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Description of the step-by-step calculation procedure for the simplified assessment of LED sources for lighting

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This procedure allows the assessment of risks arising from exposure to artificial optical radiation in all those circumstances where the sources of optical radiation are represented by general lighting systems (GLS), be they intended for offices or for larger environments such as industrial warehouses.

In all these cases, the radiation emitted is substantially white light, even if of different tonalities, and staring directly into the source is not part of the visual task of the operators.

In principle, these sources should never represent a risk to the exposed persons, as they are consumer goods. However, the rapid development of innovative technologies for lighting, and in particular of LED systems, that occurred in recent years has raised the problem of the photobiological hazard associated with the emission of blue light, that is potentially detrimental to the retina, from general lighting systems. In order to assess the photobiological hazard of lamps and lamp systems, a specific standard was issued, IEC EN 62471:2009, which classifies these sources into 4 groups (4 classes of risk) as reported in Table 1. This standard sets up measurement methods and classification and even if it does not define specific commitments for marking, it represents the state of the art in terms of information on the photobiological safety of lamps and lamp systems (including LEDs).

Table 1 Lamp photobiological hazard classification according to standard IEC EN 62471:2009

Group	Estimation of the risk
Exempt group	No photobiological hazard under foreseeable conditions;
Group 1	Low risk group, the risk is limited by normal behavioural limitations on exposure;
Group 2	Moderate risk group, the lamp does not pose a hazard due to the aversion response to very bright light sources or due to thermal discomfort. However, such reflex responses do not occur universally;
Group 3	High risk group, may pose a risk even for momentary or brief exposure.

The IEC safety standard specifications for each type of source are currently being adapted in order to adopt the photobiological safety criteria and classification reported in Table 1 and introduce, for each type of source, specific emission limits that ensure its safe use in relation to eye hazard.

Even if the product standards are being adapted, at the moment manufacturers do not provide information suitable to ensure the photobiological safety of LED systems for workers and for the general public.Thus, considering the current lack of legislation, which does not allow to estimate a priori the actual risk of the above mentioned commercially available lighting sources, and considering their potential harmfulness, we have developed the following procedure, that

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is suitable to verify if these lighting sources installed in any environment determine a negligible exposure when compared to the limits set out in the Directive, starting from their main lighting engineering and installation features.

In line with the principle actually adopted by manufacturers, we consider that sources belonging to the classes "exempt" or "1" of the standard IEC/EN 62471:2009 on photobiological safety are associate with a negligible risk, while the sources belonging to class 2 or 3 are considered as having a non negligible risk as they need the implementation of specific protection measures, in order to be safely used. It is generally advised against using these sources for lighting the environments, except in case of very particular needs, to be assessed specifically.

The result is thus expressed as 3 risk levels: low, moderate and high, according to the following criteria:

Low-risk: No photobiological hazard. Trial source for the purposes of the Directive

Moderate-risk: Compatible with limit values associated with the Group 1 (IEC EN 62471:2009: no photobiological hazard under normal conditions of use). It could entail a risk if stared into for more than a 100 seconds cumulated in the day.

High-risk: Exposures greater than the maximum ones acceptable for Group 1 (IEC EN 62471:2009). Risk is present, even for staring times lower than 100 seconds.

The result of the calculation should always lead to a situation of "low" risk, because a system intended for general lighting purposes must be chosen so that its optical emissions entail a negligible risk from the point of view of the photobiological safety.

If the risk is "moderate" alternative solutions for installation should be found.

If the risk is “high”, generally there is an improper use of the sources, because the photobiological hazard is not negligible. In this case, alternative solutions in the choice of sources and/or in the modes of installation should be found.

This step-by-step procedure is based on criteria defined in two documents, both of which are available under the AOR section "Documentation" in the portal: Lightingeurope; “LightingEurope Guide on photobiological safety in general lighting products for use in working places ”, February (2013). These documents typify the commonly used light sources on the basis of the photobiological hazard criteria set out in the standard IEC EN 62471, which defines lamp classification. In particular, they demonstrate that a tight correlation exists between the colour temperature of a source and the illuminance value that marks the boundary between group 1 and group 2 for blue light hazard.

More precisely, by using formulas, the parameter

$$K_{B,v} = \frac{\int \Phi(\lambda) B(\lambda) d\lambda}{K_m \int \Phi(\lambda) V(\lambda) d\lambda} \quad (20)$$

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can be defined, where, starting from the source spectrum, the effective irradiance for blue light damage is calculated in the numerator, while the illuminance is calculated in the denominator and $K_m = 683\ lm \cdot W^{-1}$ .It has been experimentally demonstrated that the parameter $K_{B,v}$ strongly depends on the correlated colour temperature (CCT) of the souce and mildly depends on other features, such as the type of the source (incandescent lamp, compact fluorescent lamp, LED, halogen lamp), represents an experimental data.
As a consequence, for a given source, if its colour temperature and its illuminance in a given position are known, it is possible to assess its level of risk from the point of view of the photobiological safety. It should be noted that these considerations on safety follow the detailed criteria set out in the ICNIRP guidelines (on which are based the Directive limits) and in the above-quoted document on general lighting systems classification; these criteria do not correspond to those followed when choosing the level and the mode of lighting for a working or an everyday life environment that instead concern the visual comfort.

Algorithm for calculating the level of risk

The calculation is divided in two main procedures, depending on the fact that the source is housed in an opaque or transparent enclosure, in order to take into account the different emitting surface in the two conditions. If the enclosure is transparent each LED is visible and the comparison with the limits is made by using the illuminance; if it is opaque, the luminance is used.

The LED tubes represent a particular case, as length is generally much higher than width. In this case, when calculating the illuminance, it can't be assumed that the luminous intensity of all LEDs comes from the central point of the source, because this would represent a too precautionary hypothesis. Thus, in this case the illuminance is calculated as if the LEDs would all locate along the axis of a cylinder having a radius equal to the source-observer distance and all the luminous flux would be emitted only through a portion of the lateral surface of the cylinder, whose angular width corresponds to the beam width of the LED tube under consideration.

Made these premises, the steps followed by the procedure are the following:

1. Calculation of the solid angle of emission starting from the parameter “beam width” α , given the hypothesis of point source and conical emission (to be used for the types "bulb" and "spotlight"):

$$\Omega = 2\pi\left(1 - \cos\frac{\alpha}{2}\right)$$

2. Estimation of the source-eye distance for the operator starting from the location chosen in the installation section.

3. Calculation of the average dimension of the source r_m , that corresponds to the diameter in the "spotlight" or "bulb" cases, while in the "LED tube" case an arithmetical mean of the two dimensions is performed, as indicated in the ICNIRP documents:

$$r_m = \frac{L_1 + L_2}{2}$$

4. The luminance for the "spotlight" and "bulb" types calculated from the luminous flux Φ_v, from the mean dimension of the source r_m and from the solid angle of emission Ω such as:

$$L_v = \frac{\Phi_v}{\Omega \cdot \pi \cdot {r_m}^2}$$

For the "tube" type the calculation takes into account the emission surface, while considering always the same solid angle:

$$L_{v,tube} = \frac{\Phi_v}{\Omega \cdot L_1 \cdot L_2}$$

This calculation does not take into account how luminance varies with the angle of emission and, strictly speaking, it is valid only for small angles in the direction perpendicular to the surface of the source.

5. In the case of the "bulb" or "spotlight" types the illuminance is calculated from the luminous flux Φ_v, the distance d and the solid angle of emission Ω :

$$E_v = \frac{\Phi_v}{\Omega \cdot d^2}$$

In the case of the “tube” type, the illuminance is calculated, as previously said, by assuming that the emission takes place only through one part of the lateral surface:

$$E_{v,tube} = \frac{\Phi_v}{\alpha \cdot d \cdot L_1}$$

where L_1 is the length of the tube.

6. Choice of the limit luminance and illuminance from the reference table, as a function of the inserted colour temperature.

7. Calculation of the angle subtended by the source from the mean size r_m and from the distance d in the case of a circular source:

$$\alpha_s = \frac{r_m}{d}$$

If the source subtends an angle α_s lower than $11\ mrad$ or if the housing is transparent, the calculated illuminance is compared to the limit illuminance, otherwise the comparison with the limit is made in terms of luminance.

The level of risk resulting from the calculated entity M and the corresponding limit one L is the following

$M \leq L$ "low" level of risk

$L \leq M \leq 2 \cdot L$ "moderate" level of risk

$M \geq 2 \cdot L$ "high" level of risk

In order to interpret these levels one should keep in mind that the luminance and illuminance levels are obtained from the maximum levels of radiance and irradiance of the Group 1's sources according to the technical standard IEC EN 62471, by applying a safety factor roughly equal to 2.

Thus, if the level of risk is low, the associated exposure time is typically greater than 200 seconds; the moderate-risk level is associated with an exposure time ranging from about 100 and 200 seconds, while the high-risk level concerns sources having exposure times normally lower than 100 seconds.

Additional hypothesis

In the absence of information on the beam width and on the basis of the other inserted parameters, the assumptions in Table 3 are made.

Type	Surface	Width
spotlight	opaque	50 °
spotlight	transparent	30 °
bulb	opaque	150 °
bulb	transparent	120 °
tube	opaque	120 °
tube	transparent	120 °

Table 3: Beam width assumed depending on the type of the source and on the surface

Furthermore, the following rules are valid:

1. If the field "Typical position" is missing, then the "distance" is equal to "0.2" and the following sentence is added: " the field Typical position is missing, the calculation has been performed assuming that the Typical position is equal desk light (source-observer distance: 20 cm)"

2. If the field "source-observer distance" " is missing and the field "Typical position" is equal to "other", then "distance" is equal to "0.2" and the following sentence is added: " the field Source-observer distance is missing, the calculation has been performed assuming that Observer-source distance: 20 cm"

3. If the fields "breadth" and "length" are missing, but the field "source surface" is equal to "transparent" the calculation can take place, otherwise an error condition is reported.

4. If the fields "length" is missing and the field "source surface" is equal to "opaque" but the field "type" is different from "tube" the calculation can take place, otherwise an error condition is reported.

5. If one of the following fields is missing: "colour temperature" or "luminous flux" then an error condition is reported.

Bibliography

EN 62471 : "Photobiological safety of lamps and lamp systems , Comité Européen de Normalisation (2008)
IEC/TR 62778 : "Application of IEC 62471 for the assessment of blue light hazard to light sources and luminaires", International Electrotechnical Commission, ed. 1 (2012)
IEC/EN 62471 - Photobiological Safety of Lamps and Lamp Systems