beam or used for linear light effect such as strip lights. In most cases this arrangement is used together with reflectors in order to direct the luminous flux of all the LED packages.

Figure D.2 – Examples of LED arrays with bare LED packages

The assessment for the evaluation of the blue light hazard for any kind of array starts with the procedure from step 1 to step 4 of D.2.1. When the second option of step 4 occurs, the manufacturer of the final product (i.e. LED lamp, LED module and/or luminaire manufacturer) has the possibility to go on with the analysis, so step 5 is presented. As optional, step 6 is presented too.

Step 5:

– Determine the distance d_1 where the E_{thr} of the single LED packages (with or without optic) occurs.
– At this distance d_1, evaluate if one or more LED elements are included in 11 mrad field of view.
– In case of only one LED element included, case a, then d_1 will be the distance at which the boundary condition for the whole array occurs. The assessment ends here and d_1 is reported as the threshold distance for the array, $d_1 = d_{\text{thr}}$
– In case of more than one LED element included, case b, then d_N will be the distance at which the boundary condition for the whole array occurs. The assessment ends here and d_N is reported as the threshold distance for the entire array, $d_N = d_{\text{thr}}$

Figure D.3 shows the difference between case a and case b. The condition for case b to occur is that in the 11 mrad field of view is present one complete element plus, at least, part of a second one.

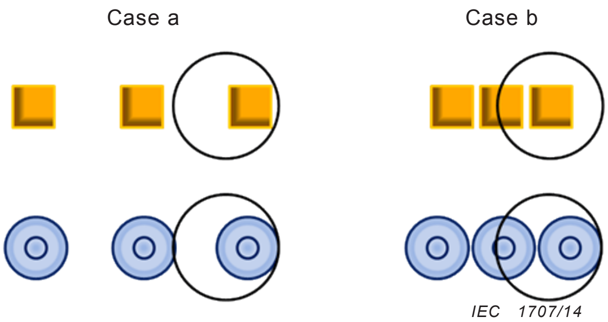


Figure D.3 – Evaluation whether one or more LED elements fall in 11 mrad field of view at distance d_1

Step 6 (optional):

- If case b occurs, it is possible to perform a measurement of the photobiological assessment of the array using an 11 mrad field of view at the distance d_1.
- If the blue-weighted radiance, measured at the distance d_1, does not exceed 10 000 W/(m^2·sr), then the boundary condition of the whole array will occur at the distance d_1, $d_1 = d_{thr}$
- If the blue-weighted radiance, measured at the distance d_1, does exceed 10 000 W/m^2·sr, then the boundary condition of the whole array will still occur at the distance d_N, $d_N = d_{thr}$

For arrays built up with bare LED packages with a diffuser screen on top, steps 1 to 4 are considered to be exhaustive for the assessment of the evaluation of the blue light hazard.

For arrays built up with optics different than those mentioned above, steps from 1 to 4 are considered to be exhaustive and the threshold distance is considered to be d_N. Furthermore a relation between the distance d_N and the installation distance can be found considering the light distribution of the final product.

D.2.3 Complete flowchart

Figure D.4 shows schematically the steps described in D.2.1 and D.2.2 to do the detailed assessment of the photobiological hazard of an array of LEDs.

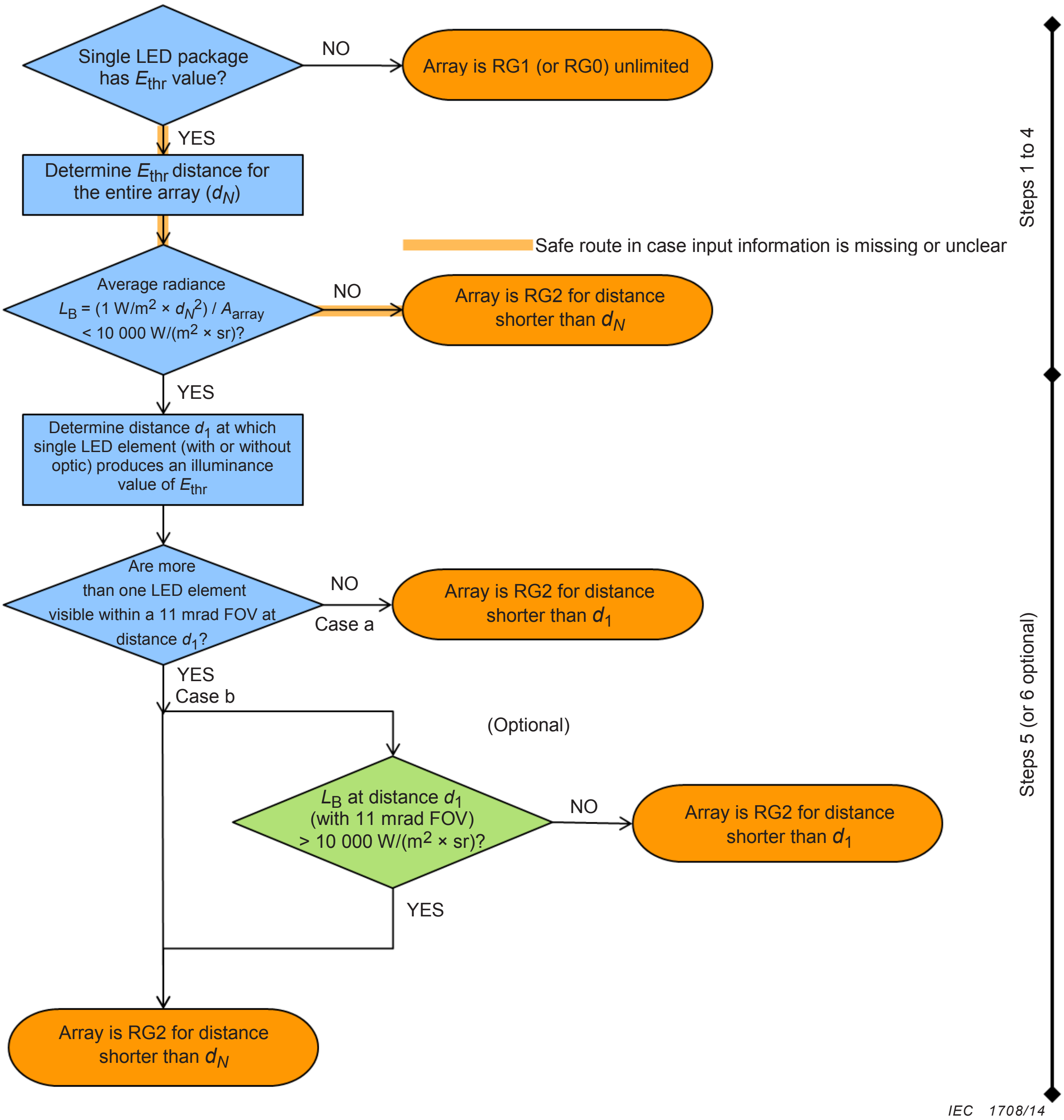


Figure D.4 – Complete flowchart of the detailed assessment of arrays and clusters of primary light sources

D.3 Derivation of the formula for average radiance of the full array

This clause gives the derivation for the formula that is used in the flowchart to assess the average blue-weighted radiance of the full array.

With Formula (A.4), the average blue-weighted radiance within the 11 mrad field-of-view is found:

$$E = L \cdot \Omega \Rightarrow E_B = L_{B,array} \cdot \Omega_{array} \quad \text{(D.1)}$$

Because of the fact that we are evaluating at distance d_N the irradiance E_B is equal to 1 W/m^2. In that case Formula (D.1) can be rewritten to:

$$1 = L_{\mathrm{B,array}} \cdot \Omega_{\mathrm{array}} \tag{D.2}$$

From this formula it can be deduced that only arrays that have an average radiance of $>$ 10 000 W/(m^2·sr) will have a solid angle of $<$ 10^{-4}sr; 10^{-4}sr being the solid angle that corresponds to a cone that has an 11 mrad top angle.

Meaning that if an array has an average radiance larger or equal to 10 000 W/(m^2·sr), it has, at a distance d_N, a subtended solid angle that is smaller or equal to the one corresponding to 11 mrad. And as such d_N qualifies for being the threshold distance for the full array.

If the average radiance is lower than 10 000 W/(m^2·sr), the full array does not have a threshold distance and the appropriate distance is closer to the array, where a single element will produce the necessary irradiance and radiance.

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