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TECHNICAL REPORT

RAPPORT TECHNIQUE

colour inside

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

Application de la CEI 62471 aux sources de lumière et aux luminaires pour l'évaluation du risque lié à la lumière bleue

IEC/TR 62778:2012

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

FOREWORD

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

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

Enquiry draft	Report on voting
34A/1541/DTR	34A/1566/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- withdrawn,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.

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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 60050-845:1987, *International Electrotechnical Vocabulary – Part 845: Lighting*

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 and CIE S 017/E:2011 as well as the following apply.

NOTE Other terms and definitions related to lamps, LED modules and luminaires are to be found in the relevant standards.

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: The 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: The correlated colour temperature is expressed in 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 $d\Phi$ incident on an element of the surface containing the point, by the area dA of that element

Note 1 to entry: The illuminance is expressed in lm/m^2 = lx.

[SOURCE: IEC 60050-845:1987, 845-01-38]

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: The 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 t_{max} < 100 s, regardless of the light source's L_B value

Note 1 to entry: It can be calculated by taking the E_B value for t_{max} = 100 s, which is E_B = 1 W/m², and dividing it by the $K_{B,v}$ value corresponding to the spectrum of the light source.

Note 2 to entry: The threshold illuminance is expressed in $lm/m^2 = lx$.

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, unit: m^2sr. 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: The etendue is expressed in m^2sr.

3.8
irradiance (at a point of a surface)
$\boldsymbol{E_e}$
quotient of the radiant flux $d\Phi_e$ incident on an element of the surface containing the point, by the area dA of that element

Note 1 to entry: The 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 document, 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: Note 2 and Note 3 introduced.]

3.9
luminance (in a given direction, at a given point of a real or imaginary surface)
$\boldsymbol{L}$
quantity defined by the formula

$$L = \frac{d\Phi}{dA \cdot \cos\theta \cdot d\Omega}$$

where $d\Phi$ is the luminous 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: The illuminance (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 notes of 845-01-34 are not referred to.]

3.10
blue light weighted radiance
$\boldsymbol{L_B}$
radiance spectrally weighted with the blue light spectral weighting function as defined in IEC 62471

Note 1 to entry: The blue light weighted radiance is expressed in $W/(m^2 \cdot sr)$.

3.11
light source
any product that produces light, be it e.g. an LED package, an LED module, a lamp, or a 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]

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 document, it may refer to an LED package, an LED module, or a lamp.

[SOURCE: IEC 60050-845:1987, 845-07-01]

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: The 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 1 to 5 have been dropped, new notes 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

3.18
true luminance
luminance value as obtained by integrating the equation as given in the definition of luminance according to IEC 60050-845, definition 845-01-35, 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 according to IEC 60050-845, definition 845-01-34, 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: A LED package is a discrete component and part of the LED module. For a schematic build-up of a LED package, see Annex A of IEC/TS 62504[1].

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 to 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

1 In preparation.

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, Subclause 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, Clause 6 states the standard conditions where photobiological safety must 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.

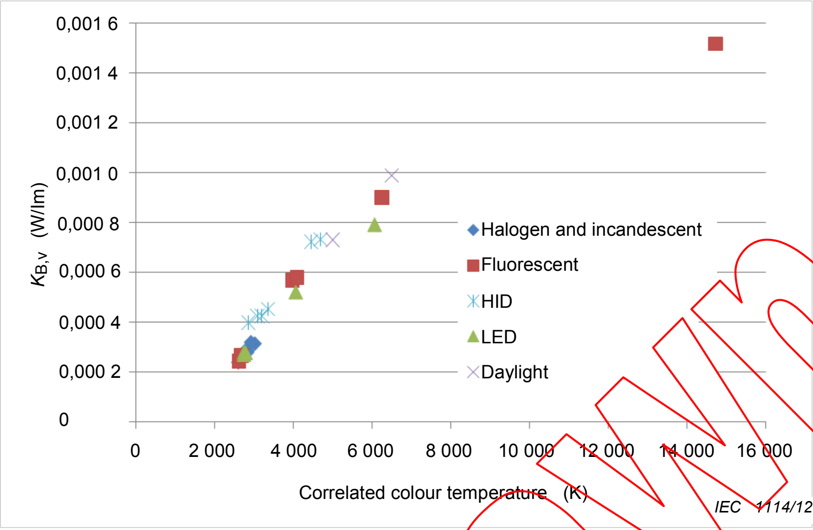
It is important to note that there is a close relationship between these blue light weighted quantities and two corresponding photometric quantities with which many lighting designers and lighting product engineers are familiar with. The blue light weighted radiance L_B is closely related to the luminance 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 a large overlap with the CIE 1931 *Z* curve. These are two of the curves used to determine the colour point (x, y) of a certain spectrum. From the definition of the CIE 1931 x, y coordinates through

$$x = \frac{X}{X+Y+Z} \tag{1}$$

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 $K_{B,v}$.