Photobiological Safety of Luminaires: Refining the new approach

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Abstract

Driven by the desire to circumvent issues encountered in applying IEC/EN 62471, and to reduce the measurement burden of luminaire manufacturers, a new approach to the evaluation of the photobiological safety of luminaires is now in place.

According to the latest edition of the luminaire standard, IEC/EN 60598-1, implementing IEC TR 62778, assessment should be made to determine whether or not the luminaire under test exceeds the limits of IEC/ EN 62471 blue light hazard risk group 1 (RG1) at a distance of 200mm. Where this limit is exceeded, the RG1 hazard distance should be determined and reported on marking on the luminaire.

It will be seen, however, that hazard distance is rarely readily calculable for extended sources, the assumptions made leading in many cases to an over-estimation of hazard distance which may have a negative impact on product marketing and the perception of hazard associated with luminaires. In this paper a refined measurement-based approach will be proposed, with the hope that this will serve as a framework to dispel the interpretations and uncertainties that has plagued luminaire photobiological safety testing hitherto.

1. Introduction

In the last ten years since the publication of IEC 62471: 2006 “Photobiological Safety of Lamps and Lamp Systems” [1], and its European counterpart, EN 62471 [2] harmonised a few years later to the low voltage directive 2006/95/EC [3], the discussion of optical radiation hazard has moved from being the preserve of laser or specialist UV lamp manufacturers to be a common discussion point in the lighting industry and many others.

In IEC/EN 62471, the photobiological safety of lamps and luminaires intended for general lighting service (GLS) applications is evaluated by implementing the general lighting service (GLS) classification criterion, namely by reporting at a distance at which the source produces an illuminance of 500 lux, not less than 200mm. Over the years, a number of issues in implementing this appproach were encountered, including differences in interpretation over which luminaires should be considered in the GLS category and questions of the value of a GLS evaluation which may not represent a realistic exposure scenario nor provide information since for the majority of GLS sources, the result is “Exempt”. This led to the formation of a photobiological safety panel (now WG6) within IEC sub-committee SC34A and the introduction of a new approach, the most recent publication of which is IEC/TR 62778 Edition 2: “Application of IEC 62471 for the assessment of blue light hazard to light sources and luminaires” [4], and the amendment of a range of lamp and luminaire standards, published and updated under the Low Voltage Directive. For completeness, it should be noted that the hitherto absent rationale for the assessment of GLS sources at 500 lux, including consideration of time-weighted average, has recently been published [5].

2. Photobiological Safety Concerns of Lighting Products

Whilst IEC /EN 62471 gives consideration to six hazards to the skin and eye over the range 200-3000nm (table 1), the optical radiation emitted by GLS products may not cover the entire spectral range, nor be of a level to present cause for concern. A consideration of photobiological safety depends therefore on lamp type, and is treated by technology-specific standards.

Hazard	Wavelength Range (nm)	Principle Bioeffects	
		Skin	Eye
Actinic UV †	200-400	Erythema Elastosis	Photokeratitis Cataractogenesis
Near UV	315-400	-	Cataractogenesis
Retinal Blue Light†	300-700	-	Photoretinitis
Retinal Thermal†	380-1400	-	Retinal burn
Infrared Radiation	780-3000	-	Corneal burn Cataractogenesis
Thermal	380-3000	Skin burn	-

Table 1: Six acute photobiological hazards posed to the skin and eyes considered by IEC / EN 62471 († denotes the use of a hazard weighting function)

Whilst the actinic UV hazard has been considered in certain such standards, and in guidance on the provision of luminaire protective shields, the retinal blue light hazard has not been previously addressed: it is on this aspect that IEC TR 62778 has focussed. The IR hazard will be dealt with by marking only.

Retinal blue light hazard is the name given to acute (type II) photochemically induced retinal damage caused by absorption of light by the retinal pigmented epithelium and the choroid, with peak sensitivity around 440nm for the phakic eye, hence the “blue” appelation [6]. The spectral dependence is accounted for by the blue light hazard weighting function.

Blue light hazard is evaluated by taking account of the weighted irradiance produced on the retina due to viewing a source, including a time dependent function of the angular subtense of the area of the retina irradiated as a function of exposure time from the 0.25s aversion response (1.7mrad) to 10000s (100mrad). This function is in turn linked to the classification system of IEC/EN 62471. The measurement of spectral radiance should be performed over a field of view (FOV) equal to the angle subtended by the area of the retina irradiated, for a given exposure time. Where the FOV is greater than the angle subtended by the source, the result is an average of the true source radiance and the dark background. It is for this reason that the measured quantity is more accurately termed spatially averaged radiance as opposed to the “true” radiance typically encountered in spectroradiometry, for which the FOV must not extend beyond the emitting area of the source.

3. IEC TR 62778

3.1. Overview

IEC TR 62778 has been written to provide guidance in the assessment of the retinal blue light hazard of all lighting products, emitting principally in the visible region, 380–780 nm, and on the transfer of data from LED/lamp to finished products. Only the latter case will be considered here.

Using IEC/EN 62471 as a basis, assessment is made to determine whether or not the luminaire under test exceeds the limits of risk group 1 (RG1) at a distance of 200mm. A source classified as RG1 is one which does not pose a hazard due to normal behavioural limitations on exposure, including aversion response and not actively staring at the source. Whilst the probability of ocular exposure at such close quarters as 200mm to a luminaire may be low, it does depend on the type and location of luminaire, and the person considered, service engineer, consumer, child etc. In the case of a luminaire exceeding the RG1 limit, the threshold illuminance, E_{thr}, and the corresponding distance, d_{thr}, from the source at which RG1 is expected to be found, should be determined.

Emission Limit	Assessment Result	Definition
100 $W.m^{-2}.sr^{-1}$	RG0	Does not exceed limit of the blue light hazard exempt risk group
10 000 $W.m^{-2}.sr^{-1}$	RG1	Does not exceed limit of the blue light hazard risk group one
-	d_{thr}	Distance from luminaire at which E_{thr} found

Table 2: Possible IEC TR 62778 assessment results of luminaires

Now, this ostensibly simple measurement procedure belies the difficulties in performing these measurements due to the biophysically significant geometrical measurement conditions required, namely a measurement field of view of 11mrad (0.63 degrees). In the initial assessment, the measurement at 200mm will encompass a circular area of 2.2mm diameter, no matter how large the luminaire to be measured. This presents a moderate challenge to the radiometrist, one with which he/she will be familiar given the history of measurements IEC/EN 62471. A new set of challenges has been presented, however in the determination of d_{thr} of extended sources, the case of almost all luminaires, as will be considered below.

3.2. Computation of E_{thr}

The threshold illuminance, E_{thr}, at which RG1 is found, may be computed by considering the irradiance-based emission limit for this RG1 measurement in an 11mrad FOV. From the blue light hazard RG1 emission limit radiance (10000 $W.m^{-2}.sr^{-1}$) and the solid angle corresponding to an 11mrad FOV($9.50332.10^{-5}$ sr), one obtains the blue light irradiance emission limit of $1W.m^{-2}$.

Since the ratio of blue light radiance ($W.m^{-2}.sr^{-1}$) to luminance ($cd.m^{-2}$) will be equal to the ratio of the blue light irradiance emission limit (1 $W.m^{-2}$) to the illuminance at which this threshold is obtained, E_{thr} (lux) can be easily obtained.

3.3. Determination of d_{thr}

In the case of luminaires in excess of the limit of RG1, the distance from the luminaire, d_{thr}, at which the threshold illuminance, E_{thr}, is to be found, should be determined and reported on marking on the luminaire.

The recommended method to determine d_{thr} is to use goniophotometric data of the product under test, where available. Knowledge of the maximum luminous intensity, I_{max} (cd), and the inverse square law allows calcualtion from $d_{thr} = \sqrt{(I_{max} / E_{thr})}$. This procedure ignores the fact that for many sources, the inverse square law will not be applicable, particularly for directional sources. In the absence of such data the location of E_{thr} can be found directly using an illuminance meter.

4. The Case of extended sources

4.1. Over-estimation of d_{thr}

In the determination of the threshold distance, the use of goniophotometric data or a direct illiminance meter measurement encompasses light from the entire luminaire. Where the source subtends an angle greater than 11mrad at d_{thr}, too large an area of the source was included in the determination and this value of d_{thr} can be said to be overly conservative. To what extent d_{thr} is over-estimated depends on the size and the directionality of the luminaire under test, a factor of ten (and more!) has been seen. Over reporting is the correct way to err in a safety assessment, but the impact of an over-estimated d_{thr} on the marketing of a product may prove problematic, and may have a negative impact on the perception of hazard associated with luminaires.

4.2. IEC TR 62778 Approach

In the 2014 edition of IEC TR 62778, guidance is provided in annex D to address the case where a source subtends >11mrad at the initial estimate of d_{thr}, here labelled d_N for clarity. Having determined d_N, one should evaluate whether or not the luminous area of the source extends beyond the circular area described by an 11mrad FOV at d_N, of diameter $0.011.d_N$. Where the source falls entirely with this area, then $d_N = d_{thr}$, otherwise (as is the case in figure 1, upper) d_N is overly conservative and can be refined using the following process.

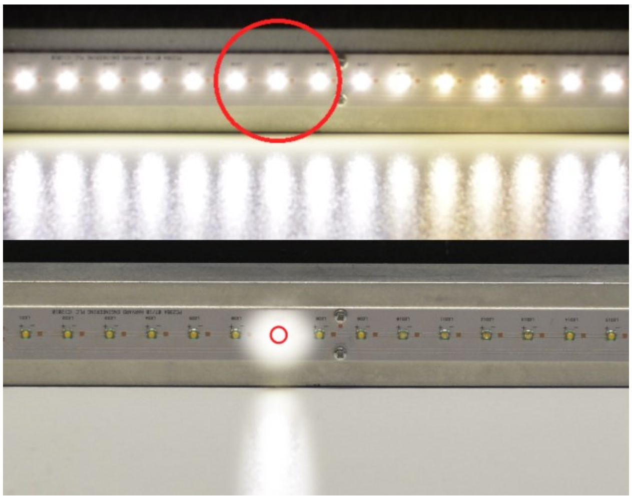

Figure 1: (Upper) Source extending beyond 11mrad FOV at d_N: over-estimation of threshold distance. A refined, but not practically realisable assesement show that at d_1 (lower), only one emitter falls in 11mrad FOV. $d_1 = d_{thr}$.

The distance, d_1, at which the E_{thr} of a single LED package occurs, should be determined then the area described by an 11mrad FOV at d_1 of diameter $0.011.d_1$ should then be considered. If only one emitter falls within this area as is the case in figure 4 (lower) then $d_1 = d_{thr}$. Where more than one emitter falls within this area, and where E_{thr} was taken from the LED emitter datasheet, as opposed to resulting from the measurement of the luminaire, it does not necessarily follow that RG1 be exceeded at this distance. It is in this case recommended to perform a spectral radiance measurement at d_1 in an 11mrad FOV, if the result is below the RG1 limit, d_1=d_{thr}. In all other cases the true value of d_{thr} lies between these extremes, so the default position is to adopt the worst case, d_N =d_{thr}.

The refinement of d_{thr} in this manner is in the majority of cases not practically feasible (how does one turn off or block emission from all but one emitter in a luminaire?) and therefore can be considered largely redundant.

4.3. Consideration of hazard Distance

In determining hazard distance, the variation of blue light radiance with distance should be determined, and yet this parameter is not easy to predict since it includes two components: spatial averaging over the 11mrad FOV and the irradiance at the plane of the pupil.

As demonstrated in figure 2, spatial averaging over 11mrad is strongly dependent on the size of the emitter, spacing and the shape of the luminous area of the source with respect to the circular FOV, whilst the irradiance at the pupil plane depends on the emission characteristics of the source, reducing more quickly with distance for Lambertian sources compared to very narrow beam sources for example.

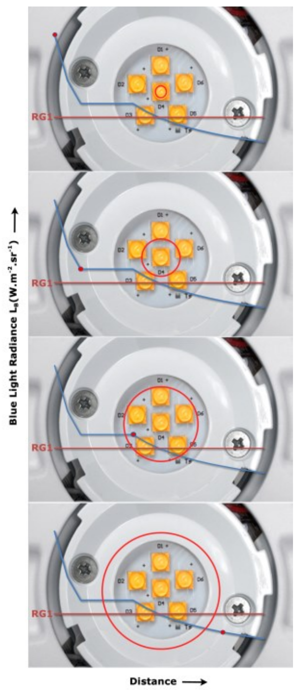

Figure 2: Example of the variation of blue light radiance in 11mrad with distance, the average radiance over the FOV reducing below the RG1 limit only where the source falls entirely within the FOV

4.4. Proposed Approach

Having determined d_{thr}, one should evaluate whether or not the luminous area of the source extends beyond the circular area described by an 11mrad FOV at d_{thr}, of diameter $0.011.d_{thr}$.

Where the source falls entirely within this area, then the determined value of d_{thr} is correct and should be reported. It is expected that for the majority of directional sources, the correspondingly great value of d_{thr} will be one at which the luminaire subtends less than 11mrad, and d_{thr} thereby confirmed.

Where the luminous area of the source extends beyond the circular area of diameter $0.011.d_{thr}$, further refinement is required. Given that peak blue light radiance of today's high power white LEDs rarely exceed 40 000 $W.m^{-2}.sr^{-1}$, one can determine that a spatial averaging of factor four is required to reach the RG1 limit. Adding to this the small size and typical spacing of LED emitters, it can be determined that spatially averaged radiance will quickly decrease with distance, in most cases reaching the RG1 limit with a single emitter in view. It is expected that in the case of omni-directional sources, d_{thr} be no greater than 500mm. It is therefore proposed to perform additional measurements at 300, 400 and 500mm and to report the minimum distance at which L_B<10 000 $W.m^{-2}.sr^{-1}$.

5. Conclusions

The implementation of IEC TR 62778 and the new approach to the evaluation of the photobiological safety of sources intended for lighting applications will in many instances lead to a simpler assessment. In others, where a refinement of d_{thr} is sought, additional interpretation will be required, and yet interpretation in standardisation can be problematic. A simple measurement based approach has been presented, the adoption of which may serve as a framework to determine realistic hazard distances and to dispel the interpretations and uncertainties that has plagued luminaire photobiological safety testing hitherto.

6. References

[1] IEC, IEC 62471 Photobiological Safety of Lamp and Lamp Systems. IEC, Geneva (2006)
[2] CENELEC, EN 62471 Photobiological Safety of Lamp and Lamp Systems. CENELEC, Brussels (2008)
[3] European Union, Directive 2006/25/EC- Artificial optical radiation. Off. J. Eur. Union, Brussels (2006)
[4] IEC, IEC TR 62778: Edition 2 Application of IEC 62471 for the assessment of blue light hazard to light sources and luminaires. IEC, Geneva (2014)
[5] D. Sliney et al., Photobiological Risk Classification of Lamps and Lamp Systems- History and Rationale, Leukos, 00:1-22, 2016
[6] ICNIRP, ICNIRP Guidelines on limits of exposure to incoherent visible and infrared radiation, Health Phys. 105-1 (2013)