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LEDs and Solid-State Lighting: the potential health issues

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Abstract

Solid-state lighting (SSL) is expected to become the most widely used type of light source, promising to bring significant energy savings as it replaces older technologies. However, due to specific spectral characteristics of white light emitting diodes (LEDs), as compared to other artificial sources, some concerns have been raised regarding safety. SSL products should be proven to be at least as safe as the products they intend to replace, and new or unusual conditions of usage should be considered.

This paper deals with potential health issues related to LED lighting, with a focus on light flickering and the “blue light hazard”. An overview is given on current studies and latest expert opinions on photobiological safety. Following our measurements, the risk groups of a few consumer LED lamps are determined. We also make recommendations on how to limit the risk through regulation at the EU level. In addition, we have studied the flickering of fifty LED lamps, which were found to have widely varying behaviour (ranging from zero to one hundred per cent flickering). This last result is rather embarrassing because light flicker may cause temporary illness and visual fatigue. It is rather clear that the potential impacts of LED products on human health and well being has to be taken into account seriously before low quality and potentially harmful products submerge the European market.

Introduction

Solid-state lighting (SSL) is currently revolutionizing the field of lighting and its practices. In the long term, inorganic and organic light emitting diodes (LEDs) will become the most widely used light sources. White LEDs have shown a steady growth of their luminous efficacy for more than fifteen years; promising to bring significant energy savings as they replace older lighting technologies. However, as any new or emerging technology, SSL products should be proven to be at least as safe as the products they intend to replace. Also, in new lighting applications where older technologies could not be employed, the safety of SSL products should be assessed considering new or unusual conditions of usage.

The potential risks posed by SSL to the human health can be classified into the three following categories:

- potential risks due to the emitted optical radiations: interactions of the optical radiations with the skin and the eye (photobiological safety), undesired effects of optical radiations on vision (glare and flickering effects in particular);
- effects of optical radiations on circadian rhythms;
- electrical safety;
- and potentials risks due to exposure to electromagnetic fields.

The first two points are due to the specific spectral characteristics of white LEDs as compared to other artificial light sources. This paper focuses on these issues, and more especially on the blue light hazard and flickering. A paper section is devoted to each one of those points. Experimental results obtained at both LAPLACE¹ and CSTB² are used to support the discussion.

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Photobiological hazards

Photobiological hazards are related to the effects of optical radiation on the skin and the eye. The interactions of radiation with biologic systems occur through absorption, with the radiant energy being transferred to the biological tissues. Two main mechanisms can be distinguished [1]:

- heat related, where radiant energy is converted into molecular movement (kinetic energy) such as vibration, rotation and translation;
- photochemistry, where radiant energy causes excitation of atoms or molecules, displacing the outermost valence electrons to higher orbital energy levels. This energy can subsequently be utilized in (photo-)chemical reactions yielding 'photoproducts'.

Two key features of LEDs have attracted the attention of lighting specialists, ophthalmologists and photobiologists:

- most LEDs are small sources emitting very bright visible light;
- the vast majority of commercial LEDs producing white light rely on a chip emitting blue light associated with layers of phosphors to produce longer wavelengths by fluorescence. As a consequence, the emission spectrum of a white LED consists in a narrow blue primary peak and a large secondary peak in the yellow-orange-red region. These two peaks are separated by a region of very low emission in the blue-green part of the spectrum. Such typical white light LED spectrum is illustrated on Figure 1.

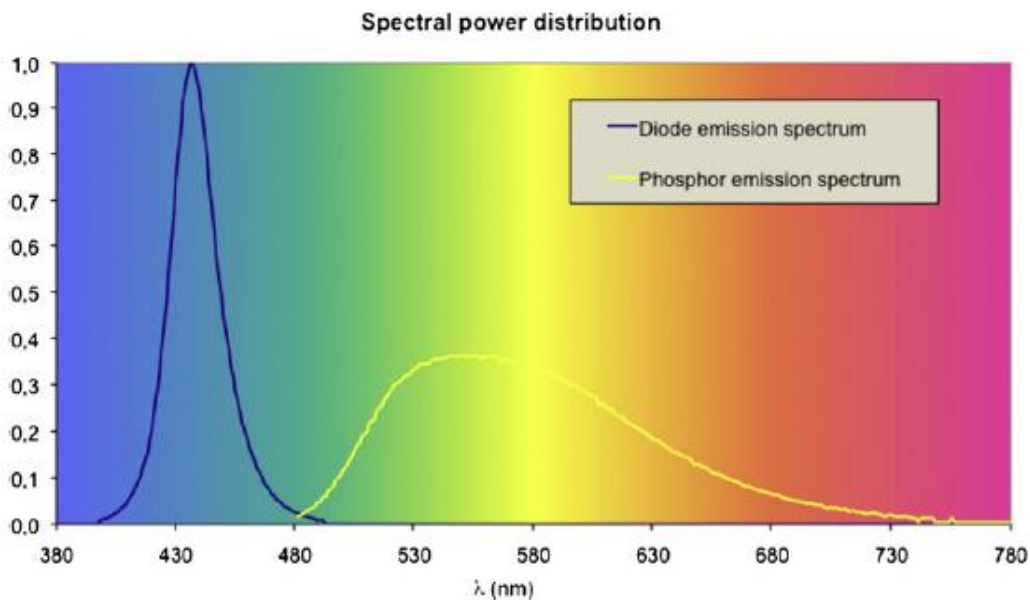


Figure 1: The two components of a typical white high-brightness LED spectrum.

Note that LEDs currently used in SSL emit negligible amounts of ultraviolet and infrared radiations, hence only visible light related effects are under scrutiny.

Radiation hazards for the human eye

The exposure levels needed to produce thermal damage on the retina cannot be met with light emitted by LEDs of current technologies. As far as the eye is concerned, adverse photochemical effects of light are summarized in Figure 2.

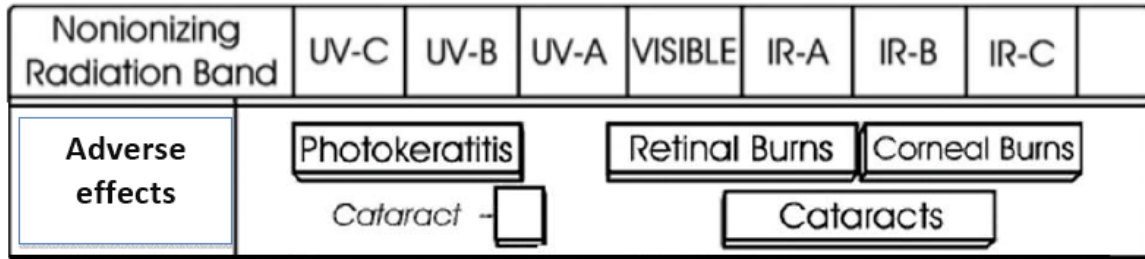


Figure 2: Adverse photochemical effects on the eye tissues as a function of wavelength [2]

In general, photochemical damages on the retina depend on the accumulated dose to which the subject was exposed (*i.e.* short exposure of high intensity or low intensity over longer periods).

The only effect of acute exposure to UV, particularly UVB and UVC below 300 nm, is photokeratitis of the cornea and conjunctiva. The accepted threshold levels for photokeratitis is 3-4 mJ/cm² at 270 nm and 10 mJ/cm² at 300 nm. Infrared radiation may be responsible for cataracts; the accepted threshold is in the order of 4 W/cm² for wavelengths higher than 800 nm [2]. As LEDs used in lighting applications emit negligible amounts of UV and IR, it should not be expected to contribute to the apparition of photokeratitis and cataracts. However, chronic effects of exposure to LED light are unknown. It should be noted that chronic UV exposure from sunlight might cause corneal lesions (climatic droplet keratopathy), as well as cortical and nuclear cataracts of the lens.

As far as other wavelengths are concerned, visible light is focused on the retina by the cornea and the crystalline lens. The amount of light falling on the retina is directly proportional to the radiance of the light source. Due to the high brightness of LEDs, the retinal illuminance levels are potentially high and must be carefully considered. For this reason, it is important to consider the potential retinal toxicity of LEDs.

Radiations in the blue end of the spectrum have long been known to provoke photochemical retinal injuries [3]. The underlying physiological mechanism causes important injuries for exposures over ten seconds. Symptoms include permanent scotoma (or “blind spot”), and there is a strongly suspected link with age-related macular degeneration (AMD) [4]. Light-induced retinal degeneration is known to involve complex series of events such as apoptosis (cellular death), inflammatory response, and free radicals, but the full understanding of the phenomenon is still an active research field in ophthalmology.

Retinal blue light exposure can be estimated using the ICNIRP³ guidelines [5]. A quantity called the blue-light weighted radiance L_B can be obtained as a function of the viewing distance and the exposure time. It can be calculated as follows:

$$L_B(\vec{x}, \vartheta) = \int_{300nm}^{700nm} L(\vec{x}, \vartheta, \lambda) B(\lambda) d\lambda$$

Where $L(\vec{x}, \vartheta, \lambda)$ is the spectral radiance at wavelength λ at a position \vec{x} on a surface in a direction defined by angle ϑ to the normal of the surface and $B(\lambda)$ is the Blue Light Hazard sensibility function given in Figure 3.

³ International Commission for Non-Ionising Radiation Protection

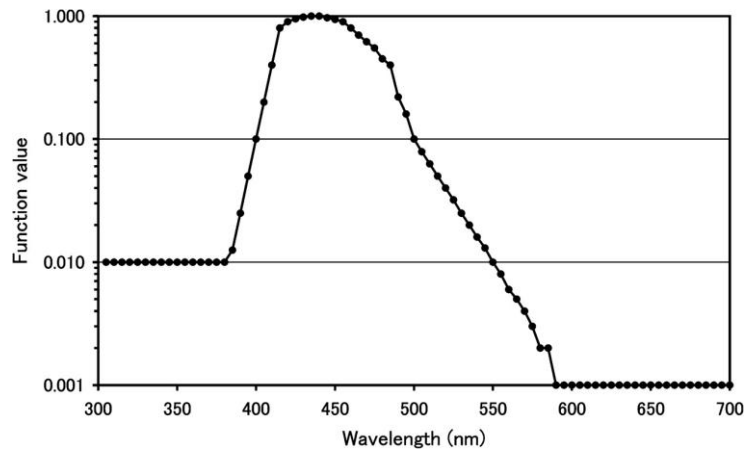


Figure 3: Blue light hazard function as given by [6]

Maximum permissible exposure values (MPEs) were set by ICNIRP to provide limits for L_B as a function of exposure time [17,18]. These limits are dependent on the exposure time. In addition L_B is not intended to be measured for infinitesimal solid angle and surface, but averaged over a finite field of view called the “effective field of view” (FOV). The FOV is precisely defined by the ICNIRP guidelines. It increases with the exposure time in order to account for the spreading of the image of the light source on the retina with the micro-movements of the eye.

For all LEDs and products using LEDs, a photobiological blue light hazard assessment must be carried out to determine whether or not the MPEs can be exceeded in the conditions of usage. The main tool to perform photobiological risk assessment is the CIE S009 publication whose content was transposed in an international standard (IEC 62471) and other national standards (IESNA RP27, JIS C8159, etc.).

Based on IEC 62471, lamps and lamp systems are classified into risk groups for various photobiological hazards. The risk group depends on the maximum permissible exposure time (MPE time) assessed at a given viewing distance:

- Exempt Group (RG0: no risk): MPE not exceeded within 10^4 s;
- Risk Group 1 (RG1: low risk): MPE not exceeded within 10^2 s;
- Risk Group 2 (RG2: moderate risk): MPE not exceeded within $2,5 \times 10^{-1}$ s (eye blink time)
- Risk Group 3 (RG3: high risk): MPE exceeded even for momentary or brief exposure (less than $2,5 \times 10^{-1}$ s).

For the past few years, blue light exposure data have been provided by LED manufacturers, professional lighting associations, independent laboratories, and governmental agencies. It was found that the retinal blue light exposure levels L_B produced at a distance of 200 mm from the user by blue and cold-white LEDs (bare LEDs and LEDs equipped with a focusing lens) exceed the MPEs limits set by ICNIRP after an exposure time comprised between a few seconds for high power blue LEDs to a few tens of seconds for high power cold-white LEDs. Figure 4 shows L_B for the six blue LEDs chosen by the ANSES working group [7] and published in [8]. In this example, the LEDs were operated such that they emitted a radiant flux of 0,5W, which is about half the rated maximum value.

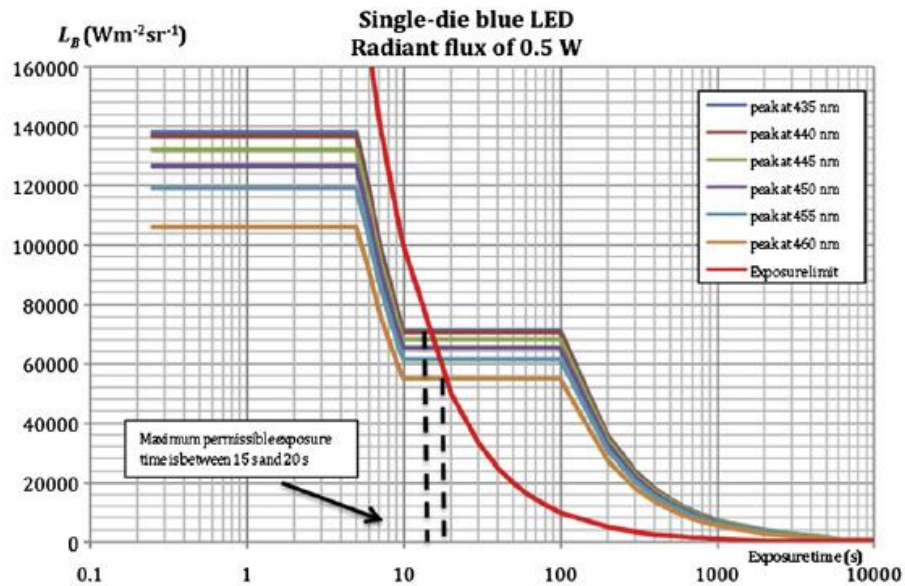


Figure 4: Variation of L_B with the exposure time determined for six types of blue LEDs (measured by CSTB). The red curve is the exposure limit value. The intersect point corresponds to the maximum permissible exposure time. It can be used to determine the risk group [8]

These L_B curves exhibit a first plateau corresponding to a uniform luminance when the FOV is smaller than the light source. When the FOV is greater than the size of the effective light source, the luminance L_B decreases following a $1/t$ law. The second plateau corresponds to a constant FOV, when the exposure time is comprised between 10 s and 100 s. After 100 s, the FOV increases again and the luminance L_B decreases again as $1/t$. In this example, the maximum permissible exposure times of these LEDs are between 15 s and 20 s. These values correspond to the Risk Group 2 (moderate risk).

For this study, we used various single LEDs under conditions of constant luminous flux. When cold-white LEDs were operated such as to provide a luminous flux of 100 lm, the exposure limit value was never reached and the risk group was always 0 (no risk). By increasing the luminous flux to 200 lm, all the cold-white LEDs fell into risk group 2 (moderate risk) with maximum permissible exposure times comprised between 40s and 100s. Similarly, neutral-white LEDs operated at a luminous flux of 100 lm all fell in risk group 0. When operated at 200 lm, the exposure limit value was reached at an exposure time of about 100 s, thus the studied products fell into the risk group 1 (low risk). Warm-white LEDs never exceeded the exposure limit value and were always in risk group 0 (no risk), even when they were operated at a flux of 200 lm. In fact these warm-white LEDs should reach a luminous flux of at least 500 lm to belong to risk group 1 (low risk). Table 1 recapitulates these results.

Table 1: Risk groups and maximum exposure times for various LED lamps as measured by CSTB

LED type	Luminous flux (lm)	Risk Group	Max exposure time (s)
Cold White	100	RG0	No Risk
	200	RG2	Moderate Risk
Neutral White	100	RG0	No Risk
	200	RG1	Low risk
Warm White	100	RG0	No Risk
	200	RG0	No Risk
	500	RG1	Low risk

None of the studied single-die LEDs presented a high risk (risk group 3). Blue LEDs and cold-white LEDs may belong to risk group 2, according to their colour temperature and their operating point. Likewise, neutral-white LEDs may belong to risk group 1. On the contrary, all warm-white LEDs belonged to risk group 0.

Several classes of products and applications based on bare LEDs or LEDs covered by a focusing lens (collimator) could result in high levels of retinal blue light exposure when viewed from a short distance. Such conditions may occur because:

- of testing and adjustments of high power blue and cold white LEDs by operators in lighting manufacturing facilities or by lighting installers;
- bright cold white LED lamps in the visual field of children;
- automotive LED daytime running lights when activated near children and other sensitive people.
- LED lamps sold for home applications (consumer market) in which case lamps can be viewed at distances as short as 200 mm.

The photobiological safety of a final SSL product (lamp, luminaire, etc.) must be assessed independently of its LED components. As a matter of fact, the L_B value of an SSL product is generally very different from the L_B value of the LED components that it uses. For instance, a higher L_B can be obtained for a luminaire using an assembly of low L_B LEDs. On the opposite, a lower L_B can be obtained for a luminaire using a diffuser in front of a high L_B LED.

The IEC 62471 standard defines two different criteria to determine the viewing distance. Light sources used for general lighting service should be assessed at the distance corresponding to an illuminance of 500 lx. Other types of light sources should be assessed at a fixed distance of 200 mm.

For LED components, there is no ambiguity in the distance since LED components are not used very often in general lighting. In this case, IEC 62471 requires using the distance of 200 mm. The application of the IEC 62471 measurement technique at 200 mm leads to a classification in risk group 2 (moderate risk) for some high power blue and cold white LEDs.

However, the choice of the viewing distance in IEC 62471 is sometimes ambiguous and not realistic in the context of the real usage conditions. For instance, let us mention stage lighting (*i.e.* theatres and concert halls) where artists are exposed to illuminance levels higher than 500 lx. Applying the 500 lx criterion would underestimate the exposure while the 200 mm criterion would largely overestimate it. In a more common context, directional household lamps fall under the 500 lx criterion, which corresponds to a typical viewing distance of a few meters. It is however quite common to have shorter viewing distances, as short as 200 or 500 mm at home. Another example is street lighting where the illuminance level is much lower than 500 lx, typically a few tens of lx. Assessing the blue light hazard associated of a street lighting luminaire by using the 500 lx illuminance distance is clearly inappropriate.

It is interesting to note that the strict application of CIE S009 and IEC 62471 to indoor LED lamps and luminaires lead to RG 0 and RG 1 classifications, similar to traditional indoor light sources (fluorescent lamps, incandescent and halogen lamps). Nevertheless, several measurement campaigns using the 200 mm viewing distance revealed that some indoor LED lamps and luminaires belong to RG2 while traditional indoor light sources (fluorescent and incandescent) remain in RG0 or RG1. This result shows that LED technology potentially increases the blue light hazard in home applications where the viewing distance is not limited, notably when light sources are accessible to children and other sensitive people. At the time of this writing, the general public is not aware of the potential since no mandatory labelling system exists for SSL products.

As a consequence, the potential toxicity of some LED components viewed at short distances cannot be neglected. When the viewing distance is increased to one meter, the maximum permissible exposure time rapidly increases to a few thousands of seconds, up to a few tens of thousands of seconds. These rather long exposure times provide a reasonable safety margin to assert that there is virtually no possible blue light retinal damage from LEDs at reasonably large viewing distances (statement valid for state of the art LEDs at the time of writing).

However, lamp installers and users awareness on the notion of a safety distance should be raised. The safety distance of a SSL product would be the minimum distance for which the blue light hazard risk group does not exceed RG1.

For SSL products aimed at consumer applications (retrofit LED lamps, for instance), the policy makers in collaboration with health authorities advocate the adoption of a regulation to limit the risk group to RG1 at the minimum viewing distance encountered at home, which is 200 mm. Equivalently a mandatory safety distance less than or equal to 200 mm should be required. The measurement campaigns carried out by several laboratories showed that the vast majority of indoor LED lamps and luminaires already comply with this requirement. It is not a critical issue for the LED industry

Other widely used lighting sources, particularly high intensity discharge lamps (metal-halide lamps for instance), are also in RG2. However, this last example is intended for clearly identified usages and can only be installed by professionals presumably aware of the safety distance required to limit the exposure.

In addition, the maximum exposure limits defined by the ICNIRP and used to define the Risk Groups in both IEC 62471 and CIE S009 are not appropriate for repeated exposures to blue light as they were calculated for a maximum exposure of one 8-hours day but do not take into account lifetime exposure effects. Moreover, neither CIE S009 nor IEC 62471 account for specific light sensitivities, such as:

- individuals having pre-existing eye condition for which artificial lighting can trigger or aggravate pathological symptoms;
- aphakics (*i.e.* absence of crystalline lens) and pseudophakics (*i.e.* artificial crystalline lenses) persons, who consequently either cannot or insufficiently filter short wavelengths (particularly blue light);
- children, as their visual system is not mature;
- and elderly people, as their skin and eyes are more sensitive to optical radiation

The case of the skin

As far as interactions with the skin are concerned, the general population should not be concerned by risks arising from the use of LEDs in lighting.

Thermal effects from visible or IR radiation emitted by lighting sources are unlikely to cause any serious health effects in healthy skin; problems may only arise with excessively intense sources and close proximity with such sources (adherence to DIN 33403 for pain thresholds [9] or more conservative expansion of the ICNIRP limit to exposure times over 10 s). Considering the data on UV effects, the sunburn reaction would appear to be the practical key for proper control of UV exposure levels on the skin, both for short- and long-term health effects. In contrast to persons deliberately exposing themselves to sunbeds for cosmetic or presumed health effects, persons staying indoors do not expect to be exposed to UV radiation from the artificial lighting system, and LEDs should therefore evidently be adequately low in UV output.

Only a small number of people suffering from photosensitive syndromes might see an aggravation of their pre-existing condition triggered by exposure to LEDs emitted blue light. Patients taking photosensitizing drugs should also be aware of a potential risk.

Light Flickering hazards

Flicker is the modulation of the light output that can be induced by fluctuations of the mains voltage supply, residual ripples in the DC current powering, or deliberate modulations of the LED input current such as the pulse-width modulation (PWM) used for dimming applications.

It is known that exposure to light flicker (in particular at frequencies between 3 Hz and 55 Hz) can cause photosensitive epileptic seizures in various forms, depending on the individual and his visual pathology, the contrast, the wavelength and the viewing angle or distance [10].

According to the literature, light flicker is not usually perceptible at frequencies higher than 70 Hz, but it can still affect people. For example, people suffering from migraines are more likely to be sensitive

to flicker at high frequencies [11]. Also, for people suffering from specific medical conditions, flicker may have some serious consequences.

Light flicker combined to rotating motion or spatial patterns may be responsible for stroboscopic effects. Stroboscopic effects might induce hazards to workers in proximity to rotating machines and tools.

On the opposite, pulsed lights may also have some positive effects: it has been reported that the pulsed operation of lamps could offer opportunities for energy savings according to the Broca-Sulzer effect [12, 13] due to enhanced perceived brightness. Thus, it is argued that energy savings can be achieved by using pulsed LEDs at very high frequency. In that case it is absolutely necessary to understand the influence of flicker on humans in order to avoid any deleterious effects appearing with products using that type of pulsed light.

In this section, we present original results that prove that some readily available consumer SSL products have very high flicker behaviour and can potentially be harmful for the end-user.

Commercially available LED lamps may have serious light flickering behaviour at twice the mains frequency (in Europe mains frequency is 50 Hz thus the observed residual flicker frequency is equal to 100 Hz). This light flicker is mainly due to the residual voltage fluctuation after the AC/DC rectifier in the lamp power supply. For this paper, we developed an experimental method to quantify flicker and then evaluate the behaviour of various commercially available products.

Definition and Experimental evaluation of flickering

There are two widely accepted metrics for measuring lamp flicker. Figure 5 is used to illustrate these two metrics.

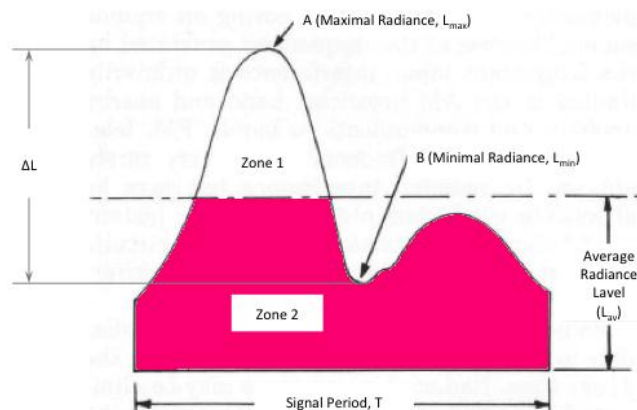


Figure 5: Definition of light flickering metrics [16]

The first, called the per cent flicker, uses the maximum and minimum points of the fluctuation levels through the following equation:

$$t_L(\%) = 100 \frac{\Delta L}{L_{av}}$$

The second metric is the flicker index and requires the calculation of the areas above and below the average level of the signal [14].

$$FI = \frac{\text{Surface zone 1}}{(\text{Surface zone 1}) + (\text{Surface zone 2})}$$

For the moment, no regulation of light flicker is implemented in the EU regulations. In the USA, the present Energy Star specifications for lamps set maximum Flicker Index values for flicker frequency of 120 Hz or higher. Draft 4 of Energy Star requirements released in late April 2013 requires that all

marketed lamps should have a maximum flicker index at those frequencies and above. It defines a maximal flicker index requirement for dimmable lamps and under any dimming condition as follows:

$FI \leq 0,001 \cdot \text{flicker frequency in Hz}$

The above formula defined an increase of the threshold with frequency in order to account for situations that might occur with pulse-width modulation supply.

This criterion leads to $FI < 1,2$ for USA and $FI < 1,0$ for Europe. The rationale used by the US Environmental Protection Agency (EPA) to establish that limit appears to originate from experiments on high-quality conventional light sources, including CFLs, performed by the US Department of Energy (DoE). In this work, the highest FI value is 0,11 for magnetically ballasted CFLs. There is also a statement suggesting a value of 0,15 for magnetically ballasted fluorescent lamps. In addition, the IES lighting handbook [16] presents a maximum flicker index value of 0,20 related to ballasted High Pressure Sodium lamps. A number of LED manufacturers are asking for a higher limit value, but none of their arguments are based on factual data. The 0,12 value might be fixed in the next months.

In order to evaluate the light flickering magnitude, a specific experimental set-up was designed in the LAPLACE laboratory. It is described in Figure 6. The set-up is based on an integrating sphere equipped with a selenium cell and a Tektronix 2002B oscilloscope for detecting and recording the light waveforms. A digital multi-metre is used to independently measure the average light output, directly proportional to the luminous flux of the lamp. All lamps were operated at 230 V, 50 Hz (mains) via a controlled voltage power supply. More than fifty different lamps of different brands have been tested with this device.



Figure 6: Diagram of the flicker measuring set up in LAPLACE

In our evaluation, the per cent flicker, as defined above, is used. However, as shown in Figure 7, we demonstrated experimentally that for periodic waveforms, there is an almost linear relationship between per cent flicker and flicker index.

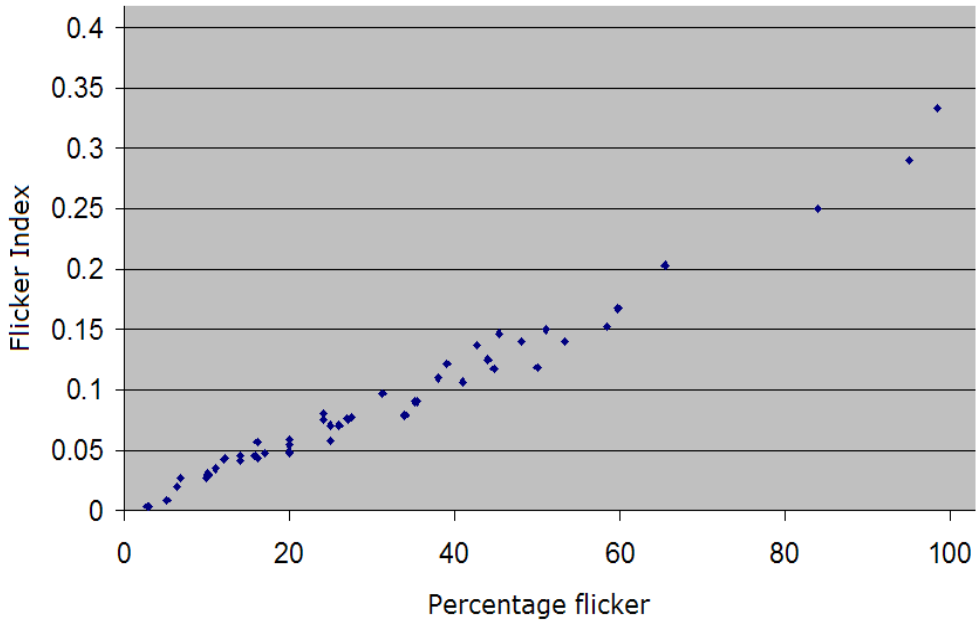


Figure 7: Correlation between flicker percentage and flicker index as measured in LAPLACE laboratory

Our set of test lamps included LEDs, as well as CFLs and incandescent lamps used as references. Figure 8 shows the experimental per cent flicker values for some tested lamps. It should be noted that a 100 W incandescent lamp has a flicker percentage of 10% due to the filament temperature variation that follows the power waveform. Good quality CFLs may reach a per cent flicker of 20%. The highest Flicker Index value for tested CFL lamps was found to be 0,14, a value rather compatible with the EPA requirements.

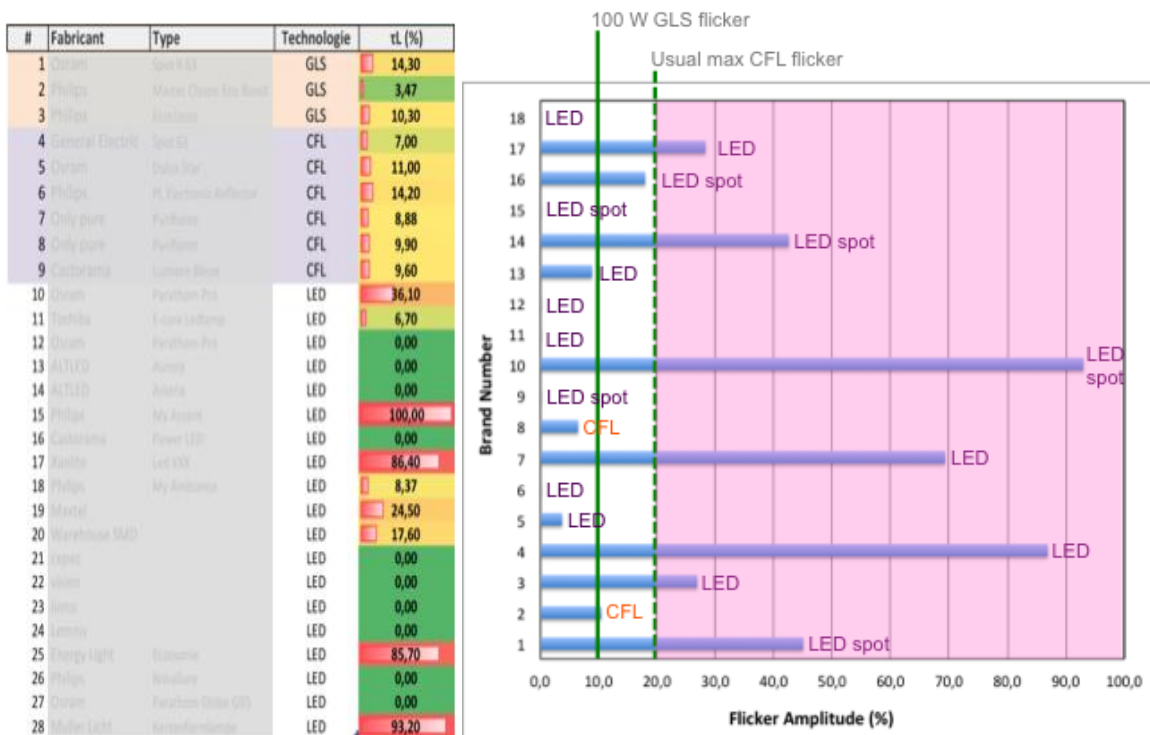


Figure 8: Some experimental percentage flicker values of various lamp technologies as obtained in LAPLACE laboratory and EU-PremiumLight projects

The situation is completely different for LEDs. As can be seen in Figure 8, LEDs had completely arbitrary behaviours. Some of them feature high quality power supplies that include reliable AC/DC rectifiers and filters. They displayed very low flicker, close to zero (not measurable). Other devices had per cent flicker values up to 100%. In this case, the light output goes off every 10ms. Eight LED lamps were found to fully respect the conditions imposed by the Energy Star requirements (Flickering Index $< 0,1$), whereas all examined CFLs fulfilled that condition.

It should be noticed that Kitsinelis et al [15] proposed a very effective way to detect light flickering using the camera of a cellular phone. Figure 9 shows the obtained results by this method. The simplicity of the method allows its use by the general consumer: just use a smart phone with an integrated camera, target the lamp and look at the phone screen. If striations appear around the lamp (dark fringes), then flicker is present. The contrast between the fringes is a straightforward estimation of the "flicker depth". The spatial frequency of the fringes is related to the flicker frequency and the frame rate of the camera.



Figure 9: Flicker detection using the built-in camera of a cellular phone obtained by LAPLACE. Flicker is leading to the appearance of dark fringes in the image.

Conclusions

Solid-state lighting (SSL) and more especially light-emitting diodes (LEDs) are presented as the next generation of light sources that may amount to 70-80% of the light source market by 2020. LEDs will unquestionably help making energy savings in both indoor (residential and tertiary) and outdoor lighting sectors. However, recent work showed that this technology might have some impact on human health.

This paper addressed potential health issues related to LEDs and based on original experimental data. More especially, we focused on the photobiological effects of blue light and light flickering phenomena.

Concerning the blue-light hazard, and more particularly in consumer applications (retrofit LED lamps for instance), we strongly support the adoption of a regulation to limit the risk group to RG1 at the minimum viewing distance encountered at home, which is 200 mm. The measurement campaigns carried out by the authors, as well as by several other independent laboratories, showed that most indoor LED lamps and luminaires already comply with this requirement. It is not a critical issue for the LED industry. However, the notion of a safety distance would actually be more appropriate to communicate to the installers and to the users, especially to the general public. The safety distance of an LED based product would be the minimum distance for which the blue light hazard risk group does not exceed RG1 and this value must be indicated on the package. For LED products handled exclusively by professionals, all necessary measures to limit the final risk group to RG1 have to be taken and guaranteed by the installers.

In addition, none of the single-die LEDs studied in the present work fell in high risk group (RG 3), corresponding to a maximum permissible exposure time of less than 0,25 s. Blue LEDs and cold-white LEDs according to their colour temperature and their brightness may belong at maximum to risk

group 2, especially if beam collimators are used. Likewise, neutral-white LEDs may belong to risk group 1. On the contrary, warm-white LEDs studied here all belonged to risk group 0.

Concerning light flicker, we tested more than fifty different lamps for flickering. Our samples included LED lamps as well as some CFLs and incandescent lamps as benchmarks. The highest Flicker Index value for tested CFL lamps was found to be of 0,14. LED lamps had completely arbitrary behaviour. Some of them, built with high quality power supply, displayed zero flicker (not measurable) while some other devices reached per cent flicker values of up to 100%. In fact only eight LED lamps have been found to fully respect the Energy Star requirement (Flicker Index < 0.1), while all the tested CFLs fulfilled that condition. Consumer should be vigilant about that fact. In this paper, we described a rapid method to detect flicker using a smart phone camera.

There is no clear requirement concerning light flicker limitation in Europe, which is clearly unacceptable. On the opposite, the value of $FI < 0,12$ was proposed in the USA by the EPA in their last draft of Energy Star requirements. The requirement seems to be very stringent and is said to threaten some innovations such as the ac-LED technology. A limit value of about 0,25 may be more realistic at least for applications in which light flicker is not a critical issue.

All in all, the European Union must rapidly engage in a systematic and cross-disciplinary research effort to better understand and quantify potential health effects, and ultimately enforce a consistent regulation protecting end-users while promoting innovation in the growing SSL market.

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