POINT OF VIEW
11/04/2017

« Blue light of LED »

Remind to the physics of light basics and its influences on human eye.

Abstract

Since the publication of the French agency ANSES report on the health effects of LED lighting systems in 2010, each scientific publication on the subject, whose conclusions are somewhat "anxiety-inducing", is taken over by the French media, who quick broadcasts alarmist messages. The last publication of INSERM in December 2016 did not escape to this trend. However, if one takes the trouble to read the article, without limiting oneself to its conclusions, the photobiological risks that would present LED, with respect to the other sources of light, are far from proved. This article attempts to evaluate the actual exposure to which rats' eyes were exposed despite the absence of parameters sizing the hazard level of blue light. Indeed, the mean level and luminance contrast, as well as the emission spectrum, are not specified. Our conclusion, which we tried to establish in scientific objectivity, is much less dramatic than those media retained.

Results less alarmist than they seem

A recent study[1] added to the troubles regarding the LED lighting hazards. It is a shame because, if the conclusion of the article can seem alarmist, the results are much less if one takes time to read them. As the authors have clearly written: at 500 lux, 12 hours per day, pupils NOT dilated[2], there is no effect of lighting on the retina of normal rats, regardless of the CFL (Compact Fluorescent) or LED source. Only albino rats seem to suffer from lighting.

The authors remind that " Extrapolation of animal experiments (to human) are challenging and particularly, rats that do not have a macula and therefore do not recapitulate human retina characteristics". The albino rats add an additional difficulty in the "extrapolation of the results", to the extend that, like humans struck by albinism, they are much more sensitive to light. We use the term "photophobia", that is to say their eyes fear the light that causes them painful visual sensations, wherever it comes from.

A well-known phenomenon

Vision results of photochemical reactions. However, several studies show that light can induce deleterious photochemical reactions in the retina. This is called phototoxicity. A specific area of the electromagnetic visible radiation, in the blue part of the spectrum, is involved. The parameters to estimate this phototoxicity are the radiance[3], in the incriminated zone of the spectrum, and the exposure length. In no case, the source produces these reactions. The photon or electromagnetic radiation ignores everything from the source that produced them and is physically indistinguishable. On reading the mentioned article, we thought it is necessary to clarify this point.

Indeed, it is not "luminosity" that counts but the energy that arrives on the retina that can induce, or not, these deleterious photochemical reactions. With equal radiance, the perceived luminosity can vary completely according to the spectrum of the light sources, and vice versa. Indeed, not all electromagnetic radiations have the same radiance. Some do not even produce light, although they are sufficiently energetic to cause some damage. For example, "sunburn" caused by UV radiation during excessive exposure to the sun.

Luminous efficiency of a radiation shows the relation between the luminosity perceived by the human eye and the energy flux of the received radiation as a function of its wavelength (FIG. 1). To achieve

[1] A. Krigel, , M. Berdugo, , E. Picard, , R. Levy-Boukris, , I. Jaadane, , L. Jonet, , M. Dernigoghossian, , C. Andrieu-Soler, , A. Torriglia, , F. Behar-Cohen - Light-induced retinal damage using different light sources, protocols and rat strains reveals LED phototoxicity, Neuroscience, Volume 339, 17 December 2016, Pages 296-307

[2] That is to say, an illuminance reasonably close to which can be exposed in an office or domestic interior under artificial lighting (50 to 500 lux), which, in any case, remains much lower than the illuminance outside during the day (100,000 lux in full sunlight). A very basic way of calculating it, is, for example, to sum the lumens of the installed lamps, divided by the area in m²: 600 lumens for 6 m² provide less than 100 lux on average.

[3] Radiance is the power of produced radiation in a given direction by unit area. It is shown in $W \cdot m^{-2} \cdot sr^{-1}$. The visual luminance express the luminosity felt by a human observer when seeing this aera. It is expressed in cd/m².

the same level of illumination, it takes between 20 and 30 times more energy to illuminate in the blue (around 450 nm wavelength) than in the green (555 nm).

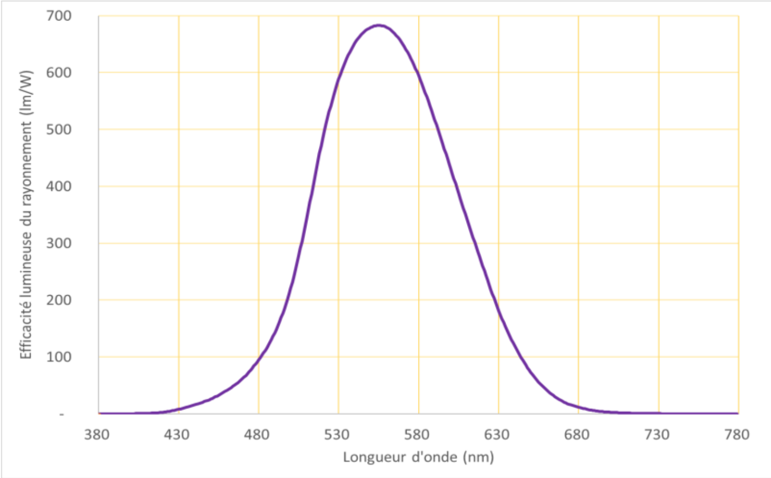

Figure 1 : Luminous efficiency V(λ) of a radiation as a function of its wavelength.

All scientists agree on the method of calculating exposure to the blue light hazard. It requires knowledge of the radiance spectral density (usually emission spectrum) L (λ) to which the eyes are exposed. To estimate the risk, the radiance must be weighted by the normalized blue-light hazard function called B (λ) (Figure 2). This function represents the "nuisance efficiency" of the light as a function of its wavelength. It is noted that risk is maximum in the 415-455 nm range of wavelength and decreases very rapidly outside this area.

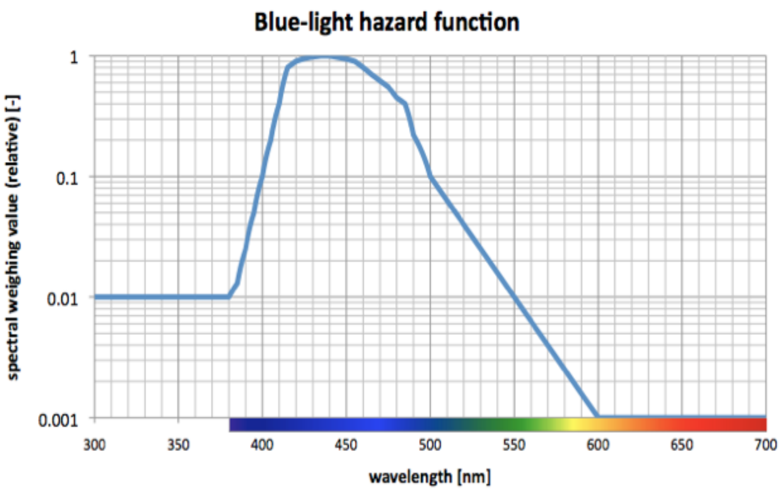

Figure 2 : Function B(λ) represents photobiological hazard level of a radiation as a function of its wavelength (ordinate axis is logarithmic).

Blue luminance directly linked to the blue-light hazard function is calculated as follow:

$$L_{blue} = \sum_{300}^{700} L_\lambda B_\lambda \Delta\lambda$$

What were exposure conditions?

None of the spectra whose knowledge is essential to calculate the level of risk are specified in this article. Only illumination levels are given. We can try to find the spectral density from the approximate wavelength of the blue and green LED or the color temperature of the white LED (6300 K). But we cannot do this work for the CFL lamp whose color temperature is unknown. It is known that, for the same luminance, the higher the color temperature is, the higher the blue light exposure (FIG. 3)[4].

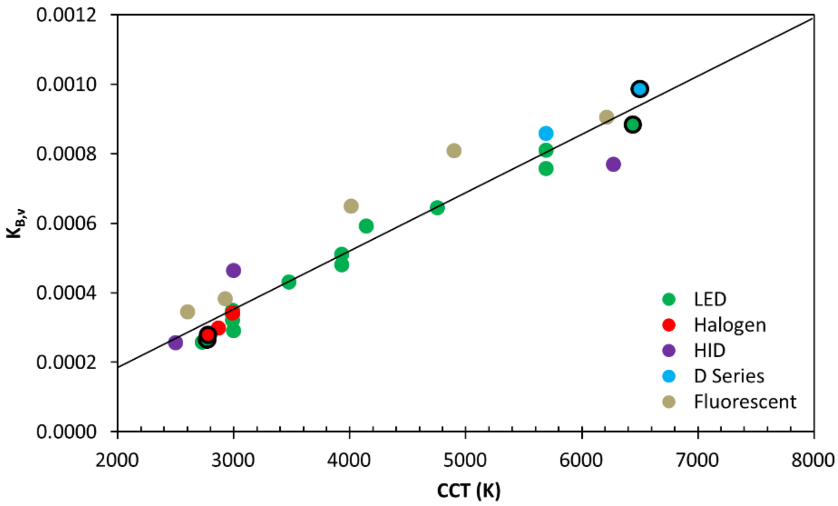

Figure 3 : Correlation between color temperature and blue light hazard factor with identical luminance (Source: Optical Safety Fact Sheet - DOE, available on web). It is clear that the level of risk is not related to the technology of the source, but to its color temperature. Note that the sun is in the highest part of the curve (5500K or 6500K).

In order to illustrate it, we compared the "Spectral Power Density", or more simply the "emission spectrum", from 2 sources at 6500K, one LED and the other fluorescent, to the "natural light" spectrum (illuminant D65 reference) (FIG. 4). At the same illuminance level, the calculated weighted blue luminance is 6% higher with fluorescent lighting than with LED lighting.

[4] By the way, it is because a white light is rich in blue that it appears cold.

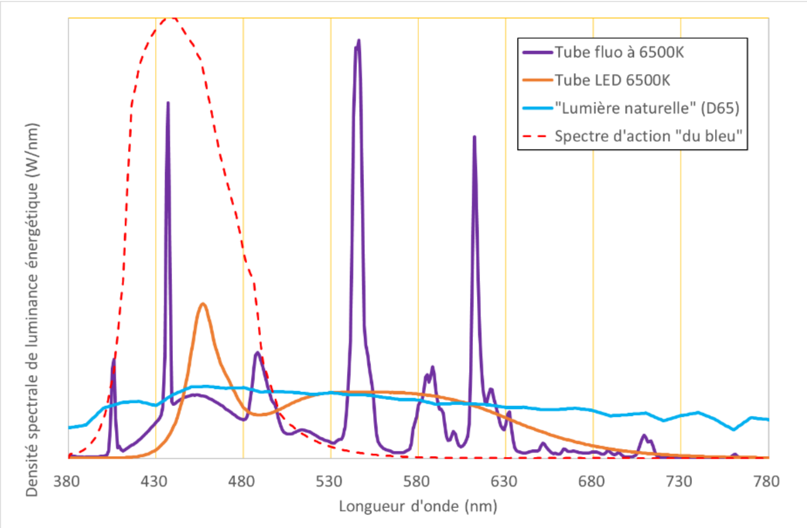

Figure 4 : Comparative spectra of "natural light" (D65), a fluorescent tube and an LED lamp with identical color temperature (6500K) for the same level of illumination. Stacked in dotted lines, the action spectrum of blue light. (PISEO measurements).

Moreover, in addition to the lack of information on the spectrum of the sources used, it is also impossible to know the distribution of luminance to which rats' retina is exposed, except to make some assumptions about this. The uniformity of this luminance is also in question since, for the same average luminance, the use of compact fluorescent lamps or simple LED (the electronic component as such) results in totally different luminance contrasts.

Difficulties to transfer these results to human

Let us now review the results of the three types of comparative exposures endured by the rats.

The first result shows that, regardless of the light source (LED, compact fluorescent or fluorescent tube), illumination of 6000 lux, with dilated pupils and 24 hours long, cause damage to retinas of albino or non-albino rats.

Usually, pupils close when the observed luminance increases. In humans, its diameter can vary between 2 and 8 mm, which corresponds to a ratio of 1 to 16 on the amount of light allowed to pass. Under a weak light, the pupil of the rat can reach a diameter of 1.2 mm, while it contracts to a small opening of about 0.2 mm diameter under intense luminance, ie a ratio of 1 to 36. In the first experiment, the illuminance is 6000 lux, it can be assumed that the corresponding average luminance[5] is typically 1500 cd / m². Under these conditions the diameter of the human eyes pupil is at its minimum. If this is also the case for rats[6], artificially dilating pupils means multiplying by 36 the received flux by the retina under these conditions of exposure in relation to their normal physiological adaptation. That

[5] Connexion between lux and cd.m-²: a perfect diffuser becomes a secondary source whose luminance is equal to 1 / π times the illuminance received in lux. Virtually, the whitest matt surfaces diffuse only about 80% of the received light, so their luminance L is L = (1 / π) x 0.8, or about 1/4 of the illuminance E received, so L (cd.m-²) = E (lx) / 4.

[6] We did not find any indication of the relationship between the iris diameter of the rat and the luminance.

is to say "effective" luminance of 125,000 cd / m² (or 24,000 if one is satisfied with the factor 16 for humans).

In comparison, the reverberation of the sun on the snow produces a luminance of about 30 000 cd / m², a truly very hard regime for the retina. Even if imagining an effective luminance 36 times greater than the actual luminance due to the artificial expansion of the pupils is not demonstrated, it is very high luminance domains and the impact on the retinas is not surprising. It would have been easier to vary only the luminance parameter after having carefully measured it (surface area, average value and contrast). The results would have been easier to determine. The difference in the result between the fluorescent tube (CCFL) and the fluorescent lamp (CFL), so spectra resulting from the same technology, lets suspect different color temperatures (a CFL lamp with the same color temperature as the tube would likely have produced an identical result).

The authors repeated the same experiment, but under a 500 lx illuminance, pupils were always dilated. They found that, only eyes of the rats exposed to the LED illumination were damaged (more precisely the photoreceptors of the upper retina).

Observing the (low) effect at 500 lx of the LED lamps, that did not appear with fluorescent lamps, they continued their study by gradually increasing exposure for LED lamps only and did not go further with CFL lamps or, at least, results have not been published. It is a pity, because the impact was perhaps simply shifted because of the characteristics of CFL lamp used, more precisely its color temperature which, it should be reminded, is not specified.

It is also important to note that, the very high color temperature of lamps used in this study (6300K) are not used for residential lighting. They can be found rarely for professional use in street lighting, but at a much lower level of illuminance, for quality control of color or in dentistry or jewellery, for example.

The final result in the publication is that at 500 lx, 12 hours per day, with NON-dilated pupils, authors clearly state, there is no impact on the retina of normal rats[7]. Only albinos seem to suffer it. As seen before, albino rats are more sensitive to light. However, only the blue light seems to affect the vision of these rats, and not green light (the margin of uncertainty is quite large, so that we can legitimately doubt the apparent deterioration at the end of a month under green lighting). This confirms that the type of light source is not for nothing and that only the luminance weighted by the action spectrum of FIG. 2 makes it possible to estimate the risk.

It should be noted that with reasonable lighting and reasonable day / night alternation, there is no effect observed for normal rats. Even under blue or green fluxes, despite the power required to obtain 500 lux in blue[8] and even after 28 days at this diet.

[7] “Long-term exposure to LED at 500 lux, in cyclic (light/dark) conditions induced retinal damage only in albinos rats but not in pigmented rats”.

[8] Typically, it requires 25 times more irradiance in blue (450 nm) than in green (555 nm) to achieve the same illuminance. This ratio varies rapidly with the wavelengths of the LED, but remains high.

Results exploited too fastly by media ?

In the conclusion, the authors themselves say how difficult it is to conduct this kind of study, because "Many factors influence retinal exposure and retinal toxicity, including retinal pigment epithelium pigmentation, pupil diameter, geometry of the face and the nature of the light radiations[9], including its spectrum[10], its intensity, the exposure sequence and timing of exposure[11]. Age, lens color (increasing yellow pigment with aging), stress-induced steroids, pre-existing retinal pathology also influence light sensitivity".

After a careful reading, results do not seem particularly surprising or inconvenient, in spite of this sentence which set of a wide diffusion of press articles: "This study shows that at the same illuminance and under similar conditions, white, blue and green LED provoke retinal damage, while CFLs do not[12]". They again underline the toxicity of blue light and particularly blue LED[10].

As said previously, light ignores everything from the source that produced it. It is not characterized by its source, but only by its spectral density of energy. A fluo-compact lamp of very cold temperature, equivalent to the 6300K of the LED lamps studied and with the same luminance would have probably produced the same results, as it would display roughly the same spectral energy density in blue.

White light with blue LED ?

The authors suggest, in the introduction, that the current method used to make white light is used because "less expensive", suggesting that there are less "dangerous" methods but more expensive[13]. Since the first white LED in the early 1990s, actually made of a blue LED and a yellow phosphor, significant progress has been made, particularly with the use of red and green phosphors to produce warmer whites and better color rendering. The other method to make white light is to mix 3 or 4 color LED. But if you want a quality color rendering, these colors are not chosen randomly. Obviously, it is necessary to have a blue LED at 460 or 455 nm, depending on the number of colors used, therefore in the blue light action spectrum. Moreover, it is true that some sophisticated electronics, and so more expensive, is then necessary to stabilize the light thus produced. The characteristics of the LED, both in color and in light level, have indeed an unfortunate tendency to evolve with operating conditions, which produces in this configuration, changes in color that are inappropriate. Finally, it should be pointed out that green LED have a very low conversion efficiency, which would compromise the energy efficiency of such lamps. Progress is still needed to see these sources of light entering the market. But in any case, it will require blue LED to perceive this color.

Finally, let us note that the luminance to which our eyes are exposed outside is typically 100 times greater than that produced by artificial lighting. The sunlight is "cold" (in terms of color), approximately equivalent to the LED used in this study, so the exposure to blue is about 100 times more intense with the sun than it would in a room illuminated at 500 lux by these LED. In other words, the dose of blue light received one minute outdoor is equivalent to that received a hundred minutes indoor. We can question about blue-light hazard in direct vision of LED, especially because of their high luminance, as

[9] A surprising conclusion: Is it suggested nature of light are different according to the source that produces it?
[10] Why the spectra of sources used are not specified?
[11] Youssef et al., 2011; Hunter et al., 2012
[12] It is albino rats retinas.
[13] Actually, we can read : "LED emit mono chromic lights, and <u>the less expensive and currently used method</u> to produce white light from LED is to combine a blue LED with yellow phosphor coverage".

much as the vision of an interior environment, illuminated at 500 lux with products using mainly diffusers or integrated lampshades, cannot present a measurable risk.

What does standards and regulations say ?

The European Directive “Low Voltage” (LVD) 2014/35/EU requires that the blue-light hazard of white LED from LED-lighting fixtures (lamps, modules and fixtures) be evaluated. To this end, the Directive refers to the following harmonized standards and technical documents:

- NF EN 62471 - 2008: Photo-biological safety of lamps and fixtures.

- NF EN 60598-1-2015: Luminaires - Part 1: General requirements and tests.

- IEC / TR 62778: Application of IEC 62471 for the assessment of blue light hazard to light sources and luminaires.

- NF EN 62031-2015: LED modules for general lighting - Safety specifications.

- NF EN 62560-2015: Self-ballasting LED lamp for general lighting.

These standards and regulations impose a very strict limitation of the levels of risk and especially for lamps and fixtures for the general public that can be "watched" without particular risk.

Conclusion

Direct exposure to "white" luminances of less than 10 000 cd / m2 is unlikely to present a photochemical hazard in the retina. For these sources of light, John Bullough, researcher at the Lighting Research Center, wrote in 2000: the calculation of blue-light hazard is not necessary[14]. This is no longer the case at higher luminances, especially those which can be exposed when looking at the emitting surface of LED chips, the electronic components that emit light. However, an avoidance reflex makes us look away from the dazzling sources.

In the case discussed here, this is indirect luminance, that is to say the luminance of the illuminated surfaces. There is, however, some doubt about the actual luminance to which rats have been exposed in the case of lighting at 500 lux. The latter do not appear to be truly homogeneous in view of the published images and there is probably a mixed vision of primary luminances (sources) and secondary (illuminated surfaces). It is possible, therefore, to deviate from the average luminance (estimated at 125 cd / m² for an average illuminance at 500 lux) and that, through multiple reflections, the eyes have been exposed to many " spots " corresponding to the LED used, despite the use of a diffuser whose characteristics are not known.

We would gladly recommend some improvements to the experimental conditions, such as renouncing to dilate pupils in order to allow the natural protections to play their part; characterize spectrally the energy luminance in mean and contrast levels; Avoid comparing albino rats - pigmented rats by focusing on pigmented rats; Assess the blue-light hazard exposure from the energy spectrum of sources and the action spectrum B (λ); Finally, to vary only the level of radiance and the duration of exposure. This

[14] Bullough, J. D. 2000. “The Blue-Light Hazard: A Review,” Journal of the Illuminating Engineering Society 29(2):6-14

approach would reveal a law (for rats) linking the occurrence of damages to the product of luminance by the duration of exposure. These experiments would probably be longer, especially for low luminance, but easier to interpret.

Finally, even if the work of scientists on the effects of light must continue in order to understand better the mechanisms involved, in particular as regards the doses received, it is necessary and useful to remind that the regulatory and normative system today in place is particularly complete and prohibits commercialization of products which could potentially present risks. Indeed, It would be a pity to deprive oneself, on the basis of erroneous conclusions, of a technology which has many interests from the point of view of energy consumption, lifetime and quality of light produced.

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About PISEO

PISEO is an independant technical center dedicated to LED based optical systems, mainly using LED. It brings together in a single entity high skilled engineers and cutting edge technical testing equipement. Created at the end of 2011 by initiative of Cluster Lumiere, CEA Leti and YOLE Développement, the company realizes expert assessment, R&D and lab services all along the product life cycle. The photometry laboratory of Piseo is accredited.

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