Optical safety of LED lighting

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1. Background

With the phasing-out of incandescent lamps in the European Union as well as simultaneously in many other countries, the introduction of many new LED based light sources (lamps, modules) and luminaires, raises the question as to whether the spectral characteristics of the LED and Energy Saving fluorescent lamps (CFL integrated) are good enough to replace traditional incandescent lamps. These concerns are generally raised by groups of people with a high sensitivity for certain radiation on their skin or eyes, especially for radiation in the UV and blue part of the spectrum. This document will focus on white light sources and their use in households.

2. Summary statement

It is often emphasized that LED based light sources are different from traditional lamps in that they contain higher proportions of blue wavelength light and are thus more likely to cause problems such as blue light hazard. Confronted with this question, the European Lighting Industry represented by ELC & CELMA, presents a detailed evaluation of the photo biological safety of common LED light sources for domestic use in comparison to traditional lamps. The focus is on white light sources used in households.

To summarize the key findings, **LED sources** (lamps or systems) **and luminaires are safe to the consumer** when used as intended. In terms of their level of photo biological safety, LED lamps are no different from traditional technologies such as incandescent lamps and fluorescent tubes. The portion of blue in LED is not different from the portion of blue in lamps using other technologies at the same colour temperature. A comparison of LED retrofit products to the traditional products they are intended to replace reveals that the risk levels are very similar and well within the uncritical range.

Nevertheless, looking straight into bright, point-like sources (LEDs, but also other strong point-like light sources, like clear filament or discharge lamps and including the sun) should be prevented. However, 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 needs to be mentioned that blue light exposure is important to human beings. Blue light with a peak at around 460-480nm regulates the biological clock, alertness and metabolic processes. In natural conditions, outdoor daylight fulfils this function. Yet, people spend most of the day indoors (offices etc.) 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. Due to the highly flexible application possibilities, LED based light sources are particularly well suited for that purpose.

3. LED and optical safety

Optical safety refers to the prevention[1] of hazards through optical radiation (electromagnetic radiation of wavelengths ranging from 100 nm to 1 mm). Effects on the eyes as well as the skin are considered, also for those people with a higher sensitivity. In response to the concerns raised by the last group, Annex 1 provides more detailed considerations for this specific group.

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. 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 reflex occurs (eyelid close reflex, aversion) that protects the eye from being harmed. 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 at extreme intensities can lead to retinal thermal injuries.

Optical radiation can also affect the skin causing for example sunburns, or, in severe cases, cancers upon long-term UV exposure. There exist certain groups of patients, e.g. 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. Nevertheless, the optical safety of artificial light sources needs to be guaranteed and light-sensitive patients are provided with appropriate lamps that are a good and safe alternative to incandescent lamps.

4. Photo biological risk assessment and conclusions

The photochemical blue light hazard can be evaluated on the basis of the standard EN 62471. The latter classifies light sources into risk groups 0, 1, 2 and 3 (from 0 = no risk through to 3 = high risk). The sun would be classified as being in the highest risk group. CELMA and ELC member companies ensure that their products comply with the photo biological safety standard.

Risks can be allocated to the risk groups according to different measurement criteria:

One method measures the distance at which an illuminance of **500 Lux** is attained (a typical value for general lighting purposes). According to EN 62471, the **500 Lux** criterion must be used for lamps intended **for general lighting** (including lamps for lighting offices, schools, homes, factories, roadways, or automobiles).

A second criterion measures photo biological 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 fundamentally purposeful to make this distinction – 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, e.g. during quality control processes. In such cases special instructions are needed to prevent eye damage.

When light sources are placed in a luminaire, the RG classification can change by the optics used in the luminaire:

1. In case a luminaire integrate a light source classified RG0 or RG1, no new tests are necessary

[1] Exposure limits defined in the standard EN-62471 are in European regulation (directive 2006/25/CE)

2. In case a luminaire is not intending to change an integrated light source with classification RG2 or RG#3, no new tests are necessary and product information shall indicate the mentioned RG class.
3. In case a luminaire is changing the original characteristics of the used light source RG2 or RG 3 in any form, a new measurement is needed to classify the luminaire.

4.1 Conclusions on blue light emission

Evaluation at a distance producing 500 Lux:
Taking the 500 Lux criterion as the measurement basis, none of the LED products belongs to risk group 2. This was also confirmed by a study of the French agency for food, environmental and occupational health & safety (ANSES) in 2010 which found that even high-output discrete LEDs are classified into risk groups 0 or 1 if the 500 Lux criterion is applied.

LED compared to other light sources
With regard to photo biological safety, LED is not fundamentally different to lamps using traditional technologies, such as incandescent or fluorescent lamps. The portion of blue light in LED 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 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), it appears that the risk group ratings are similar.

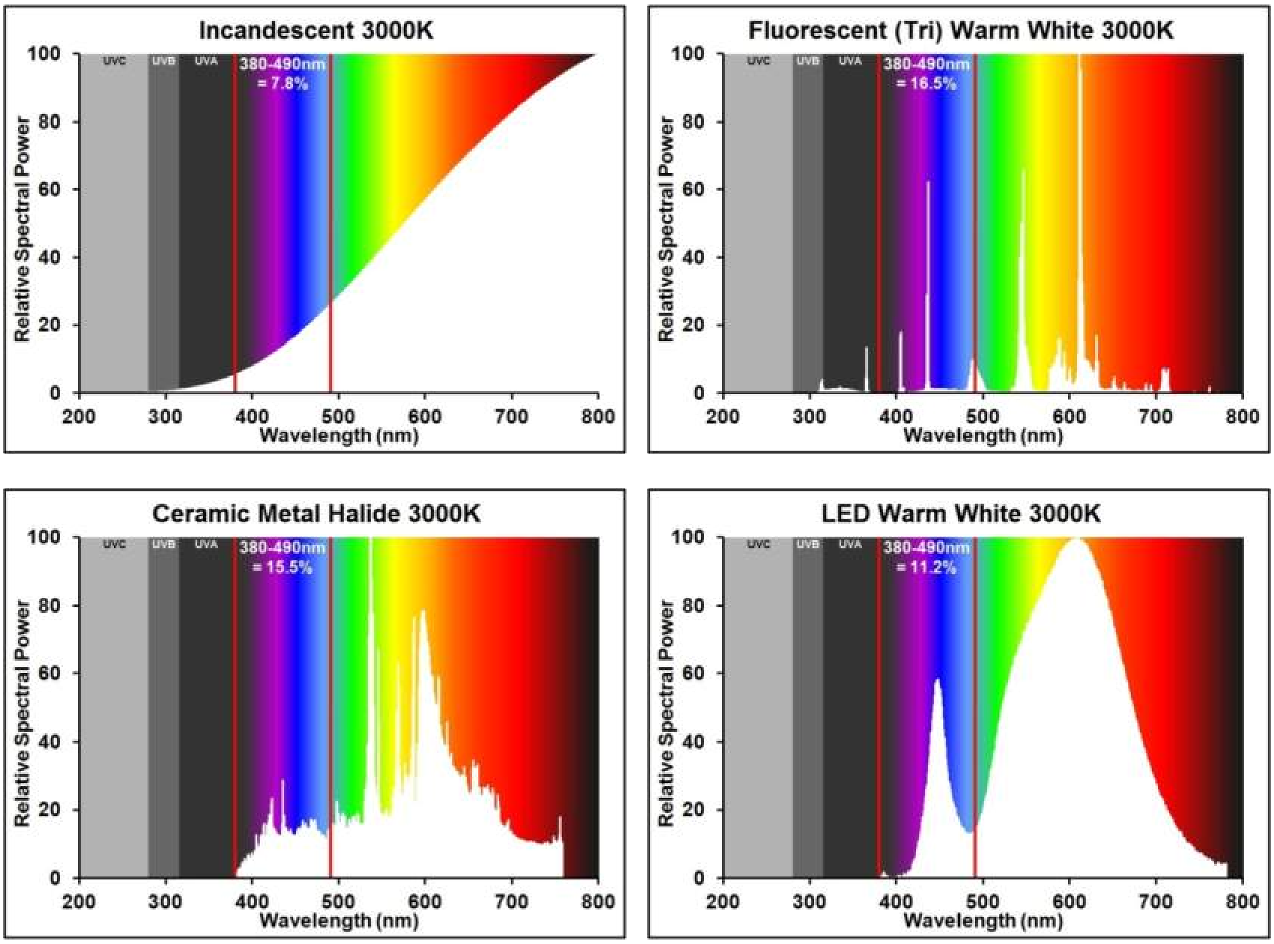


Figure 1: relative spectral power of various lightsources

Precautionary measures with regard to 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. Therefore, at places frequented by children particular care must be taken to ensure that lamps and luminaires are chosen and installed in such a way as to avoid people looking directly into the light source. It is not necessary that LEDs (or blue light in general) are avoided in an environment with children present, for the reasons stated above. If used across a broad surface or area, in a way which does not produce glare, even "pure" blue light is completely harmless; regardless of whether it is the blue in daylight or produced by LEDs or other light sources.

Guidance for people with high sensitivity for blue light

The above statements are valid for healthy people in the general public. People 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. The comparative data given in the annexes of this paper serve to give guidance in selecting the best available type of light source for a given sensitivity.

The biological importance of blue light

It needs to be mentioned that blue light exposure is important to human beings. Blue light with a peak around 460-480nm regulates the biological clock, alertness and metabolic processes. CELMA-ELC has installed a special working group to translate these findings into practical application norms and standards. In natural conditions, outdoor daylight fulfils this function. Yet, people spend most of the day indoors (offices etc.) 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. Due to the highly flexible application possibilities, LED based light sources are particularly well suited for that purpose.

4.2 Conclusions on ultraviolet radiation (UV)

LED based light sources do not emit any UV radiation (unless specifically designed for that particular purpose). Therefore, they are not harmful to 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. 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 hardly emit IR light (unless specifically designed to emit a certain type of IR). For available types of indoor light sources the IR radiation is not powerful enough to pose any risks to human.

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.

To give a little more background details:

- *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 damages 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 damages); 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 more and more accumulating in the retinal cells with age, is destroyed by blue light causing oxidative damages. 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), 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 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 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 are.

Potential effects on the skin

Optical radiation, particularly UV can be harmful to the skin. By far the most hazardous source to consider 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-i, halogen) are graphically presented and evaluated qualitatively (a quantitative evaluation will follow in **Annex 3**). Focus of interest is on the spectral irradiance in the blue and ultraviolet part of the different types of light sources in comparison to the two "golden" 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 be showing well 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 interested in 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 4**).

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.

Energy savers (compact fluorescent integrated) spectral characteristics
In Figure 1 - middle, spectra of two common types of energy savers (or CFLi, Compact Fluorescent Integrated) are shown and compared to an incandescent lamp and daylight. Typical energy savers' spectra contain multiple "sharp" peaks and dips. Again, when considering the area under the curve to determine the blue irradiance, peaks and dips level each other out. Note that the high peaks are very narrow and therefore do not contribute that much 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 very low (!) and clearly below the emissions of natural daylight.

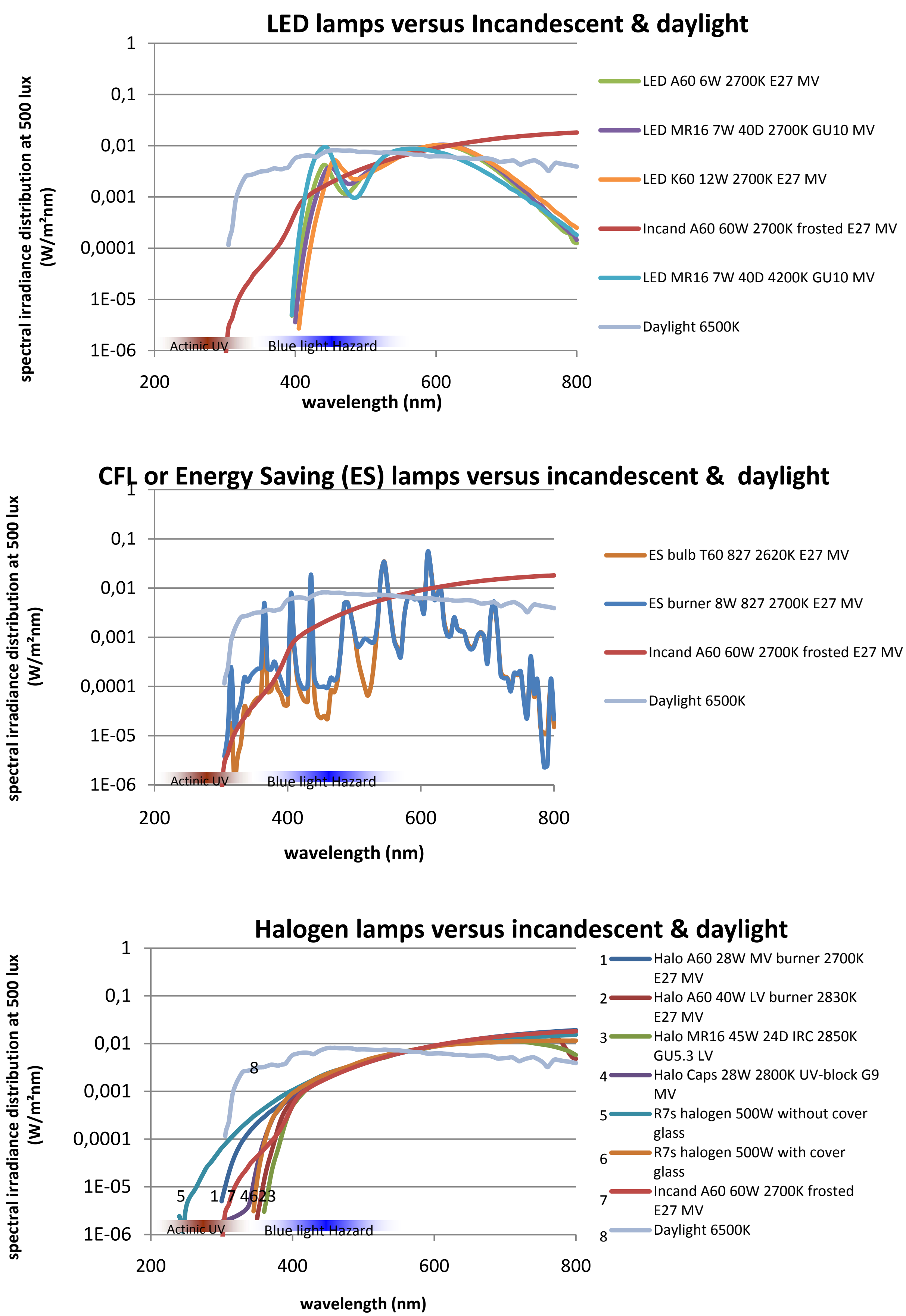


Figure 2: A collection of spectra from different common light sources is shown, together with a representative daylight spectrum scaled to the same illuminance level. The UV-Actinic and BLH action curves (as defined in e.g. EN 62471, see annex 4.3) are indicated by the brown and blue bars, respectively, 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 the 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 rather low, as the scale is logarithmic not linear.

Summary

Even though the spectra of LED, CFLi, 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 emission is well below the exposure limits as defined in EN 62471. LEDs used for general lighting are free of UV (aside very special types that are designed to emit UV).

Legend 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 (230V, 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 known incandescent lamps as a replacement for those lamps (E27 MV).
- **Fluo-ES:** Energy Saver (popular name) or Compact Fluorescent Integrated (CFL-I, technical name), can be just the fluorescent tube (burner) or have a second shell (bulb)
- **Incand:** Incandescent lamp, considered by the market as the golden 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 taken

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 amount 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 way less blue irradiance than daylight.

Case B: Looking at a light source
When evaluating photobiological risks (based on EN 62471) the more severe case of looking directly into a light source is considered. 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 causes damages.

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 here discussed in more detail:

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 (next page) 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.

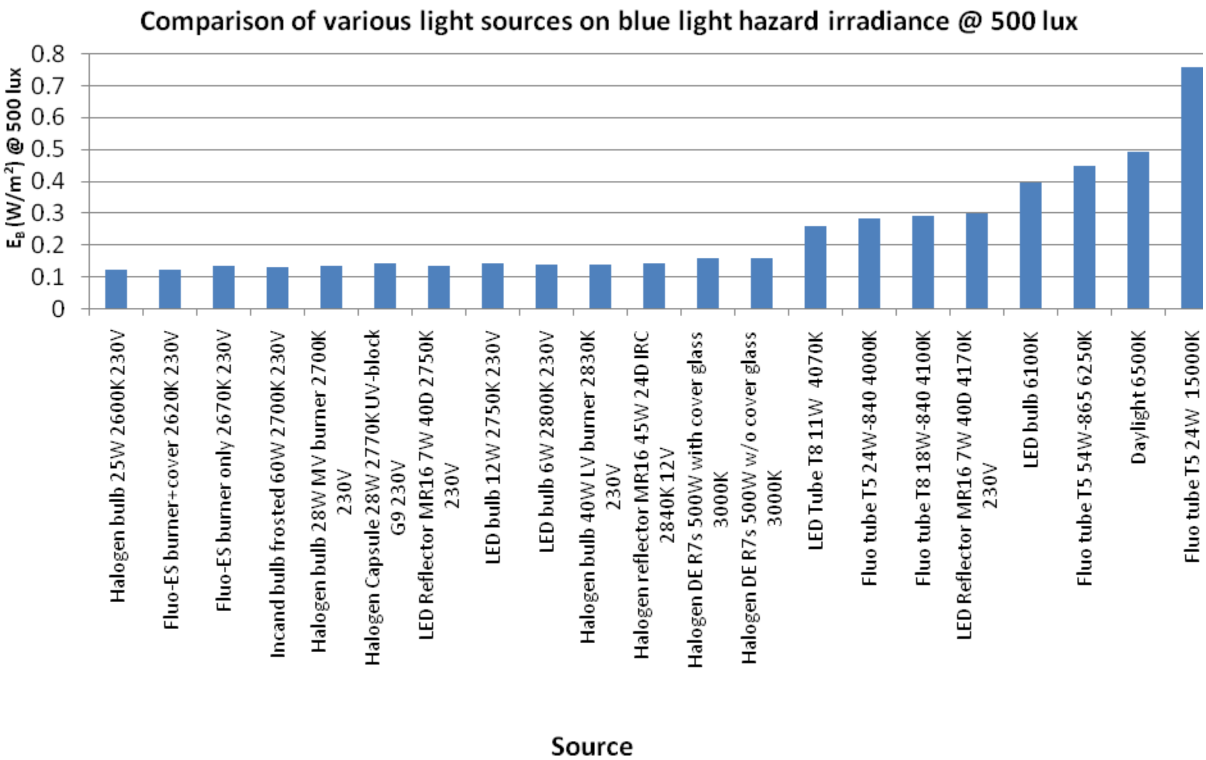


Figure 3: Comparison of E_B values of the different lamp types and daylight.

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.

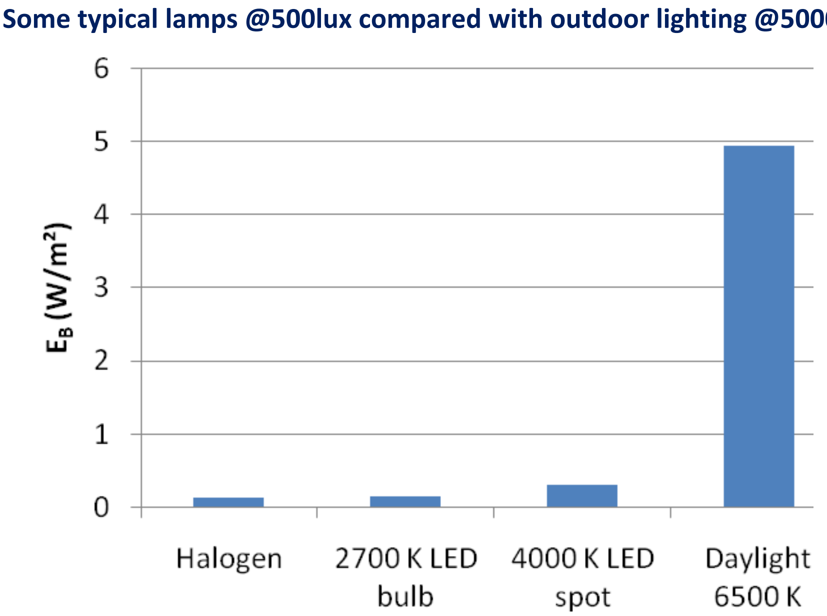


Figure 4: comparison of irradiance values of some lamp types at 500 lux (typical for indoor) with daylight at 5000 lux (typical for outdoor lighting)

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 low to 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 difference 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 difference 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 standard, 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 hits the eye (given in W/m^{2}sr). If only light in the visible spectrum is considered, we talk about Luminance (given in cd/m²).
To get an impression of the radiance/luminance of various light sources, including the sun, please stable 2 with calculated luminances of various sources:

Name product	**Luminance [cd/m2]**	**where mainly used**
CFL-I with outer bulb	23,000	home
CFL-I tube-burner	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 be able 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 <u>diffuse sources</u>

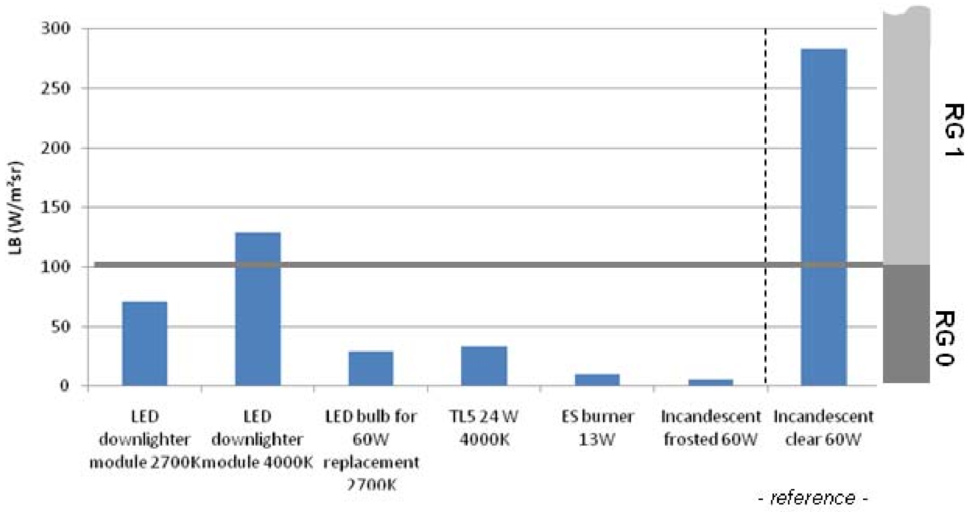


Figure 5: Blue Light radiance L_B for several common low luminance light sources: incandescent lamps, fluorescent lamps, and their LED replacements. As a reference, also a clear incandescent lamp is plotted

Blue Light Radiance L_B of some typical <u>point-like sources</u>

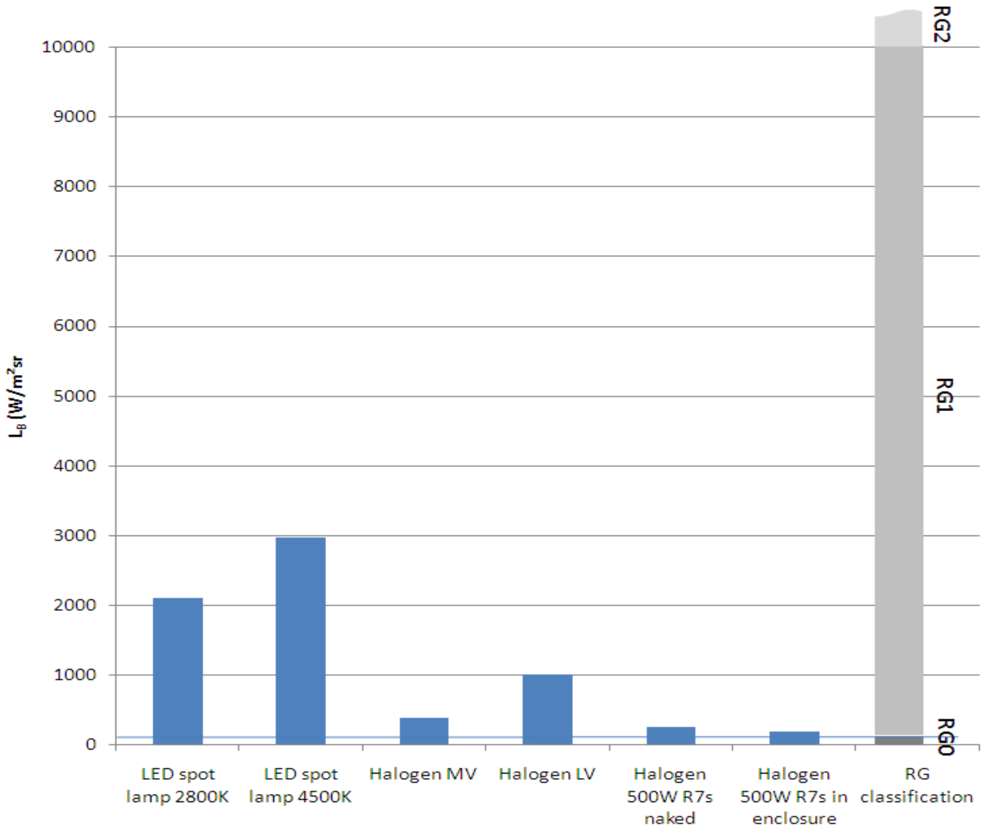


Figure 6: Blue Light Radiance L_B for several high luminance light sources: halogen lamps, high-intensity discharge lamps, and their LED replacements. (note: scale differs from Figure 4)

Conclusions on Blue Light Radiance figures:

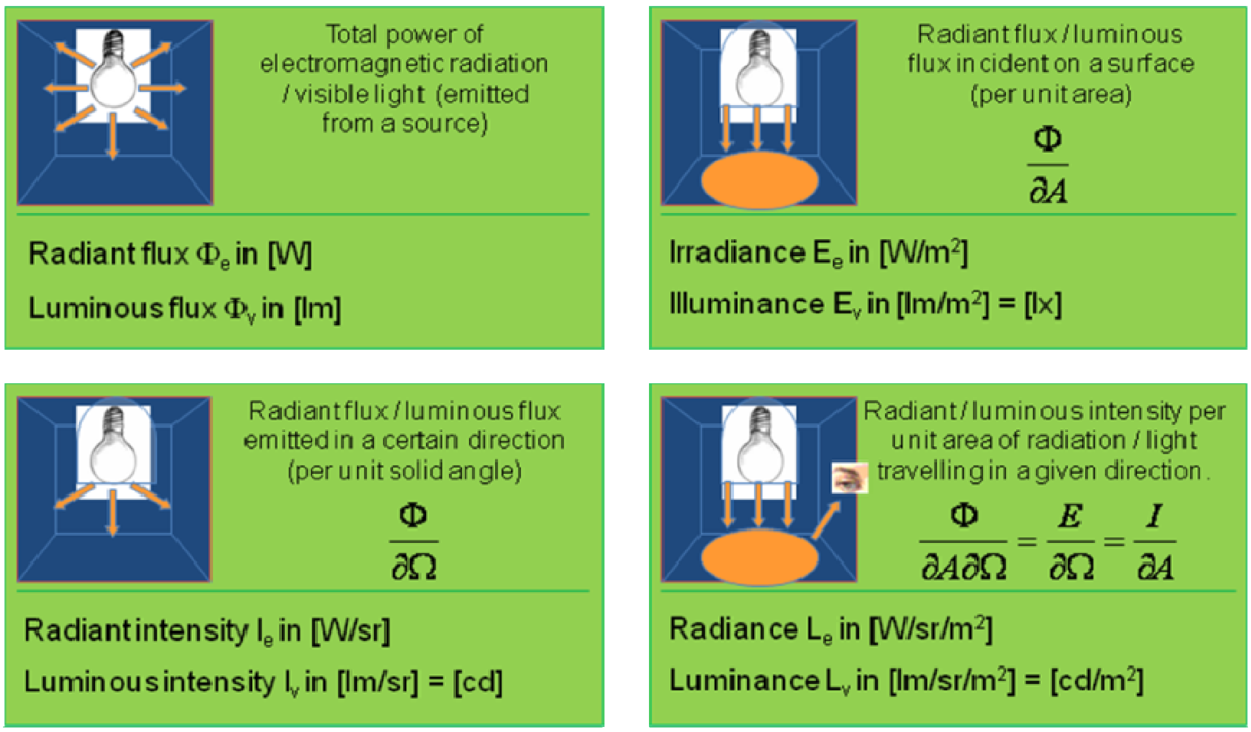
- The blue light radiance L_B of **diffuse light sources** is relatively low. Assigning the light source to risk groups (EN 62471) based on the L_B values, reveals that most of them fall into RG 0, at higher color temperature (4000 K) some may just fall in RG 1 with maximum exposure times of more than 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 bigger 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 sec 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 are longer on the market.

Annex 4: Terminology explained

quantity	symbol	unit	explanation
irradiance	E_{rad}	W/m²	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/m²	irradiance, spectrally weighted with the blue hazard curve
radiance	L_{rad}	W/m²sr	radiant intensity per area emitted from a source
luminance	L	cd/m²	radiance, spectrally weighted with the photopic eye sensitivity curve
blue hazard radiance	L_B	W/m²sr	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).

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.

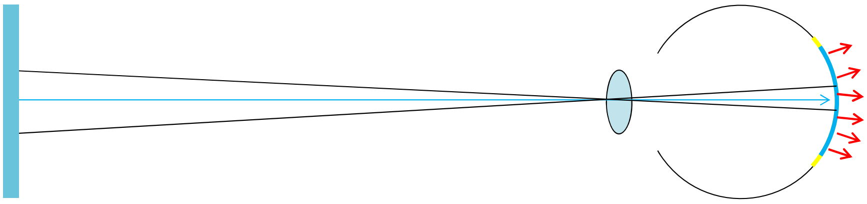
** Involves evaluation of non-GLS source

Table 4: overview risks groups (taken from EN 62471:2006)

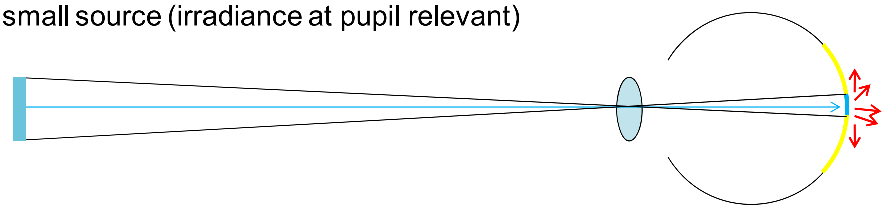
Principles behind measurements

EN 62471: relevancy large/small sources:

- large source (radiance of source relevant)

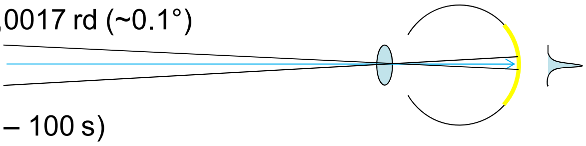


- small source (irradiance at pupil relevant)

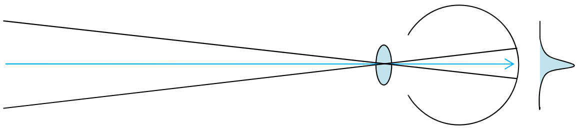


EN 62471: different methods for measuring small/large sources

- 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”

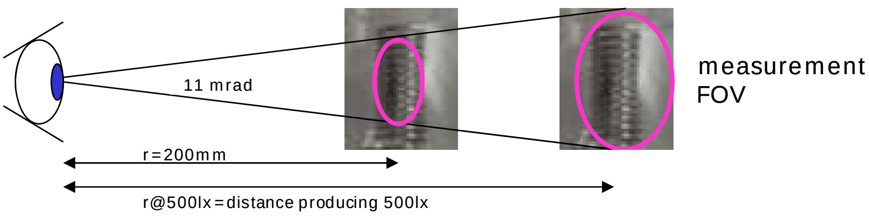
2 **11 mrad @ 200mm** **3** **11 mrad @ 500lx**

- 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**

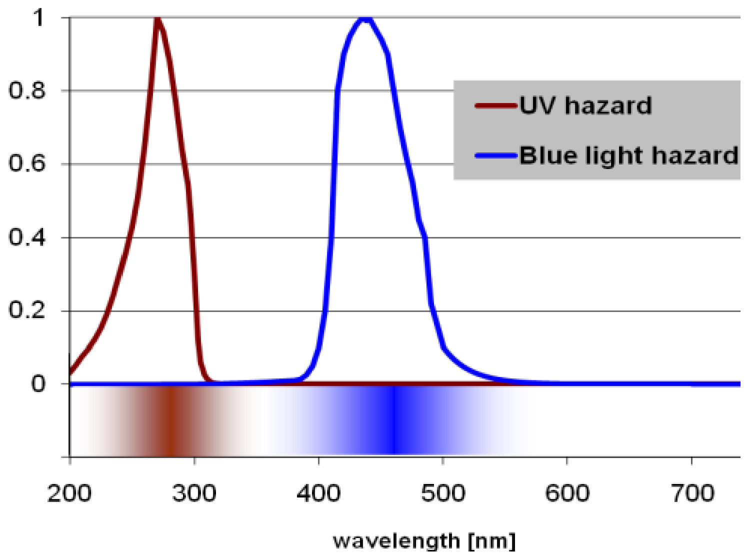
- at > 100 seconds, the image is further spread due to **task depended eye movements**, resulting in an maximal angular subtense α_{max} = 100 mrad (taken at exposure times > 10000 s)

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



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 5: 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 burner 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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