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Testing Standard on Optical Hazards of LED Luminaries on Human Beings for India – A Review

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Abstract

The light sources of high power delivering high intensity is deemed to be harmful to the human skin and eye due to the components of the light exposure containing wavelengths in the ultraviolet (UV), Blue light (400-500 nm) and infrared (IR) regions of visible spectrum. Most of the LEDs contain blue light with peak wavelength of 455 nm which causes various hazards to the retina and skin which varies with the duration of exposure. This introductory paper provides an overall review of IS 16108 series of standards which provides the test procedures for evaluating the optical hazards of LED luminaries. Specifically, the standard defines exposure limits, references measurement techniques and the classification scheme for the evaluation and control of photobiological hazards from all electrically powered incoherent broadband sources of optical radiation, including LEDs (but excluding lasers), in the wavelength range from 200 nm through 3000 nm.

Keywords: Blue Light Hazard, Light-Emitting Diode (LED), Photobiological Safety, Risk Groups

1. Introduction

After half a century ago, the conventional lamps like incandescent lamps, fluorescent lamps, etc. were invented and the transition to Light Emitting Diodes (LEDs) lead to sudden replacement of the conventional lamps to LEDs across all sectors. The adoption of LEDs was initially with small power capacity of less than 25W (covering homes, offices, small scale shops, etc. This lead to adoption of high power LEDs of capacity greater than 100W up to 1000W. Due to large usage of LEDs, the question of their photobiological safety arises in regard to an occupational and living health and safety to humans. First international standard for evaluating the photobiological effects of lamps and luminaries was released in the year 2006 naming it IEC 62471:2006 wherein the related committee was formed in the early 2000 along with organization called International Commission on Non-Ionizing Radiation Protection (ICNIRP). This standard provides the directives and test procedures in carrying out the risk assessment. These concerns often centre on radiation emissions in the UV and blue parts of the LED spectrum. Basics of photobiological safety of optical radiation are included in IS 14624 Part 2: 2012 standard and IEC 60825 series of standards. These standards deal with theme of laser safety. They evaluated lasers according to their emitted spectrum wavelengths and output optical power. Light source for general lighting cannot be evaluated according these standards, because they have incoherent light. For these sources the recommended criterias are provided in Indian standard IEC 62471:2006/ IS 16108: 2012 deals with theme of photobiological safety of light sources for general use and other sources with incoherent light[1].

Various other research work has been carried out for LED lamps and luminaries on the aspects of power quality issues (like harmonics, surge protection and flicker characteristics), photometric performance (like lumen output, efficacy, colour rendering index, correlated colour temperature), thermal characteristics, etc. It is proved that low power warm white LED bulbs are better than cool white LED bulbs in terms of power quality issues and thermal behavior[2,3]. In general the harmonics (current THD) of LEDs lie in the range from 9.5% to 127.5% which is high and needs to be reduced but the impact to the power system will be minor as the current of LEDs are in few milli-amperes to amperes (less than 5 A)[4]. Flicker is associated with driver circuit of LED and it is an

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effect of LED current consumption on the source voltage. With regard to low power LED bulbs, it is observed that cool white shows more flicker than warm white LEDs by 50% which can be reduced by designing the drivers such that probability of short term (Pst) and probability of long term (Plt) values or indices are made equal[5]. With most of the LED streetlights replacing the conventional lamps across the roads, industries, airports, etc., the importance of surge immunity for these street lights are increasing. Choosing proper Surge Protection Devices (SPD) while designing the LED controller is necessary[6]. IS 16108: 2012 standard (Indian standard issued by Bureau of Indian Standards (BIS)) for photobiological safety of lamps and lamps systems deals with the photobiological safety of optical radiation emitted by non-laser sources like LEDs and its toxic effects on human beings especially on skin and eye. This standard provides the knowledge to evaluate the light sources and light systems with regard to their effects on living tissue. It specifies the limits of radiation exposure, the reference methods of measurement and measuring techniques for full-spectrum light sources used in the light technique. This standard works with a range of wavelengths covering from 200 nm to 3000 nm.

This standard details the importance of photobiological effects and the test procedures to evaluate the various type of hazards like actinic UV hazard for skin and eye, near-UV hazard for the eye, retinal blue light hazard, retinal thermal hazard, infrared radiation hazard for the eye and thermal hazard for skin. The hazards are measured in terms of irradiance and radiance values and the distance of measurement is either at 200 mm or 500 lux from the light source[7]. A second method measures photobiological safety from a distance of 200 millimetres. The 200 millimetres (mm) criterion is to be used for all other lamps (including for example lamps for such professional uses as film projection, reprographic processes, sun tanning, industrial processes, medical treatment and searchlight applications). It is important to make such distinctions based on the application. One does not look into a ceiling luminaire in the office from a distance of 200 millimetres, but possibly in certain industrial applications workers might be required to look into light sources from a short 200mm distance – for example during quality control processes. In such occupational cases special instructions might be needed to prevent eye damage. After proper evaluation by either method, a light source is given a Risk Group (RG) classification, which indicates whether the source presents a potential exposure risk and, if so, what labelling requirements should be undertaken to alert the user. Typical common general illumination sources pose no risk. When these sources are used in fixtures or luminaires, the fixture or luminaire would also typically pose no risk. RG classification of the source or luminaire is addressed as follows: 1. a luminaire employing a light source classified RG0 or RG1 requires no warning or caution 2. If a luminaire uses a light source from a higher risk group (RG2 or RG3), product information must indicate the mentioned RG class and include suitable warnings or cautions. In this manner, the end use product is suitably labelled if a potential risk exists.

The required measurement methods and the calculation methodology are set in the harmonized standard IS 16108: 2012 "Photobiological safety of lamps and lamp systems". The standard divides the sources of incoherent optical radiation (such as incandescent and fluorescent lamps, LEDs, etc.) into four groups: in the Exempt Group (no photobiological risk) and the Risk Groups 1 to 3 with increasing hazard potential. Table 1 shows the list of standards applicable for testing and evaluating the photobiological effects of LED luminaries on human beings[9–11]. This paper is about review of available Indian standards for evaluating photobiological safety of LED lamps and luminaries.

Table 1. Indian standards for evaluating photobiological effects of LED lamps and lamp systems

Indian Standard	Equivalent IEC standard	Description
IS 16108: 2012	IEC 62471:2006	Photobiological safety of lamps and lamp systems
IS 16108: Part 2: 2018	IEC 62471-2	Photobiological safety of lamps and lamp systems: Part 2 guidance on manufacturing requirements relating to non - Laser optical radiation safety
IS 16108: Part 3: 2018	IEC 62471-3	Photobiological safety of lamps and lamp systems: Part 3 guidelines for the safe use of intense pulsed light source equipment on humans
IS 16661: 2019	IEC 62778	Application of IS 16108/ IEC 62471 for the assessment of blue light hazard to light sources and luminaires
IS 14624: Part 2: 2012	IEC 60825-2	Safety of laser products: Part 2 safety of optical fibre communication systems (OFCS) (First Revision)

2. Evaluation of Photobiological Effects

The photochemical blue light hazard can be evaluated on the basis of several global standards that are based on the same accepted science but that may differ in title in various countries and regions. In Europe and other IEC oriented countries, IEC/EN 62471 is used and required under the European safety directives. In the US the same basic requirements are found in IESNA RP27 series of standards. Other regions may reference CIE S009 as published by the International Commission on Illumination. The IEC and IESNA standards classify light sources into risk groups 0, 1, 2 and 3 (from 0 = no risk through to 3 = high risk) and provide for cautions and warnings for consumers if needed. (The sun would be classified as being in the highest risk group.) Typical consumer products are in the lowest risk category. The risk level is determined according to measurement criteria intended to reflect how various sources are used in realistic applications:

One method evaluates a light source under an illuminance of 500 lux (a typical value for general lighting purposes). This 500 lux criterion must be used for lamps intended for general lighting (including lamps for lighting offices, schools, homes, factories, roadways, or automobiles). For India, IS 16108: 2012 standard and its series are applicable for evaluating the photobiological effects from lamps and luminaries. As per the standard in similar to other standards used in various countries, there are four groups of safety limits which can be applied for LED lamps and luminaries – the exempt group, the low risk, the moderate risk and the high risk. Limits for blue light hazard are provided in Table 2.

Based on the irradiation limits provided by the standard in W/m2 units, it is understood that the irradiance values up to which the human eye or skin will not be affected due to continuous exposure and will not cause any adverse health effects. The determined irradiance values do not provide the safe or unsafe limits as all humans have different tolerance values to the exposure. These values could influence certain observers in a different way especially for people with high sensitivity to light. For such people, the limit of exposure shall be different for each individual. The limits of exposure to retina are determined based on 3 major factor viz. pupil diameter of the observer, visual impact angle on the retina and the measured angular range (radians) of the source of light.

In general, the high intensity light output from any luminary can cause damage to human eye and skin. The visible light radiation has thermal effect on human skin and photochemical effect to retina of the eye. Photoretinitis (a photochemical effect) is a common injury to eye due to short or long time exposure of high intensity light. In this scenario, the photoretinitis refers to exposure of eye to the light containing more or peak wavelength of blue light causing injury to retina. This is a type of photochemical reaction as it is involving chemical reactions on the retina due to high intensity light exposure. Every lamps and luminaries light output is having all the light components (wavelengths) of visible light. With most LED lights having blue light wavelength as peak wavelength, the blue light content reaching the retina is high compared to other light especially UV light which are also harmful. The UV light is blocked by our eye through lens and cornea. The UV light exposure is harmful to the eye if the irradiance is present for more than 10 seconds (long term exposure). The damage to the retina is observed by seeing a blind spot where the light got focused (projected) from the exposure. Depending on the individual, the damage may be permanent or may heal with time.

The spectral output of light from most of the LEDs will contain blue light wavelength which is in the range of 400 nm to 500 nm (blue light contains peak wavelength of 455 nm). This blue light emitted from certain LED lamps and luminaries cause blue light hazard.

Table 2. Limits of Blue light hazard

Particulars	**Symbol**	**Units**	**Exempt**	**Low risk (LR)**	**Moderate risk (MR)**
Blue light	L_B	$W.m^2.sr^{-1}$	100	10000	4000000
Permissible time	t_{max}	s	10000	100	0.25
Blue light small source	E_B	Wm^{-1}	1	1	400
Permissible time- small source	t_{max}	s	100	100	0.25

Table 3. Risk Groups (RG)

Risk	Group Risk	Definition
Exempt	None	No hazard
RG - 1	LR	No hazard under normal behavioral limitation
RG - 2	MR	Does not pose a hazard due to aversion response to bright light or thermal discomfort
RG - 3	High risk (HR)	Hazardous even for short-lived exposure

The IS 16108: 2018 standard defines four types of different risk groups, for all types of lamps and lamp systems (excluding lasers based systems) radiating light output in wavelengths from 200 nm to 3000 nm as shown in Table 3. The exempt group is sometimes mentioned as “RG – 0” group.

In addition to risk and hazards due to blue light, high intense bright light (example: halogen or metal halide lamps) can elevate the temperature of retinal tissue present in the eye which is dangerous and cause damage. Retinal thermal hazards are based on the point of impact and focus of light intensity in the cornea or the retina of the human eye (cornea focuses the light coming to the eye and directs it to the retina). The image formed on the retina becomes the affected area of the eye subject to thermal damage. It can be observed from the Figure 1 that the retinal thermal hazard function has a larger range of wavelengths than the blue light hazard function.

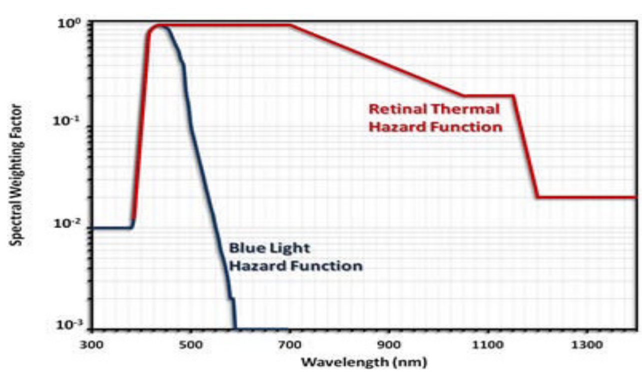

Figure 1. Retinal thermal and blue light hazard functions.

3. Permissible Exposure Time

In order to determine the risk group of a source, its spectral irradiance and radiance has to be measured at a specified distance, weighted with action spectra and maximum allowed exposure time, which is compared to corresponding exposure limits. For continuous sources, the exposure time limits are provided in Table 4. The exposure limits vary with type of hazard and the light sources are classified into 4 groups.

Table 4. Exposure Limits

Particulars	Exposure time before hazard exceeds (in seconds)			
Hazard	**Exempt**	**Group 1**	**Group 2**	**Group 3**
Actinic UV	30000	10000	1000	-
UVA hazard	1000	300	100	-
Blue light radiance	10000	100	25	-
Blue light small source	10000	100	25	-
Retinal thermal	10	10	25	-
Retinal thermal weak visual	1000	100	10	-
IR Eye	1000	100	10	-

According to IS 16108, the hazard values at a fixed distance d=200mm or distance at which the lux level is 500 lux is taken into consideration. The emission limits for the risk groups are defined in the standard are as given below (where α given in rad).

1) Exempt group

L_R £ 28000/a W.m^{-2}.Sr^{-1} within 10s

L_{IR} (low visual stimulus) £ 6000/a W.m^{-2}.Sr^{-1} with in 1000s-for retina

E_{IR} £ 100 W/m^{-2} within 1000s-for cornea

2) Risk group 1

L_R £ 28000/a W.m^{-2}.Sr^{-1} with in 10s

L_{IR} (low visual stimulus) £ 6000/a W.m^{-2}.Sr^{-1} with in 100s

E_{IR} £ 570 W/m^{-2} with in 100s

3) Risk group 2

L_R £ 71000/a W.m^{-2}.Sr^{-1} with in 0.25s

L_{IR} (low visual stimulus) £ 6000/a W.m^{-2}.Sr^{-1} with in 10s.

E_{IR} £ 3200 W/m^{-2} with in 10s

4) Risk group 3

If anyone of the limits of risk group 0, 1 and 2 is exceeded, then RG-3 group is assigned.

3.1 Actinic UV Hazard Exposure Limit for the Skin and Eye

1. The exposure limit for effective radiant exposure is 30 $J.m^{-2}$ within any 8-hour period
2. To protect against injury of the eye or skin from ultraviolet radiation exposure produced by a broadband source, the effective integrated spectral irradiance, E_s, of the light source shall not exceed the levels defined by:

$$E_s.t = \sum_{200}^{400}\sum_{t} E_\lambda(\lambda,t).S_{UV}(\lambda).\Delta t.\Delta\lambda \le 30 \qquad J.m^{-2}$$

i) The permissible time for exposure to ultraviolet radiation incident upon the unprotected eye or skin shall be computed by:

$$t_{max} = \frac{30}{E_s} \qquad s$$

3.2 Near-UV Hazard Exposure Limit for Eye

1. For the spectral region 315nm to 400nm (UV-A) the total radiant exposure to the eye shall not exceed 10000 $J.m^{-2}$ for exposure times less than 1000 S (approximately 16 minutes) the UV-A irradiance for the Unprotected eye, E_{UVA}, shall not exceed 10 $W.m^{-2}$
2. The permissible time for exposure to ultraviolet radiation incident upon the unprotected eye for time less than 1000 S, shall be computed by:

$$t_{max} = \frac{10\,000}{E_{UVA}} \qquad s$$

3.3 Retinal Blue Light Hazard Exposure Limit

To protect against retinal photochemical injury from chronic blue-light exposure, the integrated Spectral radiance of the light source weighted against the blue light hazard function, B(λ), i.e., the blue light weighted radiance, L_B, shall not exceed the levels defined by:

$$L_B.t = \sum_{300}^{700}\sum_{t} L_\lambda(\lambda,t).B(\lambda).\Delta t.\Delta\lambda \le 10^6 \; J.m^{-2}.Sr^{-1}$$

$$for\ t \le 10^4\ s \qquad t_{max} = \frac{10^6}{L_B}$$

$$L_B = \sum_{300}^{700} L_\lambda.B(\lambda).\Delta\lambda \le 100 \qquad W.m^{-2}.Sr^{-1}$$

$$for\ t > 10^4\ s$$

3.4 Retinal Blue Light Hazard Exposure Limit – Small Source

Thus, the spectral irradiance at eye E_λ, weighted against the blue-light hazard function B(λ) shall not exceed the levels defined by:

$$E_B.t = \sum_{300}^{700}\sum_{t} E_\lambda(\lambda,t).B(\lambda).\Delta t.\Delta\lambda \le 100 \qquad J.m^{-2}$$

$$for\ t \le 100\ s$$

$$E_B = \sum_{300}^{700} E_\lambda.B(\lambda).\Delta\lambda \le 1 \qquad W.m^{-2}$$

$$for\ t > 100\ s$$

3.5 Retinal Thermal Hazard Exposure Limit

To protect against retinal thermal injury, the integrated spectral radiance of the light source, L_λ, weighted by the burn hazard weighting function $R(_\lambda)$ i.e., the burn hazard weighted radiance, shall not exceed the levels defined by:

$$L_R = \sum_{380}^{1400} L_\lambda.R(\lambda).\Delta\lambda \le \frac{50\,000}{\alpha.t^0}.25 \qquad W.m^{-2}.Sr^{-1}$$

$$(10\mu s \le t \le 10\ s)$$

3.6 Retinal Thermal Hazard Exposure Limit – Weak Visual Stimulus

For an infrared heat lamp or any near-infrared source where a weak visual stimulus is inadequate to activate the aversion response, the near infrared (780nm to 1400nm) radiance, L_{IR}, as viewed by the eye for exposure times greater than 10 s shall be limited to:

$$L_{IR} = \sum_{780}^{1400} L_\lambda . R(\lambda). \Delta\lambda \leq \frac{6\,000}{\alpha} \qquad W.m^{-2}.Sr^{-1}$$

$$t > 10\ s$$

3.7 Infrared Radiation Hazard Exposure Limits for the Eye

The avoid thermal injury of the cornea and possible delayed effects upon the lens of the eye (cataractogenesis), ocular exposure to infrared radiation, E_{IR}, over the wavelength range 780nm to 3000nm, for time less than 1000 s, shall not exceed:

$$E_{IR} = \sum_{780}^{3000} E_\lambda . \Delta\lambda \leq 18\,000. t^{-0.75} \qquad W.m^{-2}$$

$$t \leq 1000\ s$$

For times greater than 1000 s the limit becomes:

$$E_{IR} = \sum_{780}^{3000} E_\lambda . \Delta\lambda \leq 100 \qquad W.m^{-2}$$

$$t > 1000\ s$$

3.8 Thermal Hazard Exposure Limit for the Skin

Visible and infrared radiant exposure (380nm to 3000nm) of the skin shall be limited to:

$$E_H . t = \sum_{380}^{3000} \sum_{t} E_\lambda(\lambda, t). \Delta t. \Delta\lambda \leq 20000 t^{0.25} \qquad J.m^{-2}$$

4. Hazardous Considerations

There are various biological hazards that are considered within different wavelength ranges in accordance with the standard IS 16108. The ill-effects of lamps and lamp systems on both the eyes and skin are considered. Commonly discussed hazards affecting the eye are Blue Light Hazard (BLH) and Age-related Macular Degeneration (AMD) which can be induced or aggravated by high intensity blue light. Furthermore, UV (ultraviolet) may affect the eye, causing cataract or photokeratitis (sunburn of the cornea); IR (infrared) radiation can induce IR cataract (also known as glassblower's cataract); and radiation of all wavelengths can lead to retinal thermal injuries at extreme intensities[12].

Optical radiation, particularly UV can be harmful to the skin. By far the most hazardous source is the sun. Sunburns (UV erythema) and skin cancers due to long-term exposure to the sun are well-known problems caused by radiation. Moreover, patients with autoimmune diseases such as lupus or photodermatoses can be highly sensitive to UV radiation, and sometimes also blue light. There is concern among some patients who suffer from such sensitivities that phasing out of the known incandescent lamps will leave them without lamps for indoor use that are low in radiation of UV and blue light[13].

The various types of phototoxic hazards from LED luminaires which affects the skin and retinal of human beings are provided in Table 5. As the radiation optical power of light emitting diodes has increased in present as well as in future also, the issue of eye safety has received an ever-increasing amount of attention within this context there has been much discussion about the correct safety standard IS 14624 Part 2: 2012 or the lamp standard IS 16108 to apply to the classification LEDs. Earlier than 2010 all LED applications were covered by IEC 60825 which is later adopted by India in 2012 with the standard IS 14624 Part 2: 2012. Nowadays most of LED applications are covered by the lamp standard. Other than lasers, lamps are only normally defined in this standard as sources made to generate optical radiation. Lamp devices can also contain optical components like lenses or reflectors. Examples are lensed LEDs or reflector type lamps which can include lens covers as well. The status for different applications of LEDs, like safety of optical products or irradiation of objects, different standards have to be used.

1. Safety of laser products IS 14624 Part 2: 2012
2. Lamp applications IS 16108: 2012

The above two safety standards do not cover normal exposure scenarios and not legally binding. However, the current methods and limit calculations are used as a basis in regional guidelines, e.g. in the European directive, which describes the minimum health and safety requirements regarding the exposure of workers to risks arising from agents.

These standards describe the possible hazards of Infrared LEDs used for lamp applications w.r.t the IS 16108 standards and how to classify Infrared LEDs according to different risk groups.

Table 5. Skin and retinal hazards

Hazard	Wavelength (nm)	Quantity	Eye	Skin
Actinic UV skin and eye	200 -400	Irradiance	Sunburn of cornea, pain, swelling of inner eyelid and increased tear production	Reddening of the retina and degeneration of elastic skin
UVA eye	315- 400	Irradiance	Cataracts	-
Retinal blue light	300 - 700	Radiance	Damage of retina	-
Retinal blue light small source	300 -700	Irradiance	Damage of retina	-
Retinal thermal	380 - 1400	Radiance	Retinal burn	-
Retinal thermal weak visual stimulus	780- 1400	Radiance	Retinal burn	-
Infrared radiation eye	780 – 3000	Irradiance	Corneal burn and cataracts	-
Thermal skin	380 - 3000	Irradiance	-	Skin burn

4.1 Blue Light Hazard: Consideration and Classification of Lighting Products

Blue light hazard (BLH) is defined as the potential for retinal injury due to high-energy short-wavelength light. At very high intensities, blue light (short-wavelength 400-500 nm) can photochemically destroy the photopigments (and some other molecules) which then act as free radicals and cause irreversible, oxidative damage to retinal cells (up to blindness). For such an injurious effect to occur, three factors are critical: first, the spectral irradiance distribution (relevant is the proportion that falls into the action spectrum for blue light hazard, in mathematical terms: the integrated spectral irradiance distribution weighted with the action spectrum); second, the radiance (at higher radiance, more photons are likely to hit photopigments and cause damage); and, third, the duration of exposure (at longer exposure, effects increase steadily). For example, when gazing directly at the sun, the retina can be injured very rapidly due to the enormous radiance. In contrast, even though for the sky the relative proportion of blue light in relation to the sky is much higher, there is no risk of retinal damages by the scattered sky light as the radiance is too low[14].

The application of the standard IS 16108 for assessment of the blue light hazard has generated in some cases, different interpretations in the evaluation of the test results. In particular, the following aspects are evaluated:

- The evaluation of the source at a distance which produces 500 lx is not always significant so that the distance between the eye of the observer and the source may be lower.
- To evaluate all sources at a distance of 200 mm (as for sources not GLS) would lead to an overestimation of the phenomenon requiring limitations even where not required.
- It is necessary to define parameters in order to transfer data from the manufacturer of the light source to the luminaire manufacturer.
- The products that fall within the risk group RG 2 are not considered dangerous even if warnings are required to use in order to avoid direct vision.

4.2 Assessment and Classification of the Light Source for Blue Light Hazard

The assessment carried out on the light source (lamp or module) is then transferable to the luminaire as follows:

- Light sources with risk group “RG 0 unlimited”: If the assessment on the light source carried out in accordance with the IS 16661: 2019 leads to a “RG 0 unlimited” for blue light hazard, each luminaire that incorporates one or more light sources of this kind, will have the same blue light hazard classification, regardless of the visual distance, optical lenses or reflector used in the luminaire.
- Light sources with risk group “RG 1 unlimited”: If the assessment on the light source carried out in accordance with the IS 16661: 2019 leads to a “RG 1

unlimited" for blue light hazard, each luminaire that incorporates one or more sources of this kind, will have the same blue light hazard classification or lower, regardless of the visual distance, optical lenses or reflector used in the luminaire.

- Sources with risk group in which the assessment leads to define an E_{thr} (threshold illuminance). If the assessment on the light source carried out in accordance with the IS 16661: 2019 leads to a threshold illuminance E_{thr} for blue light hazard, each device that incorporates one or more light sources will have the same E_{thr} which will form the basis for the calculation of the distance for a safe vision depending on the distribution curve of the luminaire.

4.3 Evaluation of Light Sources where Radiometric Measurements for Blue Light Hazard are not Available (only for White Light Source)

In IS 16661: 2019 considerations are made on the spectral distribution of the light sources. In particular a correlation has been found between the CCT of the sources and blue light hazard with the parameter KB,v. KB,v is defined as the quotient of the blue light hazard quantity to the corresponding photometric quantity.

Following the spectral analysis and the consideration made it is possible to find a photometric threshold corresponding to the threshold between RG 1 and RG 2 of blue light hazard.

On the basis of these considerations and taking into account a safety margin (corresponding to a factor of 2), it is possible to define levels of illuminance below which the source is certainly at RG 1 or less.

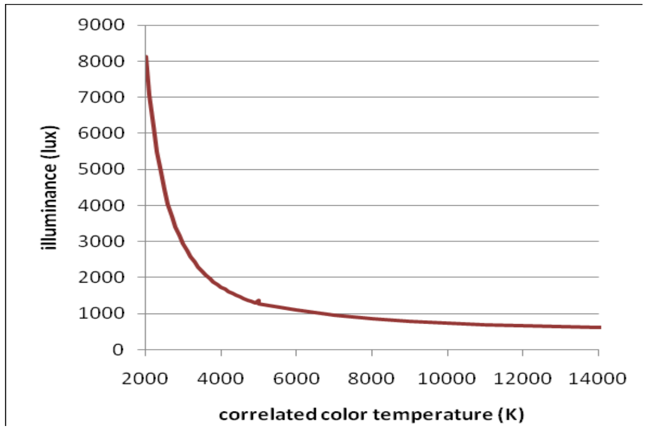

Figure 2. Estimate of the illuminance level where EB = 1 W/m², border between RG 1 (t_{max} > 100 s) and RG 2 (t_{max} < 100 s) in the small source regime, as a function of CCT.

For general lighting sources, the following measurements shall be taken according to the standard: -

i. Irradiance in order to determine:

   a. Lens near-UV hazard over the wavelength range 315 nm to 400 nm, E_{UVA}

   b. Corneal and lens infrared hazard over the wavelength range 780 nm to 3000 nm, E_{IR}

ii. Spectral irradiance in order to determine the ocular and skin hazard due to UV radiation over the wavelength 200 nm to 400 nm, E_S

iii. Spectral radiance in order to determine: -

   a. Retinal blue light hazard over the wavelength range 300 nm to 700 nm, L_B

   b. Retinal thermal hazard over the wavelength 380 nm to 1400 nm, L_R

Tables 6 and 7 summarises the type of hazards which is caused by LED luminaries especially for skin, cornea

Table 6. Summary of the Exposure Limits for the surface of the skin or cornea (irradiance-based values)

Hazard Name	Relevant equation	Wavelength range (nm)	Exposure duration (sec)	Limiting aperture rad (deg)	EL in terms of constant irradiance ($W.m^{-2}$)
Actinic UV Skin & eye	$E_s = \sum E_\lambda . S(\lambda) . \Delta\lambda$	200-400	< 30000	1.4 (80)	30/t
Eye UV-A	$E_{UVA} = \sum E_\lambda$	315-400	≤ 1000 > 1000	1.4 (80)	10000/t 10
Blue-light Small source	$E_B = \sum E_\lambda . B(\lambda) . \Delta\lambda$	300-700	≤ 100 > 100	<0.011	100/t 1.0
Eye IR	$E_{IR} = \sum E_\lambda . \Delta\lambda$	780-3000	≤ 1000 > 1000	1.4 (80)	$18000/t^{0.75}$ 100
Skin thermal	$E_H = \sum E_\lambda . \Delta\lambda$	380-3000	<10	2π Sr	$20000/t^{0.75}$

Table 7. Summary of the Exposure Limits for the retina (radiance-based values)

Hazard Name	Relevant equation	Wavelength range (nm)	Exposure duration (sec)	Field of view radians	EL in terms of constant radiance ($W.m^{-2}.Sr^{-1}$)
Blue light	$L_B = \sum L_\lambda . B(\lambda). \Delta\lambda$	300-700	0.25-10 10-100 100-10000 ≥ 10000	0.011√(t/10) 0.011 0.0011√t 0.1	10^6/t 10^6/t 10^6/t 100
Retinal thermal	$L_R = \sum L_\lambda . R(\lambda). \Delta\lambda$	380-1400	< 0.25 0.25-10	0.0017 0.011√(t/10)	50000/ ($\alpha.t^{0.25}$) 50000/ ($\alpha.t^{0.25}$)
Retinal thermal (Weak visual stimulus)	$L_{IR} = \sum L_\lambda . R(\lambda). \Delta\lambda$	780-1400	> 10	0.011	6000/α

(eye) and retina (eye) along with their exposure limits based on radiance and irradiance values.

5. Conclusion

The standard rules and testing procedures for classification of lamps in terms of risk groups based on the evaluation of the photobiological hazards caused by light sources are specified in the Indian standard IS 16108. To conlcude, the types of light sources that should be taken into consideration due to BLH are LED sources, metal-halide lamps and halogen lamps (due to intensity of lights at peak wavelength and their similarity of solar-sun wavelength spectrum).

This paper provides an overall introductory review of various testing standards to evaluate optical hazards from LED lamps and luminaries in the context for the requirements for India. This review also summarises the different categories of hazards especially BLH which are caused by LED luminaries especially for skin, cornea (eye) and retina (eye) along with their exposure limits based on radiance and irradiance values.

6. Acknowledgement

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