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Optical and Photobiological Safety of LED, CFLs and Other High Efficiency General Lighting Sources

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A White Paper of the Global Lighting Association

March 2012

Global Lighting Association

The Global Lighting Association (GLA) is a grouping of peak national and regional lighting associations. This paper is one of a series of White Papers and policy documents produced by the GLA on lighting issues of interest to the lighting industry, to lighting industry stakeholders and to consumers. For more information on the GLA and its activities see www.globallightingassociation.org.

Executive Summary

With the phasing-out of incandescent lamps in many countries, the introduction of new LED based light sources and luminaires sometimes raises the question of whether the spectral characteristics of the LED and other energy saving fluorescent lamps (such as CFLs) are suitable to replace traditional incandescent lamps. These concerns are sometimes raised particularly for radiation emissions in the UV and blue parts of the spectrum. This document will address such concerns for common ‘white light’ sources typically used in households and other general lighting use.

LED and CFL lamps, as well as other general use lighting products produced which meet applicable optical safety requirements, are safe to use by the vast majority of consumers in general lighting applications. A small portion of the population has an enhanced sensitivity to UV. These individuals may want to consider using LED based lighting for their high efficiency lighting needs if there are any concerns about even the small levels of UV that are produced by CFLs. (Another option for such UV sensitive individuals is to use a covered CFL or ensure the CFL is in a covered luminaire.)

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1. Background

With the phasing-out of incandescent lamps in many countries, the introduction of new LED based light sources and luminaires sometimes raises the question of whether the spectral characteristics of the LED and other energy saving fluorescent lamps (such as CFLs) are suitable to replace traditional incandescent lamps. These concerns often centre on radiation emissions in the UV and blue parts of the spectrum. This document will address such concerns for common ‘white light’ sources *typically used in households and other general lighting use.*

2. Global Lamps Forum (GLA) Position Statement

It is sometimes claimed that LED and CFL light sources are different from traditional incandescent lamps in that they contain higher proportions of blue wavelength light and are thus more likely to cause potential problems from exposure to ‘blue light’. This paper presents a detailed evaluation of the photobiological safety of common LED and CFL light sources for domestic use in comparison to traditional incandescent lamps, and explains how light sources are evaluated for optical safety.

The position of the GLA, based on accepted and widely adopted safety standards for lamps, is that all general lighting sources, including LED and CFL sources (either lamps or systems) and luminaires can be safely used by the consumer when used as intended.

In terms of their level of photobiological safety, LED and CFL lamps are no different from traditional technologies such as incandescent lamps and fluorescent tubes. The portion of blue light produced by an LED is not significantly different from the portion of blue produced by lamps using other technologies at the same colour temperature. A comparison of LED and CFL retrofit products to the traditional products they are intended to replace reveals that the risk levels are very similar and well within the accepted range.

Nevertheless, looking straight into bright, point-like sources (LEDs, but also other strong point-like light sources, like clear filament or discharge lamps or, in a natural setting, the sun) should be avoided. Fortunately, when people happen to look into a bright light source accidentally, a natural protective reflex occurs: people instinctively close their eyes or look away from the source.

It also well known that blue light exposure is important to the well being of humans. Blue light with a peak at around 460-480nm regulates our human biological clock, alertness, and metabolic processes. In natural conditions, outdoor daylight fulfils this function. However, in our modern society, many people spend most of their day indoors and are often lacking the necessary blue light exposure. Blue and cool white light sources can be used to create lighting conditions such that people will receive their daily portion of blue light to keep their physiology in tune with the natural day-night rhythm. Both LED and fluorescent lamps can be tailored to fulfil this purpose.

3. LEDs, CFLs and Optical Safety

Optical safety for lamps and other light sources refers to the prevention[1] of potential hazards caused by optical radiation (electromagnetic radiation of wavelengths ranging from 100 nm to 1 mm). Effects on the eyes as well as the skin are considered, including people with a higher sensitivity to light exposure. Annex 1 provides more detailed considerations for those with a heightened sensitivity.

Commonly discussed hazards from light 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. When looking directly into a bright light source, a photochemical damage to the retina (blue light hazard) can occur, depending on the intensity involved and the time of exposure. People are familiar with this phenomenon from looking at the sun. To prevent retinal damages, appropriate spectacles must be worn when observing a solar eclipse, for instance. On a bright and sunny day, however, a natural aversion reflex occurs that protects the eye from being harmed. Furthermore, UV (ultraviolet) radiation 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 at extreme intensities can lead to retinal thermal injuries.

Optical radiation can also affect the skin causing sunburns, or, in severe cases, cancers upon long-term UV exposure. There exist certain groups of patients – for example those suffering from lupus or photodermatoses - who are particularly sensitive to UV (and sometimes also blue light) radiation. Note that the above mentioned effects are predominantly caused by natural sun light; some of them can never be evoked by artificial lighting since the *exposure levels from general illumination are too low.*

Nevertheless the optical safety of commonly used light sources needs to be ensured, and this is accomplished by lighting manufacturers meeting applicable safety standards that have been developed by experts and which are adopted or otherwise accepted in their respective countries or regions.

4. Photobiological Risk Assessment and Conclusions

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).

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[1] Exposure limits defined in the standard IEC/EN-62471 are required under European regulations (directive 2006/25/CE). Most IEC oriented countries or regions have adopted or are in the process of adopting or harmonizing with these IEC requirements. For example, Australia and New Zealand are currently adopting IEC 62471. China, via GB20145-2006, and Taiwan, via CNS 1000550 /CNS 0990586, have completed such harmonization. Indian industry requirements are harmonized with IEC 62471 and will become formally adopted in the future.

In the USA the FDA acknowledges the requirements of IESNA RP27.3 (See http://www.fda.gov/Radiation-EmittingProducts/RadiationEmittingProductsandProcedures/HomeBusinessandEntertainment/ucm116400.htm) and stipulates certain other regulatory requirements.

Both IEC/EN-62471 and the IESNA RP27 series have essentially the same requirements as CIE S009 published by the International Commission on Illumination.

A second method measures photobiological safety from a distance of 200 millimetres. The 200 millimetre 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.

4.1 Conclusions on blue light emission

Evaluation at a distance producing 500 lux:
Taking the 500 lux criterion as the measurement basis, typical consumer LED and CFL products do not fall into risk group 2, which is the first cautionary risk group. This was also confirmed by a study of the French agency for food, environmental and occupational health and safety (ANSES) in 2010 which found that even high-output discrete LEDs are classified into risk groups 0 or 1.

LEDs compared to other light sources
Since LEDs are the newest lighting technology, and since earlier products tended to have bluer (cooler) color temperatures, some have mistakenly concluded this technology has an inherent ‘blue light issue’.

With regard to photobiological safety, LEDs are not fundamentally different to lamps using traditional technologies, such as incandescent or fluorescent (including CFL) lamps. The portion of blue light produced by typical LEDs is not higher than the portion of blue light in lamps using other technologies at the same colour temperature (see figure 2 in annex 3 with the blue hazard irradiance values E_B of a wide range of products with comparable Colour Temperature). If LED or CFL retrofit products are observed in comparison to the products which they are intended to replace (e.g. LED MR16 vs. Halogen MR16, or a LED retrofit with screw base vs. frosted incandescent lamp), the risk group ratings are similar.

Figure 1 displays typical spectral power spectra from commonly used general illumination sources. While the amount of energy in the blue portion of the spectra varies across lamp types, the overall contribution of blue is not appreciably different when evaluated for photobiological impact since the equations used to determine risk properly account the spectral power distribution of such sources. (Figure 1 will also be addressed in Annex 2, where this subject is discussed in more detail.)

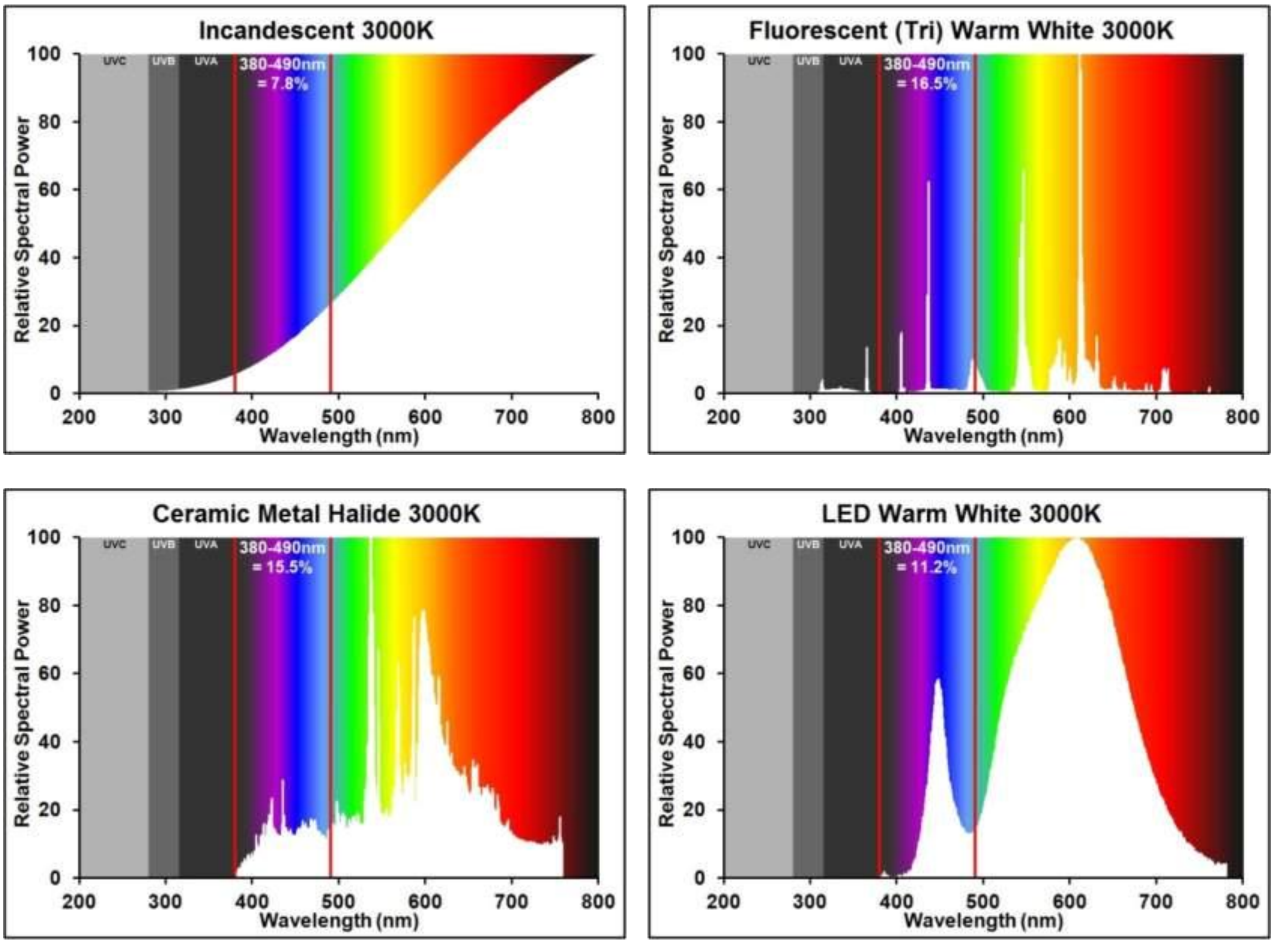


Figure 1: relative spectral power of various light sources

Energy efficient lighting and children

The lens of a child's eye filters blue light less efficiently than an adult's lens. Children are thus more sensitive to blue light hazard. However, it is not necessary that LEDs and CFLs (or blue light in general) should be avoided in an environment with children present, since general illumination products used in homes, offices, stores, and schools do not produce intense levels of blue light. Since such applications have a low surface brightness (intensity) even "pure" blue light is completely harmless, regardless of whether it is the blue produced by LEDs, CFLs or other common residential light sources, or the blue light found in sky light. (By way of a very simple example, the blue light from a blue LED holiday string is no more hazardous than the blue light produced by its less efficient blue incandescent holiday string.)

Guidance for people with high sensitivity for blue light

The above statements are also valid for healthy people in the general public. However, people who have been *medically diagnosed* with highly sensitive skin or eyes for blue light may be wise to investigate alternative light sources that operate on a more specific radiation band not covered by the applied action curves that cover a broad range of radiations. *As with any medical condition, people with blue light sensitivity (such as lupus) should consult their health care provider for special guidance.*

The biological importance of blue light

Blue light exposure is important to human beings. Blue light with a peak around 460-480nm regulates the biological clock, alertness and metabolic processes. GLA members have established a special working group to translate these findings into practical application norms and standards. In natural conditions, outdoor daylight fulfils the function of synchronizing the biological clock (called the circadian cycle). Yet, in today's society, many people spend most of the day indoors (offices, schools, retail space, etc.) and may lack the blue light exposure that was common in the past. Blue and cool white light sources can be used to create lighting conditions such that people will receive their daily portion of blue light to keep their physiology in tune with the natural day-night rhythm.

4.2 Conclusions on ultraviolet radiation (UV)

LED based light sources used by the general public typically do not emit any UV radiation. CFLs and other fluorescent lamps emit only a very small amount. Since LEDs emit no UV, they are particularly well suited for use by people with a specific sensitivity for certain UV radiation and can bring relief to certain groups of patients. In this respect, LED based light sources provide advantages over traditional incandescent, halogen and Compact Fluorescent lamps. Please note that only a doctor or other trained medical professional can determine if a person suffers from UV sensitivity. For more details see Annex 2.

4.3 Conclusions on infrared radiation (IR)

In contrast to most other light sources, e.g. halogen and incandescent lamps, LEDs and CFLs used for general illumination emit very little IR. The reason for this is that by their very nature, the high efficiencies of such technologies require that very little heat (IR) is produced. For commonly used types of indoor light sources that would be encountered by the public, any IR radiation produced is not intense enough to pose any risks to humans, and so all such light sources would be in the lowest of risk groups.

LED and CFL lamps, as well as other general use lighting products produced which meet applicable optical safety requirements, are safe to use by the vast majority of consumers in general lighting applications. A small portion of the population has an enhanced sensitivity to UV. These individuals may want to consider using LED based lighting for their high efficiency lighting needs if there are any concerns about even the small levels of UV that are produced by CFLs. (Another option for such UV sensitive individuals is to use a covered CFL or ensure the CFL is in a covered luminaire.)

Disclaimer: While GLA members have made every attempt to ensure the accuracy of the information contained herein, it does not accept responsibility or liability for any usage of this information.

Annex 1: Effects of optical radiation on eyes and skin

Potential effects on the eye

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.

Additional background:

- *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.
- *Age-related macular degeneration (AMD)* is a condition of visual impairment of the central visual field (macula) predominantly in elderly people. Blue light can progress AMD. According to the current scientific literature, lipofuscin, a molecule accumulating in the retinal cells with age, is destroyed by blue light causing oxidative damage. Note that the prevalence of AMD is not higher with higher exposure to blue light in younger years, e.g., in professionals working predominantly outside such as sailors or farmers. As for blue light hazard, the *spectral irradiance distribution* and *radiance* are the relevant factors influencing AMD. But different than in blue light hazard, AMD cannot be caused by a one-time acute above-threshold exposure to light but is instead influenced by long-term exposure to blue (and also green & yellow) light, possibly even at lower doses. But note that blue light is not the main risk factor; instead, in the recent medical literature, genetic factors (ERCC6 gene) and environmental factors including age, smoking, hypertension and diet are discussed to cause/influence AMD.
- *Cataract* is a disorder that develops over a person's lifetime. When people are born, the crystalline lenses are fully transparent for light. Due to natural aging and the absorption of UV radiation, the lenses turn opaque/yellow, obstructing the passage of light. The severe form of this age-related problem is called a cataract. As a side effect, when turning yellow the lens serves as a blue light filter, and, thus, as a kind of natural protection for the retina when people grow older. In severe cases, surgical removal (aphakia) or replacement (pseudophakia) of the lens may become necessary. Such patients as well as children are often more sensitive to blue light than healthy adults.

Potential effects on the skin

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.

Annex 2: General spectral comparison of light sources used in households

In this section, spectral data of different types of light sources (LED, CFL, halogen) are graphically presented and evaluated qualitatively (a quantitative evaluation will follow in **Annex 3**). Of interest is the spectral irradiance in the blue and ultraviolet part of the different types of light sources in comparison to the two historical “gold” standards of lighting for most consumers: daylight and incandescent lamps.

Irradiance spectral measurements were done to obtain the spectra of a number of common light sources, all at a similar overall illuminance level of 500 lux and in accordance with the international standard EN 62471. For reference: 500 lux is also the light level used in a wide range of indoor workplace lighting applications such as office lighting; in-home lighting varies between 50 lux (TV corner) to 500 lux (dinner table, kitchen). Outdoor lighting conditions are a multiple of indoor lighting: 5000 lux (overcast sky) to 50.000 lux (sunny day).

Note 1: The measured sources are presented against a logarithmic scale as the linear scale would not demonstrate the differences between the various curves.

Note 2: The *area under the spectral curves* of the light sources is a measure of the energy in a particular part of the spectrum (eg blue emission). When considering a particular risk, as blue light hazard or emission of actinic UV, the area needs to be spectrally weighted by the action curve for blue light hazard or actinic UV, respectively (for more details on the BLH and actinic UV action curves see **Annex 7**).

LED spectral characteristics

In Figure 1 - top, different LED sources are compared to an incandescent lamp and daylight. White LEDs typically show a peak in the blue (at around 450 nm when a royal blue LED is used) and more broadband emission in the green/yellow part of the spectrum. Next to the blue peak, a dip is visible at around 490nm that also falls under the BLH action curve (indicated here by the blue horizontal bar). The blue peak of the LED lamps is “compensated” by the dip, therefore the total blue output (given by the area under the curve!) of LED of 2700K is comparable to an incandescent lamp of 2700K.

CFL spectral characteristics

In Figure 1 - middle, the spectra of two common types of energy saving CFLs (designed to replace traditional incandescent lamps) are shown and compared to an incandescent lamp and daylight. Typical CFL spectra contain multiple “sharp” peaks and dips. Note that the high peaks are very narrow and therefore do not contribute significantly to the blue irradiance (as it might intuitively seem from the graphs). On the left hand side, the spectral curves extend slightly into the actinic UV action spectrum. But note that considering that the data are plotted against a logarithmic axis, the energy in the actinic UV part is extremely low and clearly below the emissions of natural daylight.

(Note: There are two basic types of CFLs. In one type the fluorescent tube is bent or otherwise compacted, does not have a covering envelope, is sometimes called an ‘uncovered CFL’. In the following CFL data , emissions from a typical uncovered CFL are labelled as ‘ES Burner’, which is an industry term meaning the emissions are from an uncovered energy saving CFL.

In the second CFL type there is an additional outer jacket that covers the compacted fluorescent tube. Since this covered type looks more like a traditional ‘light bulb’, its emissions are labelled ‘ES Bulb’ in the following CFL data.

Both types are commonly available.)

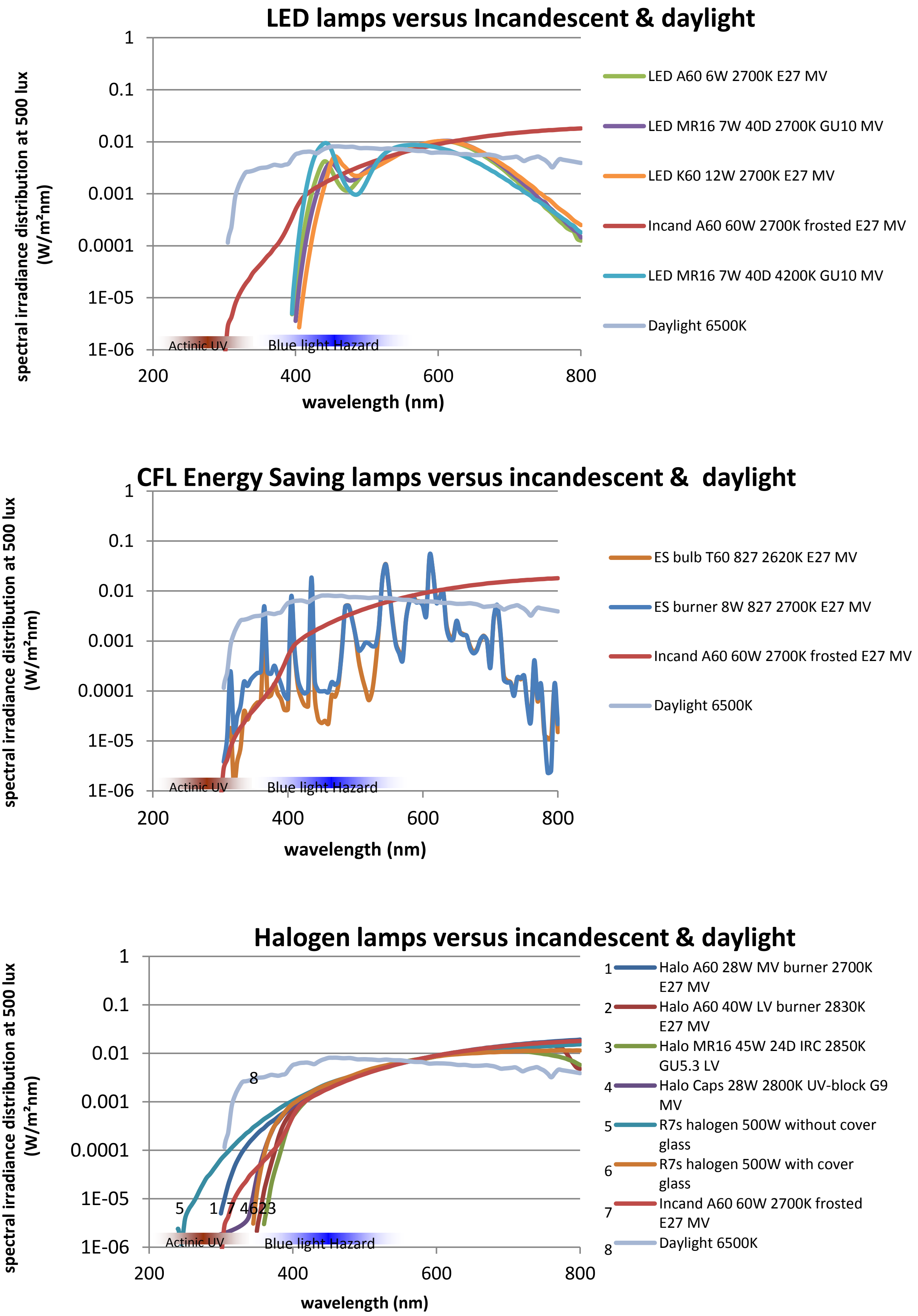


Figure 2: A collection of spectra from different common light sources is shown, together with a representative daylight spectrum scaled to the same illuminance level. The UV-Actinic and BLH action curves (as defined in e.g. EN 62471 and IESNA RP27, see Annex 5 and Annex 7) are indicated by the brown and blue bars, respectively, the color intensity illustrates the effectiveness

Halogen spectral characteristics

In Figure 1 - bottom, various halogen lamp types are compared to an incandescent lamp and daylight. Halogen lamp spectral curves show a similar shape as incandescent lamps: the curves continuously increase towards higher wavelengths and bend downward again in the IR. Halogen lamps can therefore offer a good alternative to conventional incandescent lamps.

The green line represents a halogen lamp with an infrared coating (IRC curve clearly bends downwards in the IR). The purple line shows that the UV filtering quartz indeed effectively filters the UV, bringing it close to the incandescent curve. The other types show more UV output than incandescent lamps, especially the 500W double ended lamp, but that lamp should be always used with a suitable cover glass (flood light)or sleeve (in uplighter); with the cover glass the lamp is close to the Incandescent curve.

Note that, compared with daylight, the UV output of all lamps is very low, as the scale employed is logarithmic, not linear.

Summary

Even though the spectra of LED, CFL, halogen, and incandescent lamps have different “typical shapes”, the proportion of blue light does not vary much between lamps of different technologies with a similar colour temperature and is always significantly lower than the blue (or UV) emission of daylight.

For all lamps intended for general lighting applications, the UV emissions are well below the exposure limits as defined in IEC/EN 62471 and IESNA RP27. LEDs used for general lighting are free of UV (aside very special types that are designed to emit UV for very specialized, i.e., industrial, applications).

Legend and further explanation for the various lamp types shown in Figure 1 (see also Annex 5 for a more detailed description):

- **Halo**: halogen lamps, can be low voltage (12V, 3000K) or mains voltage (120V or 230V depending upon region, 2800K). Halogen lamps can be a capsule (caps) or reflector (MR16) operated in a special halogen lamp holder or they can be integrated into the outline of the traditional incandescent lamps as a replacement for those lamps.
- **Fluo-ES:** Energy Saver (popular name) or Compact Fluorescent lamps, can be just the compacted fluorescent tube (*discharge tube or ‘burner’* depending upon terminology used in various regions) or have a second outer cover (bulb).
- **Incand:** Incandescent lamp, considered by the market as the historical, traditional standard.
- **LED:** replacement alternatives are taken: for incandescent bulbs, and halogen reflector lamps (MR16) or T8 fluorescent tubes
- **Daylight:** the official CIE daylight curve of 6500K is assumed

Annex 3: Blue light radiation data of light sources

When evaluating the risk of blue light hazard posed by LED (and other) light sources, two fundamentally different cases need to be considered:

Case A: Looking at an illuminated scene
In the vast majority of cases, humans look at an illuminated scene: Typically daylight illuminates the scenery and a direct view into the light source, the sun, is avoided. Or, in indoor lighting, artificial light sources illuminate the room while luminaires prevent a direct view of the light source – primarily to avoid glare.

In the case of looking at an illuminated scene, the (geometrical) properties of the light source such as the size of the area from which the radiation is emitted (measure of the density of radiation ~= radiance) are not relevant. Instead, the **irradiance** which refers to the radiation hitting a surface (scene) is the relevant property.

Case A can generally be considered safe. To give an example, looking at the scattered blue sky (high blue irradiance but low radiance) is completely safe, and so are artificial light sources, containing much less blue irradiance than daylight.

Case B: Looking at a light source
When evaluating photobiological risks we need to consider the more severe case of looking directly into a light source. In everyday situations, this rarely happens. But note that the standard EN 62471 was originally developed to protect workers particularly in the lighting industry, as lighting installers or in similar fields. It may happen that such professionals look into light sources several times a working day accumulating exposure to several seconds. In this situation, the blue **radiance** is the critical factor for BLH (the higher the radiance in the relevant action spectrum, the higher the likelihood that light hits photopigments (with sufficient energy) and cause potential damage.

Looking straight at a light source (Case B) is also in general safe for diffuse and warm white light sources, like frosted or white diffusing lamps. Yet, caution is advisable for cool white or blue, bright (high intensity), point-like light source, for instance an incandescent filament, electric arc or an LED die, even an LED die behind the lens of a directional lamp. Such point-like sources are projected on the retina as a concentrated light spot and can damage that spot on the retina when the intensity is high enough and the spectrum contains blue light in congruence with the blue light hazard action spectrum curve.

Both cases are discussed in more detail below.

Data on Case A: Looking at an illuminated scene (irradiance)

In Annex 2 an overview is given of the spectral data of various light sources in direct comparison with each other. From these spectra, the blue hazard irradiance values E_B were calculated using the standard blue light hazard (BLH) action curve.

In Figure 2 an overview is given of the E_B values of the different lamp types. It is clear that all sources of a similar colour temperature (Tc in Kelvin) have a similar E_B value. This is because the blue portion has a fixed relation to the other colours to make the colour white.

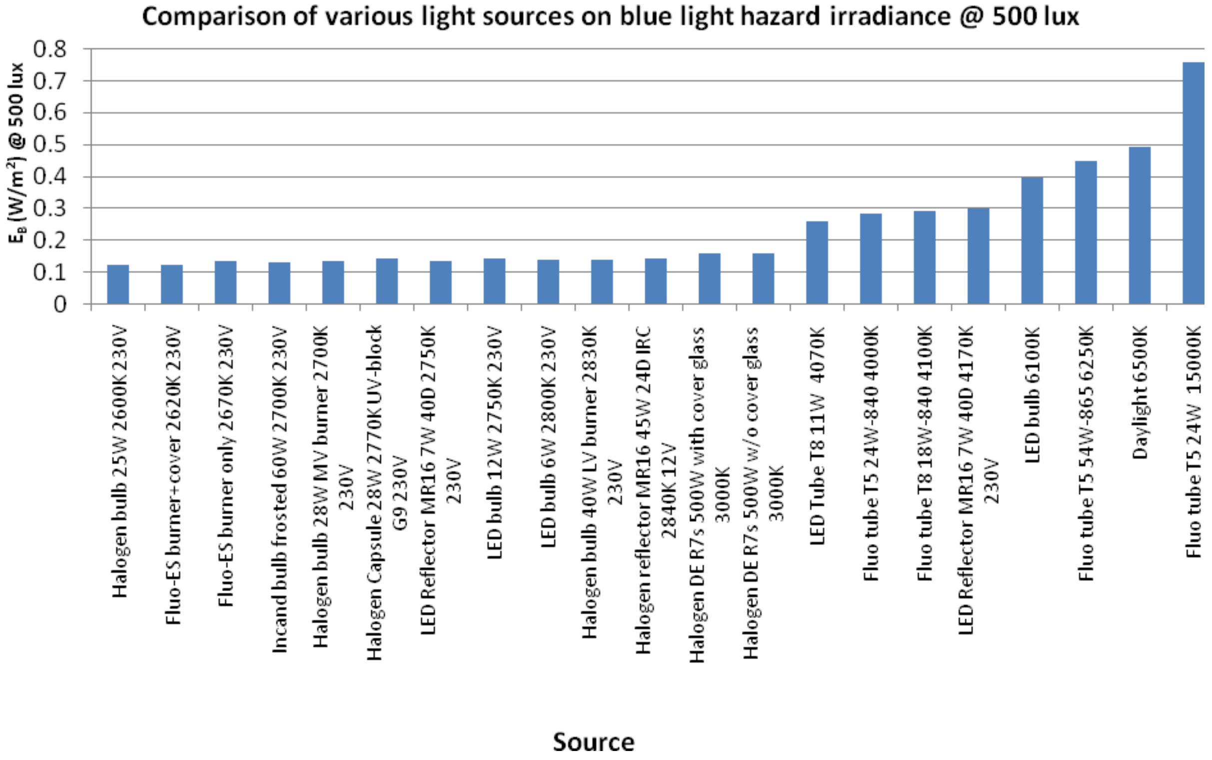


Figure 3: Comparison of E_B values of the different lamp types and daylight. Note, data is from laboratory measurements of typical products.

In order to better compare with the effect of daylight, it must be noted that daylight normally provides illuminance levels that are much higher than 500 lux. Figure 3 shows the comparison of the E_B of a number of light sources at 500 lux, compared with daylight at 5000 lux, which is an average value for moderate latitudes.

Some typical lamps at 500 lux compared with outdoor lighting at 5000 lux

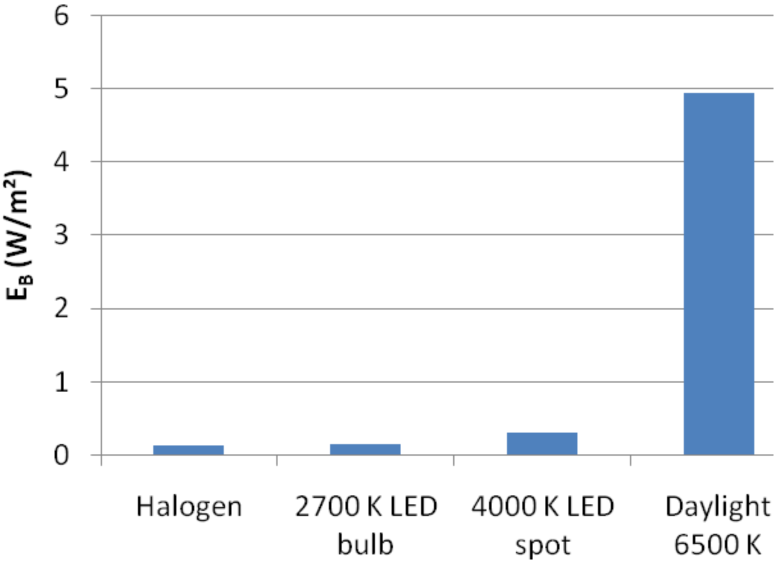


Figure 4: Comparison of irradiance values of some lamp types at 500 lux (typical for indoor) with daylight at 5000 lux (typical for outdoor lighting)

The actual outdoor illuminance value can vary over a wide range, up to 50,000 lux for a sunny summer day on moderate latitudes and even 100,000 lux at tropical latitudes. This shows that the quantity of blue light of any indoor general lighting compared to outdoor conditions is very, very low.

Data on Case B: Looking at a light source (radiance)

In order to compare the light sources for case B, we refer to the standard (EN 62471) as described above. In these standards a distinction is made between large sources and small sources. The image of a small source (< 11 mrad) will be smeared over a larger area of the retina due to voluntary and involuntary eye movements, thus reducing the blue light that hits a particular spot (receptor) on the retina, which reduces the risk of retinal damages. Moreover, for the testing method, a distinction is made between light sources for general lighting and those for all other purposes (professional/specialty applications). In the comparison below, we will use the most severe testing method: the one for all other purposes. In this case, the light source has to be measured at a distance of 200 mm, which is shorter than the distance relevant for GLS (distance producing 500 lux). At the distance of 200mm, most light sources are a “large source” according to the EN 62471, and the blue-light radiance (L_B) must be used to classify the source, which is a quantity derived from the density of the radiation in the relevant BLH action spectrum, see below for an explanation. In the standard, the L_B value is used to calculate the maximum exposure time (i.e. the maximum safe time to look directly into the light source) and a resulting classification into risk groups (RG). This is given in Table 1.

LB value (W/m²sr)	Maximum exposure time (s)	Classification
0-100	no maximum time defined	RG 0 Exempt
100-10,000	100-10,000	RG 1 Low
10,000-4,000,000	0.25-100	RG 2 Moderate
>4,000,000	<0.25 (aversion response)	RG 3 High

Table 1: RG classification from EN 62471

Radiance is a measure of the density of the radiation that enters the eye (expressed in W/m^2sr). If only light in the visible spectrum is considered, we talk about luminance (expressed in cd/m²). Table 2 provides typical luminance values of common light sources.

Light Source	**Luminance [cd/m2]**	**Where mainly used**
CFL-I with outer bulb	23,000	home
CFL-I discharge tube	50,000	home
LED Diffuse bulb	150,000	home
Incand. 60W clear bulb 230V	7,000,000	home
Halogen 42W clear bulb 230V	8,000,000	home
Halogen 230W DE R7s 230V	13,000,000	home
Halogen 12V (also IR-coated))	15,000,000	Shops/home
SUN	160,000,000	outdoor

Table 2: Calculated luminances of various sources

Fluorescent tubes emit large amounts of light, but do so over a large lamp surface and have low luminance, usually in the range of tens of thousands cd/m². On the other hand, a halogen filament emits light from a very small surface area and has high luminance, usually in the range of several millions cd/m². The luminance of the brightest bare LED (component) on the market today is in the order of ten million cd/m². The sun has a luminance in the order of 1 billion cd/m2.

The luminance of a number of light sources was determined using the method described in EN 62471, section 5.2.2.2. The spectral characteristics were determined simultaneously in order to perform the calculation of the Blue Light Radiance L_B (Radiance spectrally weighted with the action spectrum for blue light hazard) values.

The results are plotted in the next two figures:

Blue Light Radiance L_B of diffuse sources

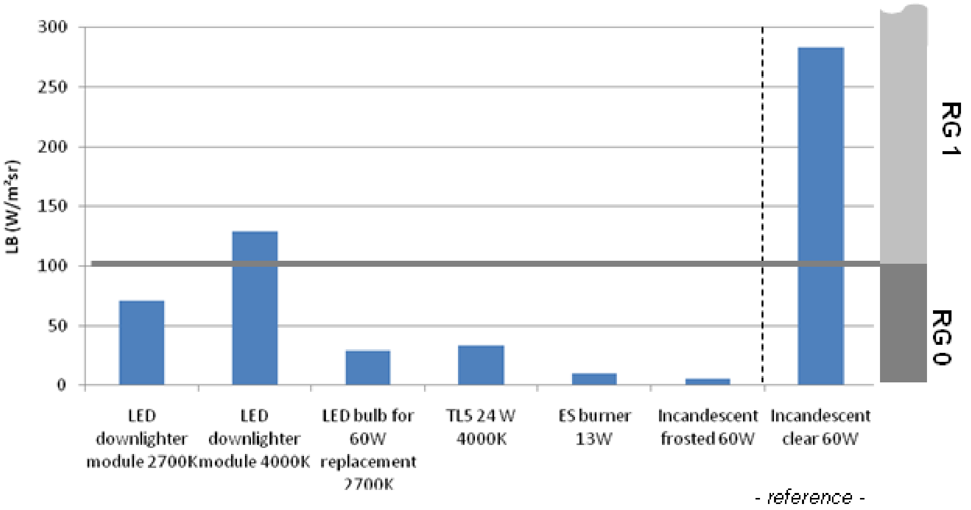


Figure 5: Blue Light radiance L_B for several common low luminance light sources: incandescent lamps, fluorescent lamps, and their LED replacements. As a reference, a clear incandescent lamp is also plotted

Blue Light Radiance L_B of some typical point-like sources

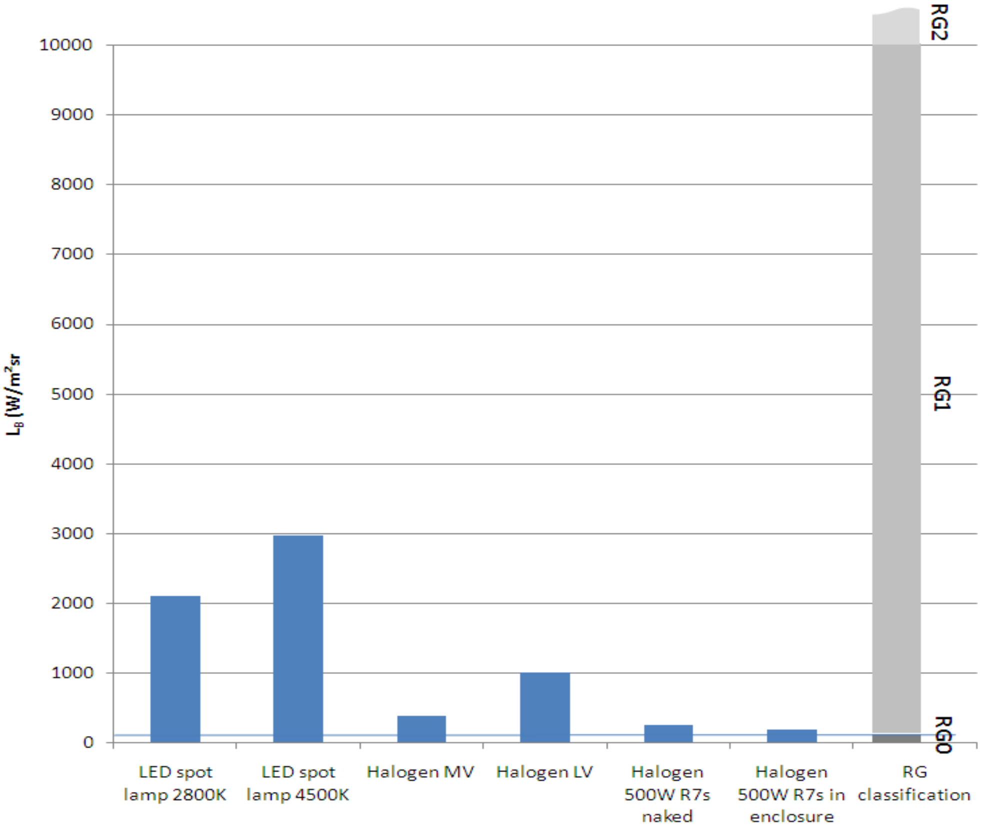


Figure 6: Blue Light Radiance L_B for several high luminance light sources: halogen lamps, high-intensity discharge lamps, and their LED replacements.

Conclusions on Blue Light Radiance:

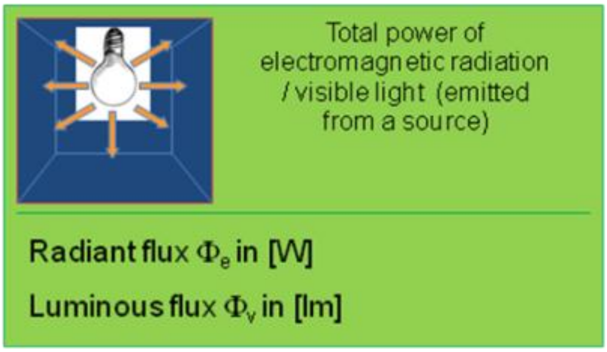
- The blue light radiance L_B of **diffuse light sources** is relatively low. Assigning the light source to risk groups (EN 62471) based on the L_B values, reveals that most fall into RG 0. At higher color temperature (4000 K) some may barely fall into RG 1 with maximum exposure times of more than an hour. Please note that this exposure time refers to a close direct gaze into the source. In normal conditions of use, where distances are much greater than the measuring condition of 200mm to the source, this is completely safe. In addition, in a reflexive reaction humans turn away from bright light sources, so that such exposure times are not reachable.

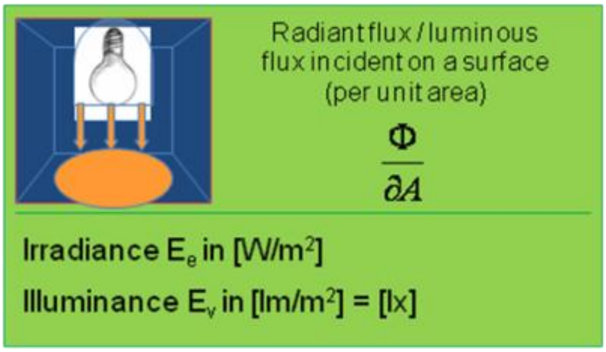
- All **point-like light sources** evaluated here fall in RG 1 and are considered to be safe by the standard and do not require additional warning markings, but prolonged direct viewing directly into these sources must be avoided especially at short distances. Maximum exposure times for the lamps shown here are 200 seconds or longer, but as already mentioned earlier, people will close their eyes or look away in such cases (instinctive aversion reaction). This holds for the high-luminance LED sources just as much as for the high-luminance light sources that have traditionally been used for general lighting for many years.

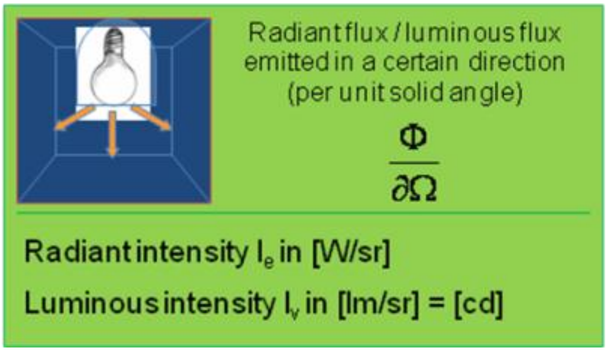
Annex 4: Terminology

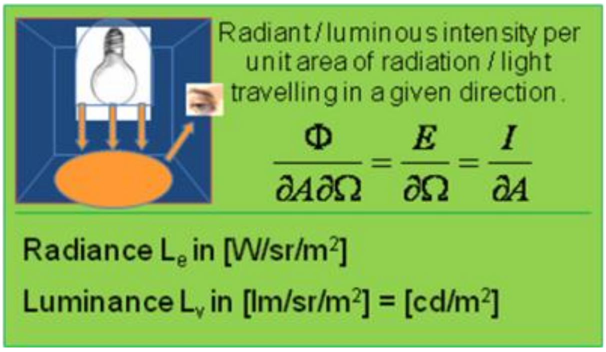
quantity	symbol	unit	explanation
irradiance	E_{rad}	W/m^2	radiant power per area arriving on a certain plane
illuminance	E	lux	irradiance, spectrally weighted with the photopic eye sensitivity curve
blue hazard irradiance	E_B	W/m^2	irradiance, spectrally weighted with the blue hazard curve
radiance	L_{rad}	W/m^2sr	radiant intensity per area emitted from a source
luminance	L	cd/m^2	radiance, spectrally weighted with the photopic eye sensitivity curve
blue hazard radiance	L_B	W/m^2sr	radiance, spectrally weighted with the blue hazard curve

Table 3: overview of units of measure relevant in this article



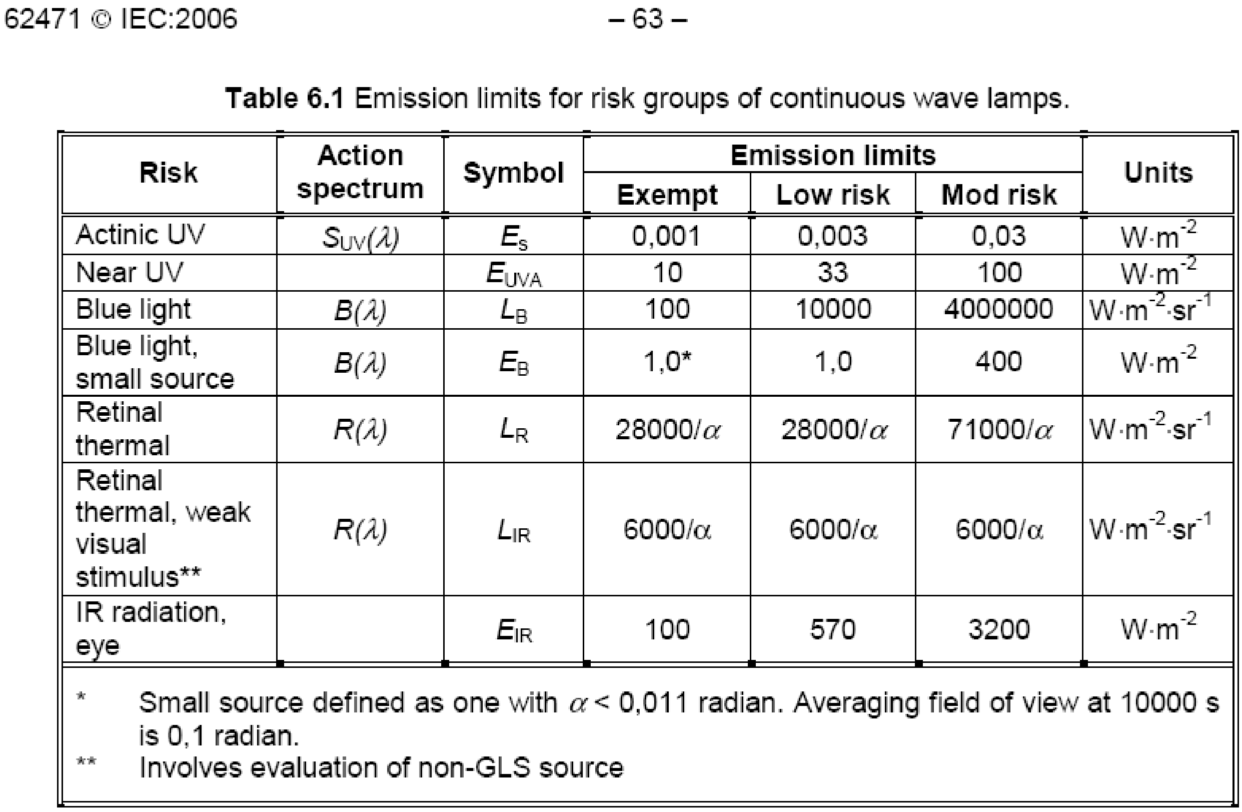






Radiant flux, irradiance, radiant intensity and radiance refer to radiation across all wavelengths. Luminous flux, illuminance, luminous intensity and luminance give the analogue dimensions, but limited to the visible spectrum (spectrally weighted with the visual sensitivity curve of the human eye to light of different wavelengths).

Annex 5: Summary of Photobiological Risk Assessment Criteria in IEC 62471



62471 © IEC:2006 – 63 –

Table 6.1 Emission limits for risk groups of continuous wave lamps.

Risk	Action spectrum	Symbol	Emission limits			Units
			Exempt	**Low risk**	**Mod risk**	
Actinic UV	$S_{UV}(\lambda)$	E_S	0,001	0,003	0,03	$W \cdot m^{-2}$
Near UV		E_{UVA}	10	33	100	$W \cdot m^{-2}$
Blue light	$B(\lambda)$	L_B	100	10000	4000000	$W \cdot m^{-2} \cdot sr^{-1}$
Blue light, small source	$B(\lambda)$	E_B	1,0*	1,0	400	$W \cdot m^{-2}$
Retinal thermal	$R(\lambda)$	L_R	$28000/\alpha$	$28000/\alpha$	$71000/\alpha$	$W \cdot m^{-2} \cdot sr^{-1}$
Retinal thermal, weak visual stimulus**	$R(\lambda)$	L_{IR}	$6000/\alpha$	$6000/\alpha$	$6000/\alpha$	$W \cdot m^{-2} \cdot sr^{-1}$
IR radiation, eye		E_{IR}	100	570	3200	$W \cdot m^{-2}$

* Small source defined as one with $\alpha < 0,011$ radian. Averaging field of view at 10000 s is 0,1 radian.

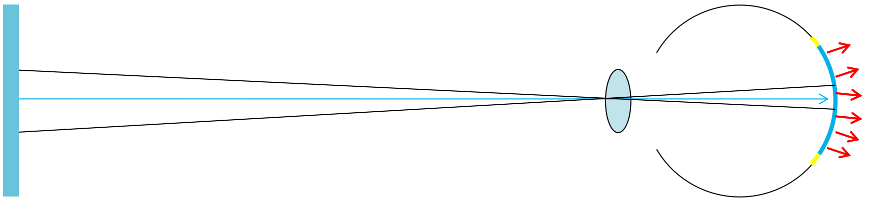
** Involves evaluation of non-GLS source

Table 4: Overview of risks group (RG) criteria (contained in EN 62471:2006)

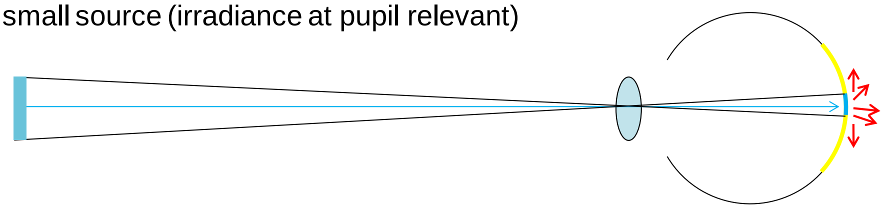
Annex 6: Optical Principles behind measurements

From EN 62471: relevancy large/small sources:

- large source (radiance of source relevant)

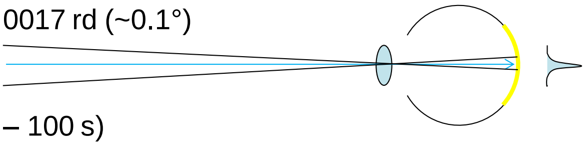


- small source (irradiance at pupil relevant)

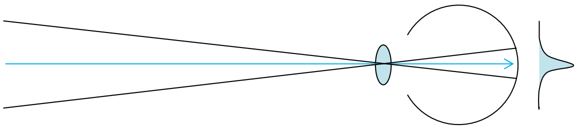


From EN 62471: different methods for measuring small/large sources

- very short exposure (< .25 s)
  small (point) source α_{min} = 0,0017 rd (~0.1°)
  due to intrinsic unsharpness



- intermediate exposure (10 s – 100 s)
  small source α_{eff} = 0,011 rd (~0.63°)
  due to rapid eye movement



- long exposure (> 10000 s)
  small source α_{eff} = 0,1 rd (~ 5.7°)
  due to task oriented eye movement

Eye movements & angular subtense

1 **1,7mrad**

- the smallest image that can be formed on the retina of a **still eye** is limited to a minimum value, α_{min} = 1,7 mrad (at exposure < 0,25 seconds = blink reflex time)

pure source radiance
"worst case"

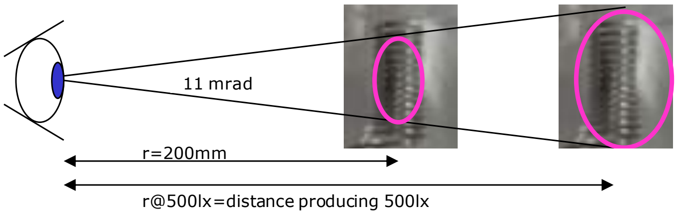
2 **11 mrad @ 200mm** **3** **11 mrad @ 500lx**

- at times greater than about 0,25 seconds, **rapid eye movements** begin to **smear** the image of point-like source over a larger angle, called α_{eff} = 11 mrad
- a light source subtending an angle less than 11mrad is defined as a "small source"

4 **100 mrad**

- at > 100 seconds, the image is further spread due to **task depended eye movements,** resulting in an maximal angular subtense α_{max} = 100 mrad (taken at exposure times > 10000 s)

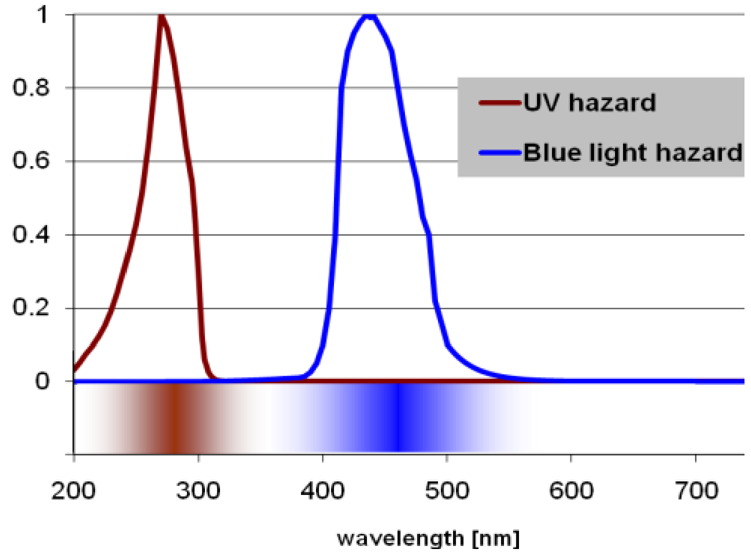
Measurement Field of View @ 200mm & @ distance producing 500 lx



measurement
FOV

Annex 7: Actinic UV and Blue Light Hazard action spectrum

The action curves for UV and Blue hazard are giving a weighting factor to the spectral radiation in the relevant part of the spectrum:



By multiplying the action curve values with the (normalized) spectral data of UV and/or light sources, comparative factors are obtained to compare these sources on the mentioned hazards.

Annex 8: Overview of lamps discussed in this paper

The lamp data presented in this paper are representative for the portfolio of the ELC companies

Used product name in document	Technology	Shape	Wattage	Colour temperature Tc [K]
Halo A60 28W MV burner 2700K E27 MV	Halogen 230V	A60 bulb	28	2700
Halo A60 40W LV burner 2830K E27 MV	Halogen 12V	A60 bulb	40	2830
Halo MR16 45W 24D IRC 2850K GU5.3 LV	Halogen 12V IR coated	MR16 reflector	45	2850
Halo Caps 28W 2800K UV-block G9 MV	Halogen 230V UV reduced	capsule	28	2800
Halo A60 25W 2600K E27 MV	Halogen 230V	A60 bulb	25	2600
ES bulb T60 827 2620K E27 MV	Compact Fluo	T60 bulb	11	2620
ES discharge tube 8W 827 2700K E27 MV	Compact Fluo	bended tubes	8	2700
Incand A60 60W 2700K frosted E27 MV	Incandescent	A60 bulb	60	2700
LED A60 6W 2700K E27 MV	LED	A60 bulb	6	2700
LED MR16 7W 40D 2700K GU10 MV	LED	MR16 reflector	7	2700
LED MR16 7W 40D 4200K GU10 MV	LED	MR16 reflector	7	4200
LED K60 12W 2700K E27 MV	LED remote phosphor	K60 bulb	12	2700
TLD 18W/840	Fluorescent 26mm	Tube	18	4000
T5 54W/6500K	Fluorescent 16mm	Tube	54	6500
T5 24W/4000K	Fluorescent 16mm	Tube	54	4000
T5 24W/17000K	Fluorescent 16mm	Tube	24	15000
TLED 11W/4000K	LED tube 26mm	Tube	11	4000
LEDlamp 6500K 350lm	LED	A60 bulb	6	6500
R7s halogen 500W	Halogen 230V	double ended	500	2700

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End of White Paper