Eco Design Notes

Issue 5 Sept 2015

LIGHTING GLOBAL
Catalyzing Markets for Modern Lighting
AN INNOVATION OF IFC International Finance Corporation World Bank Group THE WORLD BANK

LED Lights and Eye Safety Part II: Blue light hazards

This Eco Design Note continues a discussion of safety issues related to LED lights and the consumers who use them. Part II explores in more detail blue light hazards for LEDs and incorporates additional safety testing procedures that have been published since the first Eco Design Safety Note. Some evaluation guidelines are provided for companies interested in self-testing their products.

Introduction

Part I of this LED Eye Safety series examined concerns related to the use of LEDs in pico-powered solar lighting products[1]. Part II will continue this discussion with updates to current safety standards and some guidelines on assessing products for potential hazards. Several concepts mentioned in this Note have been introduced in Part I and the reader is encouraged to reference this first part for further information.

The primary area of safety investigation for LED lighting products is in the blue portion of the visible spectrum (400-500 nanometers)(Fig. 1). The light output of a typical LED has a spike in the emission around 450 nanometers. Outside this blue region, LEDs used for general lighting service (GLS) do not emit radiation with enough energy to pose a hazard to the human eye. Within the blue region it has been shown that some LEDs are capable of posing a Risk Group 2 (RG2) hazard and that some pico-powered lighting products can fall into this classification. This is not to overstate the hazard, however, as RG2 represents a range (and includes the light output of the Sun), and those few products tested by Lighting Global that did fall into RG2 were at the very end of the range where it borders the low hazard classification Risk Group 1 (RG1).

There are two aspects of LED blue light emission that have raised questions with regard to safety:

- Is the wavelength distribution of an LED's light output (i.e. its spectral power distribution (SPD)) inherently dangerous?
- Is the radiant intensity from an LED emitter capable of harming people who look directly at it?

Both of these issues will be explored in more detail in this Note.

[1] Lighting Global "LED Lights and Eye Safety" Eco Design Notes Issue 2, January 2013

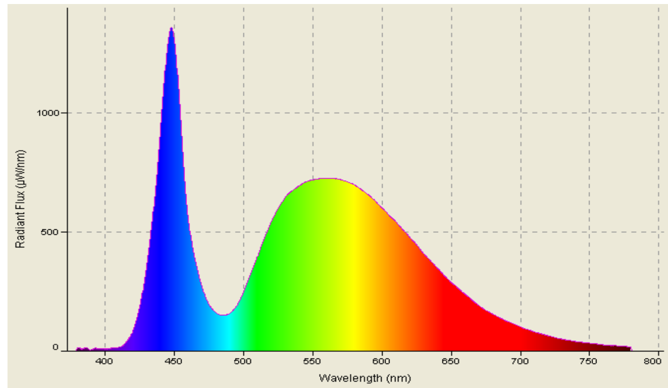

Figure 1. A graph showing the spectral output of a white LED within the visible spectrum. The LED emits light at different wavelengths including a sharp blue spike at 460 nanometers.

Optical safety standards and reference documents

The details of photobiological safety testing can be complex and difficult to understand for people not familiar with radiometric and photometric measurements. A number of safety standards and reference documents are available that can help explain these test procedures and provide support in understanding the core technical concepts (Figure 2). This Note is not intended as a stand-alone document, and these other reference documents will prove useful for those interested in learning more about this topic and conducting safety testing for LED lighting products.

IEC 62471:2006 establishes methods to make an evaluation of the photobiological safety of lamps independent of lamp type. The standard sets exposure limits for the 3 Risk Group categories and defines a general lighting service (GLS) lamp and luminaire category. IEC 62471-2 gives additional guidance on product safety requirements and labeling. IEC TR 62778 addresses issues with the GLS lamp category and provides guidance on applying the blue light hazard classifications to LED lighting products.

International standards and reference documents

Testing standards – these have harmonized definitions for performing eye safety testing:

- **CEI/IEC 62471:2006 [CIE S 2009-2002]** 'Photobiological safety of lamps and lamp systems'
- **ANSI/IES RP27** 'Recommended practice for photobiological safety for lamps and lamp systems'
- **IEC/TR 62471-2** 'Photobiological safety of lamps and lamps systems – Part 2: Guidance on manufacturing requirements relating to non-laser optical radiation safety'
- **IEC/TR 62778** 'Application of IEC 62471 for the assessment of blue light hazard to light sources and luminaires'

Reference documents – these references may be useful in understanding the underlying concepts and applying the test procedures:

- Lyons, L. "LED-based products must meet photobiological safety standards: Parts 1-3" LEDs Magazine (Oct 2011, Nov 2011, Feb 2012) This three part series details IEC 62471 with supporting information and diagrams.
- Lyons, L. "The IEC addresses characterization of the blue light hazard" LEDs Magazine (Jan 2015)
- US Department of Energy "Optical Safety of LEDs" Solid-state lighting technology fact sheet, PNNL-SA-96340 (June 2013)
- Martinsons, C. "Potential Health Issues of SSL" Energy Efficient End-Use Equipment (4E) International Energy Agency (Sept 2014)

Figure 2. Safety testing and reference documents

Blue light hazards and correlated color temperature

The correlated color temperature (CCT) of a white light source is a measure in degrees Kelvin (K) of how 'cool' or 'warm' the light appears. Incandescent lamps often have warm color temperatures at or near 2700K CCT. The color temperature of daylight changes throughout the day but is commonly listed as 5500K.

CCT is a function of the wavelengths that make up the white light source. A higher *ratio* of blue light will yield higher (cooler) CCT's while more red will lower it (make it warmer). Given two light sources with equal lumen outputs but different CCT's, the light with the higher CCT will emit more blue light radiant energy.

Light at any given wavelength is the same regardless of the source of that radiation. For light in the 400-500 nm region, IEC 62471 identifies the potential for 'photochemically induced retinal injury' when certain exposure limits are exceeded. These exposures are weighted by a blue light hazard function B(λ) (similar to the photopic V-lambda curve V(λ)) to assess the risk posed by a source and accounts for all of the emitted radiation in this region.

IEC 62778 also defines a blue light hazard efficacy of luminous radiation $K_{B,v}$ with units in watts per lumen (W/lm). $K_{B,v}$ relates the blue light weighted radiance or irradiance of the source to the corresponding photometric values of luminance and illuminance. IEC 62778 shows that $K_{B,V}$ has a strong correlation with the source CCT (Fig. 3) but does not correlate with the source technology. Higher color temperatures have higher $K_{B,v}$ values, and a comparison of different light sources shows that at any given CCT, LEDs do not exhibit higher $K_{B,v}$ values than other technologies.

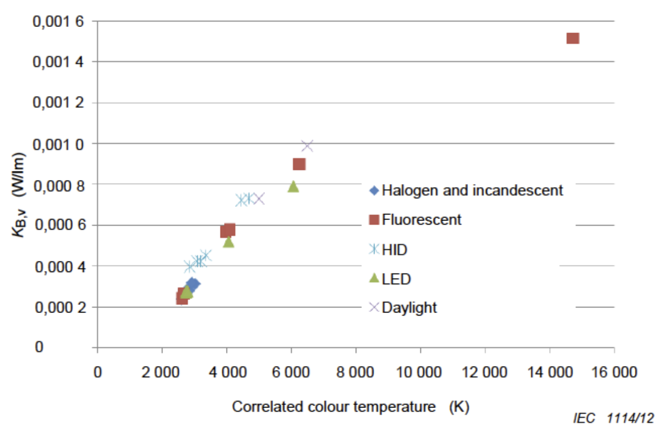

Figure 3. $K_{B,v}$ correlation with CCT (from IEC 67778)

This leads to the conclusion that the light emitted by an LED source does not pose a unique hazard specific to the spectral power distribution of a typical LED. Stated another, less technical way, LED light is not inherently dangerous when compared to light emitted by other lamp technologies. This is still an active research topic and Lighting Global continues to monitor related discussions and research findings.

LED Intensity and Risk Group 2

LEDs are small, bright point sources of light that are capable of producing RG2 hazard levels under the right power and viewing conditions. While people are very unlikely to experience these conditions under normal use for pico-powered lighting products, Lighting Global recommends that manufacturers familiarize themselves with photobiological hazard levels, investigate their products in this context, and consider labelling where appropriate. The viewing conditions for these assesments are defined here and some simple tests are suggested to assist manufacturers in this investigation.

Exposure distance

One key aspect of IEC 62471 testing concerns the viewing distance between the observer and the light source. This viewing distance depends on the type of lighting appliance and how it is mounted. As an example, an outdoor streetlight mounted on a pole will normally be viewed only by persons standing on the ground, and the viewing distance will be physically limited to 'at least' the distance bewteen a tall person and the lamp head. In the case of architectural lighting (these are defined in IEC 62471 as 'General Lighting Service' (GLS) lamps) these are typically mounted in such a way as to also provide a minimum distance between the observer and the light source. Generally speaking most lights are not meant to be viewed directly nor are they meant to be viewed at close distances. One provision in IEC 62471 defines a standard viewing distance for GLS lamps as that distance which produces a 500 lux level of illumination. Under this condition, it can be shown that no light source will produce a hazard greater than RG1.

Pico-powered lighting products are unique in that they typically offer very flexible means by which to position the light, either with portable stands that hold the light for task purposes or by the use of a wire that allows the light to hang at a variable distance from the ceiling. In almost all cases, this will allow the direct viewing of the light source at close distances and it should be expected that some end users will do this. With this reasoning it then becomes more appropriate to use a short distance for IEC safety testing. Lighting Global recommends a **200 mm viewing distance** which represents the eye's maximum ability to focus an image on the retina. It is entirely possible and perhaps even probable that pico-powered light sources will be viewed by some customers at this distance.

IEC 62471 testing

The IEC 62471 test procedures to establish a risk group for a light source are based on a number of physical parameters that include both the optical properties of light and the physiological properties of the human eye's visual system. The details of this testing are technically advanced and require a strong understanding of optical geometries, photometric, and radiometric concepts. The risk group categories cover possible eye damage from a number of different mechanisms and exposure scenarios.

The testing procedures necessary to conduct a formal hazard assessment require optical equipment capable of measuring the luminance of the source under specific optical geometries. The field of view (FOV) of the measurement is a key concept that helps determine the light that can reach the retina, and controlling for the FOV requirements depends on the type of measurement and the size of the emitter. A 'Blue light small source' measurement is defined in IEC 62471 that covers some types of LED products that have visible bright LED chips, while other products with an LED array or strong diffusers may be tested by another procedure. The test lab performing the analysis will have the ability to make these determinations and perform the necessary set ups required to run the tests.

Exposure limits

For a blue light hazard risk with LED's, the risk groups are defined by two basic parameters: the radiometric energy of the blue light that reaches the retina (weighted by the potential damage these wavengths can do), and the duration of the exposure. Risk Group 2 is the primary risk group of concern for pico-powered lighting products and is defined for exposure times $0.25s < t < 100$ s. Put another way, an LED product is an RG2 source when it produces enough blue light energy to cause some level of cellular retina damage, as defined in IEC 62471, if the product is stared at for less than 100 seconds. The **exposure limit** is the time it takes to reach RG2, so an RG2 source with an exposure limit of 1 second (the sun, if tested to IEC 62471) is a greater risk than an RG2 source with an exposure limit of 99 seconds. The Lighting Global program has measured a pico-powered lighting product in the RG2 risk category with an exposure time of 58 secondsat an exposure distance of 200 mm, though this was among a small sampling of products that were considered to be very 'bright' by the Lighting Global technical team and cannot be considered representative of the product genre as a whole.

Manufacturer self-testing

There are several investigations that a manufacturer can perform to make a preliminary assessment of a product that may be bright enough to fall into the RG2 risk category. The first considers the LED source itself and an optical law called the 'Conservation of Radiance'. This law states that the radiance of a source cannot be increased by passive optical systems where the spectral power distribution (SPD) of the light source is not altered. For LED systems, this means that any luminaire cannot increase the radiance of the component LED and therefore cannot exceed the risk group rating of that LED. An LED with an RG1 rating will never produce a product with an RG2 rating if that product uses only passive optics, including focusing optics, that do not change the spectrum of the LED source. This also applies to an array of multiple LEDs, and so an array cannot exceed the risk group category of the indivual LED used for the array.

LEDs are increasingly being tested for phtotobiological safety by LED manufacturers as the efficiency and light output of LED technology continues to increase. The industry has seen considerable growth in the availability of IEC 62471 LED results made available to luminaire manufacturers.

IEC 62278 also outlines certain luminance and illuminance criteria that must be met for a product to reach an RG2 rating based on the CCT of the source. The luminance requirements may be difficult for manufacturers to self-test because of the equipment requirements and technical aspects of these tests, but the illuminance tests are simple and require only an illuminance meter and the CCT of the LED(s).

The illuminance, in lux, is measured at the appropriate exposure distance for the product (200 mm recommended for pico-powered lighting products). The result is used to estimate how close the product is to the RG1/RG2 border (Table 1, Figure 4). It should be noted that this method is an *estimate* that uses the CCT of a light source instead of a $K_{B,V}$ calculation based on an SPD measurement. IEC 62778 cautions that using the illuminance and CCT of a light source in this way is accurate only to within ±15% of true $K_{B,V}$ measurements that involve the specific SPD of the light source. Nevertheless, this is a quick and easy test that may provide manufacturers with a first step when assessing the photobiological safety of their products. When the product illuminance falls at or near the RG1/RG2 boundary, manufacturers are encouraged to consider additional technical testing and labelling.

Table 1. Illuminance values giving risk group not greater than RG1 (from IEC 62778 Table C.2 Annex C)

Rated CCT	Illiminance E (lux)
CCT ≤ 2350 K	4000
2350 K < CCT ≤ 2850 K	1850
2850 K < CCT ≤ 3250 K	1450
3250 K < CCT ≤ 3750 K	1100
3750 K < CCT ≤ 4500 K	850
4500 K < CCT ≤ 5750 K	650
5750 K < CCT ≤ 8000 K	500

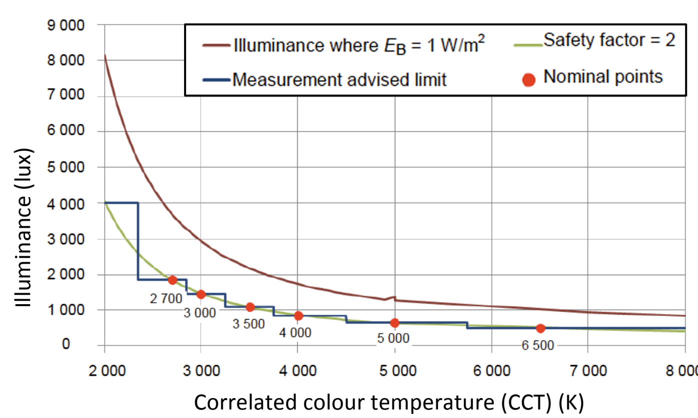

Figure 4. Illuminance values from Table 1 in relation to the RG1/RG2 border as a function of CCT (from IEC 62778 Figure C.2 Annex C)

LED Photobiological Safety Labelling

In 2015 the only primary requirement for safety labelling for LED products is with the European Union low voltage directive CE certification. Voluntary labelling is encouraged by some organizations and stakeholders for products with RG2 hazard ratings cautioning users to not stare directly at the light source (Fig. 6). IEC 62471-2 has labelling suggestions for manufacturers who want to test and label their products. Voluntary labelling may change to mandatory labelling as countries and specifiers consider adding safety labelling requirements for LED lighting products.

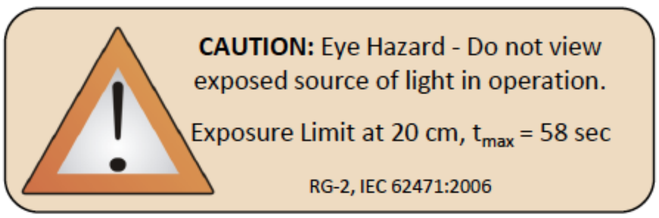

Figure 6. Sample warning label for RG2 source

Hazard distances and labelling

Products that exhibit an RG2 hazard rating will have a threshold distance (d_{thr}) at the RG2/RG1 boundary that can be calculated and reported on a caution label. This provides additional detail to the nature of the hazard and is under consideration as part of the safety discussion taking place in the industry. Any pico-powered lighting product will have a safe viewing distance (RG1 or RG0), and reporting d_{thr} for an RG2 hazard classification is an additional safety mechanism that can be communicated to end users. In some ways, reporting d_{thr} is a more realistic assessment of a product's hazard potential and will not tend to overstate the hazard as much as a simple RG2 caution label.

A threshold illuminance value E_{thr} can also be calculated that gives the illuminance of the product at the RG1/RG2 boundary.

Blue light hazards and children

One very important element of a hazard assesment concerns the natural tendency for people to look away from bright light sources. This aversion response helps to establish the 0.25 second RG2 exposure time, as this is approximately how long it takes a person to look away. The sun, as tested by procedures in IEC 62471, has an exposure limit of 1 second and therefore lies close to the 0.25 second boundary condition between RG2 and RG3. No artificial white light sources are expected to pose an RG3 risk.

Some concern, however, has been expressed for individuals with elevated vulnerability to bright light and also for young children who may not yet have developed an aversion response. This is a realistic concern and one that should be taken seriously, though not overstated, for pico-powered lighting products. In some ways, this is the strongest argument for mandatory labelling requirements and may play an important role in the debate over photobiological safety testing in the future.

Conclusion

As of 2015, Lighting Global continues to believe that pico-powered lighting products based on LED light sources are safe for use by the general public. Any possible photobiological hazard from this product class is far outweighed by the significant economic and health benefits associated with moving away from the incumbent fuel based lights that solar products replace.

Manufacturers of LED based products should, however, be aware of any potential safety issues associated with their products including those that can exist regarding the high brightness levels of some LEDs. This can empower manufacturers to design their products to mitigate or essentially remove this hazard altogether. By understanding LED photobiological risk groups, manufacturers can avoid RG2 hazards in their products by either avoiding LEDs capable of producing an RG2 rating or by using appropriately designed optics to lower the source radiance of LEDs that are RG2.

As a first step manufacturers are encouraged to assess the LEDs used in their products and perform the illuminance test outlined in this Note. Further inquiry can then be made and formal IEC 62778 testing done for products that may pose an RG2 hazard, with subsequent safety labelling where appropriate.