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Potential harm to health from new generation light sources

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Abstract

The article presents the characteristics of the new generation of light sources – LEDs; these sources generate white light with various spectral distribution that could pose a potential hazard to people's sight. The impact of electric light sources on human health, divided into ultraviolet radiation hazard, infra-red radiation hazard and visible radiation hazard – taking into account the so-called AMD (age-related macular degeneration), has been discussed in this paper and the laws on photobiological safety have been presented. The New Approach Directive and a related harmonized standard, which is the fundamental document relating to the evaluation of photobiological hazard, have been specified; related documents established in Poland have also been presented. Based on the results of the author's research and a review of the literature, the paper ultimately concludes that LED sources (both individual ones and modules) are safe for the user in terms of photobiological safety, as long as they are used as intended.

Introduction

The electric light sources that produce white light are mainly considered in terms of utility: that is the parameters that provide comfort and safety for visual work (luminous flux, illuminance, color reproduction ability) and energy saving (power consumption, luminous efficiency). However, due to their design, the method of generating light and the radiation spectrum, special hazards to the users' health that may be posed by these sources should also taken into consideration.

Due to withdrawal of traditional light bulbs rated at over 7 W on the 9th of September 2016 and the withdrawal of halogen bulbs that were a substitute for the traditional light bulbs and also due to lighting companies ceasing manufacture of compact fluorescent lamps, consumers are practically being forced to use the new generation light sources – light emitting diodes (LEDs). However, the radiation characteristics of these sources are different from those of traditional incandescent light sources or fluorescent lamps due to the different manner in which they generate light. Therefore, the potential photobiological hazard caused by the emitted ultraviolet and visible radiation which, unlike the traditional bulbs' spectrum, contains a wider range of blue light, must be taken into account when using LED sources.

Characteristics of LED sources

The luminous efficiency values of contemporary LED sources exceed those of fluorescent lamps. In practice, the on/off cycles are neutral for the diodes themselves (the chips), but the electronic systems may have limited resistance to this feature. Additionally, depending on the power supply unit's design, it may cause flickering in these sources, introduce interference to the mains (reactive power, too) and can cause activation delays (Fryc et al., 2017).

LED sources emit radiation in a very narrow wavelength range, not exceeding a dozen nanometres, in which they somewhat resemble laser devices. They also generate light of a specific color, whereas

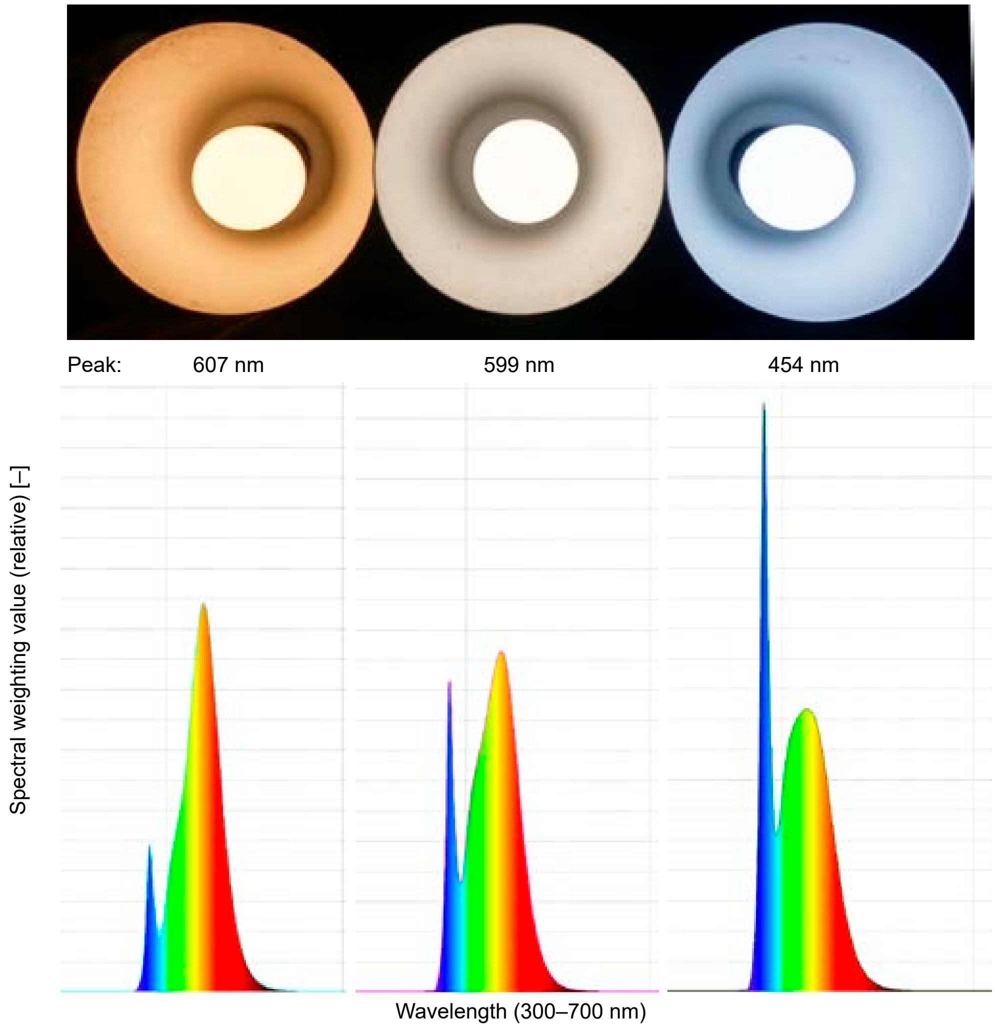

Figure 1. Examples of warm (2671 K), neutral (3790 K) and cool white (6306 K) LED sources and the corresponding radiation spectrum with a maximum value for the wavelengths 607 nm, 599 nm and 454 nm

white light, with a wide range of the visible range wave spectrum should be used for lighting purposes.

The most common method of generating white light with LED sources is the so-called hybrid method, where luminophores are excited with blue light. A blue light emitting diode emits light with a wavelength of about 450 nm; the blue light then stimulates the phosphor placed in the diode housing causing it to emit light. The phosphor, e.g. YAG:Ce, emits yellow-green light which, when mixed with the blue light from the diode, produces white light. Depending on the type of phosphor used, white light with a different color temperature can be obtained (Figure 1). The higher the proportion of the blue component in the light, the higher the color temperature will be. A diode of this design does not emit UV radiation, like fluorescent lamps do, nor does it emit infra-red radiation, like traditional light bulbs do. The only potentially dangerous type of optical radiation from such sources may be excessive visible radiation in the blue light range (the so-called blue light hazard).

The impact of electric light sources on human health

The acknowledged system of classification of the safety of optical radiation sources specifies the potential risk of the occurrence of effects that are harmful to health. Exposure may cause harmful effects, depending on the type of radiation emitted by the source, the conditions of use for a given source and the exposure time to its radiation; eyes (Figure 2) and skin are particularly at risk here.

Ultraviolet radiation hazard

Photokeratitis, photoconjunctivitis and cataracts are the commonly listed conditions of the eyes that can be caused by exposure to hazards. Keratitis is

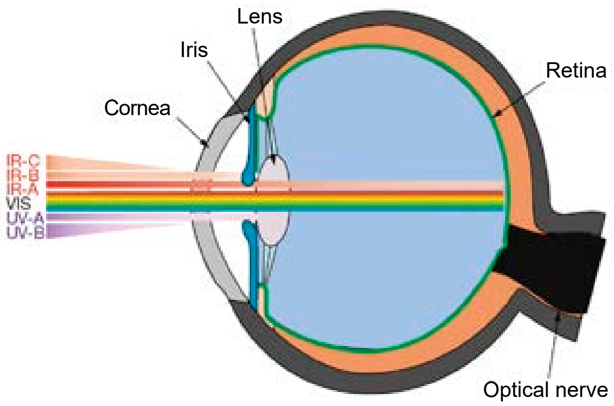

Figure 2. A simplified view of the visual organ, showing the penetration of optical radiation (Stich, Wolfgang & Rafael, 2010)

a photochemical reaction that is most commonly caused by radiation in the 200÷320 nm range that is emitted by mercury or xenon light sources etc. The symptoms include the sensation of sand in the eyes and sudden, involuntary and violent contractions of the eyelid muscles or blurred vision. The reaction is delayed for 4 to 12 hours after exposure and depends on the intensity; most often, the symptoms cease after 24÷48 hours. Cataracts manifest with blurred vision; it also is a photochemical reaction, most often caused by radiation in the 290÷325 nm range. The reaction is delayed by 4 or more hours following exposure, depending on the intensity, and generally leads to permanent clouding of the lens of the eye. Additionally, skin may become reddened where it has been exposed to this kind of radiation as a result of a photochemical reaction, most commonly in the 200÷320 nm range; symptoms usually cease after 24÷48 hours (Wolska & Pawlak, 2010; WHO, 2020).

Practically speaking, LED sources should not emit any UV radiation (unless specifically designed for this purpose). They are more beneficial in this regard than either halogen bulbs or compact fluorescent lamps (Pawlak, 2015).

Visible radiation hazard

Visible radiation, or light, can affect the skin and eyes; the effect of exposure depends on the type of tissue that has been exposed, the intensity of the radiation, the wavelength of the radiation and the exposure time. Visible radiation passes through the eye's optical centers and reaches the retina which has been focused on; which results in the retina being exposed to radiation that is up to several hundred times stronger than of the radiation the cornea is exposed to. This is why light is mainly considered a hazard to the eyes, and much less often to the skin.

Figure 3. Photochemical damage to the retina – direct observation of the source (HD Warrior, 2009)

The hazard from visible radiation can be narrowed down to retinitis caused by blue light. When exposed to very high intensity blue light (mainly in the 400÷490 nm range) the photopigments, which are the light-sensitive substances in the eye, may be destroyed, leading to irreversible damage of the retinal cells (possibly even leading to blindness) (Figure 3). Three factors are necessary for such harmful changes to occur: radiation spectrum distribution (the component of radiation attributable to the blue light spectrum is of significance), energy luminance (at higher values more photons reach the photopigments) and the duration of the exposure (the harmful effect grows with exposure time). For example, due to very high luminance, looking directly at the sun can damage the retina very quickly. However, with the sky, for which the relative share of blue light is much higher, there is no risk of retina damage, because the luminance is considerably lower (CELMA 2011). The symptoms of retinal damage are gaps in the field of vision, observed within 48 hours of exposure. Regeneration is limited, but the natural aversion response usually limits the exposure, thus making damage to the retina unlikely.

For the elderly, blue light may accelerate the onset of a condition that damages the central field of vision (Figure 4), namely AMD – age-related macular degeneration (Figure 5) (Insight Eye Clinic, 2019).

Two forms of AMD can be identified: **dry** and **wet**: **The dry (atrophic) form** constitutes 90% of cases. It is the milder type of AMD, where eyesight sharpness deteriorates gradually over months or even years. The changes taking place in the macula in this form are mainly atrophic in nature. The cells responsible for the correct reception of visual stimuli (photoreceptors) and the cells responsible for the

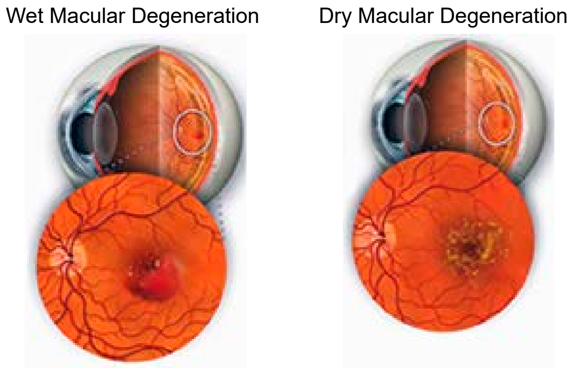

Figure 4. Gradual intensification of the central field of vision damage (Insight Eye Clinic, 2019)

operation of the retina die; as a result, central vision is gradually lost.

The wet form constitutes around 10% of cases. Usually, this form takes a severe course and it may only take days to lose a significant percentage of eyesight. This form consists of the formation of abnormal vessels near the macula, which makes up the so-called subretinal membrane. Transudates and hemorrhage appear in the bottom of the retina, scarring may appear and the retina may be permanently damaged in the final stage (Benedetti, 2012).

It should be noted that, unlike the blue light hazard, AMD may not be caused by a one-off exposure to high luminous intensity. It is caused by long-term exposure to light (including green and yellow light) of low luminous intensity as well, and even to reflected light (CELMA, 2011).

It should be also noted that light plays a major role in regulating the daily rhythms of the body, mostly by inhibiting the production of melatonin. Two completely different methods of the reception of light take place in the human eye. The first type of reception is based on photodetection with receptors: cone cells and rod cells, thanks to which humans can see. The second type of reception of light has only been recently discovered and consists of recording real-time changes to the light that reaches the retina and is a part of the so-called extra-visual responses of the body to light. Newly discovered light receptors take part in this type of light reception and are called Intrinsically Photosensitive Retinal Ganglion Cells (ipRGC); these receptors contain melanopsin. The receptors are found in ganglionic cells, which practically cover the entire area of the retina. Stimulated by light, melanopsin controls both the circadian rhythm and the process of narrowing the pupil. As more light reaches the ipRGC cells, the stronger the inhibition of melanopsin generation by the pineal gland there will be. On the other hand, the lack of light informs the pineal gland that it is night-time and this is when the process of the secretion of melanopsin into the blood begins. Consequently, ganglionic cells with melanopsin are responsible for regulating the extra-visual response to light, namely the circadian physical activity cycle. Melanopsin's spectral sensitivity is the highest for wavelengths of around 480 nm, corresponding to blue-green light (Panda et al., 2005). Light sources which emit blue radiation and have a strong impact on the retina may, depending on luminance, intensify the extra-visual light reception effects (West et al., 2011). Consequently, extra-visual mechanisms in which light impacts the human body should be taken into account when designing lighting systems; this is particularly important for night-shift employees. Illuminating their work stations with bright light sources, especially LED sources with a high share of blue light in their spectrum, will lead to increased

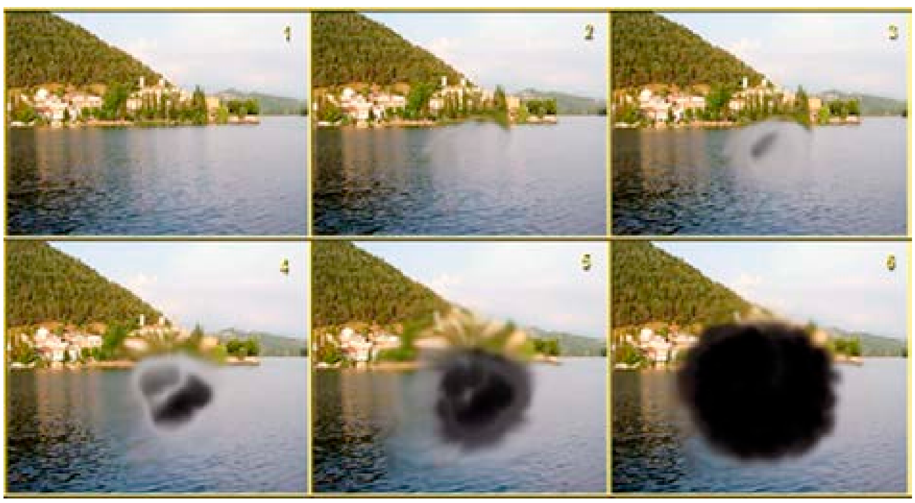

Figure 5. Dry and wet forms of macular degeneration (Benedetti, 2012)

efficiency, but will disrupt their natural day-night cycle, possibly leading to serious health issues.

Light sources using LED technology allow the spectral distribution of the emitted radiation to be controlled, which makes it possible to control the light's extra-visual effects on the body. For example, this may play a role in treating conditions related to biological clock dysfunctions (Fryc et al., 2017).

On the basis of a list of LED sources and halogen bulbs that serve as GLS substitutes, prepared by CELMA (CELMA, 2011), it has been determined that the classification to a risk group is similar in both cases.

In terms of photobiological safety, LED sources do not differ significantly from either halogen bulbs or compact fluorescent lamps. The blue light share in the LED sources spectrum is not higher than its share in incandescent or discharge sources for a given color temperature.

However, the prudent application of downlighter LED sources which, on the basis of examination, fall into the first hazard category and, when equipped with LED modules, fall into the second hazard category due to blue light risk, has been underscored in the literature (LightingEurope, 2013).

The study presented by the US Department of Energy shows that lighting products based on LED technology are no more hazardous than other lighting technologies of the same color temperature. However, caution should be exercised (U.S. Department of Energy, 2013) when the eyes are exposed, in close proximity, to very bright light sources or light sources emitting light in a color other than white, especially colors emitted by blue LEDs. The impact of blue light on small children should also be carefully evaluated, as their defense mechanisms, such as blinking or turning away from sources of intensive light, have not yet developed.

Infra-red radiation hazard

Light can cause thermal or photochemical damage to the eyes. Thermal damage prevails if the exposure time does not exceed 10 seconds, while photochemical damage is more prevalent in cases of longer exposure. This is explained by the fact that photochemical effects are cumulative when repeated throughout longer exposure, while thermal damage is limited to a one-off exposure. The most common hazard to eyesight is the risk of thermal damage to the retina and the occurrence of cataracts. Retinal damage is a thermal reaction caused mainly by radiation in the 400÷1100 nm range; the symptoms are gaps in the field of vision, which can be observed as soon as 5 minutes after exposure. Regeneration is limited, but the natural aversion response usually limits exposure, thus making damage to the retina unlikely. Cataracts manifest with opacity of the lens; it is also a photochemical reaction, most often caused by radiation in the 700÷1400 nm range. It is most often diagnosed in steel or glass mill workers (the so-called glassblower's cataract) and is only caused by exposure to technological processes in practice. Noticeable lens opacity usually occurs after years of exposure, depending on the intensity, and is an irreversible process. However, very intensive radiation exposure at any wavelength can cause burns to the retina (Wolska & Pawlak, 2010; ILO Content Manager, 2011; ICNIRP, 2020).

In the case of the light sources that are commercially available for indoor use, LED sources emit the least infra-red radiation of all the sources, but this does not mean that all products used for all purposes will not pose a hazard to humans (Pawlak, 2015).

Legal acts related to photobiological safety

Aspects of terminology, methods of measuring spectro-radiometry and effective values of optical radiation, as well as the exposure limits of the human eye and skin to optical radiation and the classifications of light sources and luminaires according to hazard groups are specified in the European standards:

- EN 14255-1:2005 Measurement and assessment of personal exposure to incoherent optical radiation – Part 1: Ultraviolet radiation emitted by artificial sources in the workplace.
- EN 14255-2:2005 Measurement and assessment of personal exposure to incoherent optical radiation – Part 1: Visible and infrared radiation emitted by artificial sources in the workplace.
- IEC/EN 62471:2006 Photobiological safety of lamps and lamp systems.

The international IEC 62471 (European Standard, 2006) standard based on the American standard ANSI/IESNA RP 27.3-96 Recommended Practice for Photobiological Safety for Lamps. Risk Group Classification and Labeling (American Standard, 1996).

The IEC 62471 (European Standard, 2006) standard is complemented with two technical reports:

- IEC/TR 62471-2 (IEC Technical report, 2009) Photobiological safety of lamps and lamp systems. Part 2: Guidance on manufacturing requirements relating to non-laser optical radiation safety.

- IEC/TR 62778 (IEC Technical report, 2014) Application of IEC 62471 to light sources and luminaires for the assessment of blue light hazard.

The IEC TR 62778:2014 technical report contains explanations and guidelines on the evaluation of blue light hazard from lighting products that mainly emit optical radiation in the visible range.

In Poland the IEC/EN 62471 (European Standard, 2006) document is the PN-EN standard 62471 (European Standard, 2010), that was harmonized with Directive 2014/35/EC of the European Parliament and of the Council on the harmonization of the laws of Member States relating to making electrical equipment available on the market that is designed for use within certain voltage limits (New Approach Low Voltage Directive (LVD) (European Parliament, 2014). According to the document, it is mandatory to classify substitutes according to their hazard to health, as related to their potential use. The direct or time-delayed effects of using a product (including the level and probability of the loss of health or life by consumers) are taken into account when evaluating whether a product is safe. Four risk groups have been distinguished according to EN 62741 (Table 1).

Table 1. Classification of the hazard level of light sources and lighting systems according to EN 62741 (European Standard, 2006)

Risk group	Risk level	Explanation
0	None	No photobiological hazard
1	Low	No risk for normal exposure limits when used correctly. In case of exposure, the risk is limited by normal behavioral limits
2	Moderate	The risk is limited by natural aversion reactions to very bright light stimuli
3	High	The risk is present even in case of momentary or short-term exposure

The risk evaluation covered in EN 62741 (European Standard, 2006) is related to the possibility of damage to the retina by means of photochemical or thermal factors; in any case, the risk depends on the wavelength of the light. Figure 6 shows that blue light in the 400÷500 nm wavelength range may create a risk of thermal damage to the retina that can be even 10 times higher than that caused by light in the 500÷700 nm range. Consequently, various light sources may be of a different nature and may cause different levels of hazard. Pursuant to the requirements in standard EN 62471 (European Standard, 2006), irradiation measurements should be made at a distance at which the illuminance E is 500 lx and, at the same time, the distance is not shorter than 0.2 m. Therefore, the classification within a particular risk group should be always considered at the level of the final product, rather than its components.

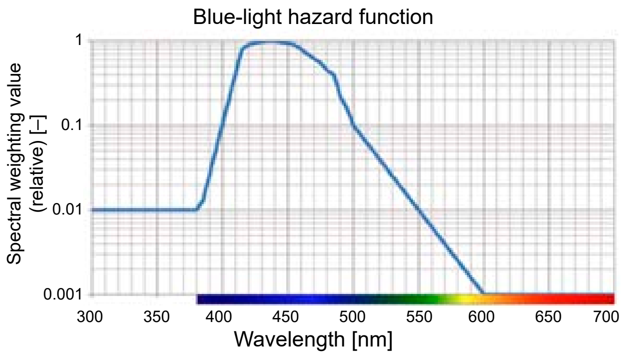

Figure 6. The spectral efficiency function serving as the basis of determining the level of risk related to photochemical damage of the retina – *B curve* (*λ*) (Van der Steen, 2011)

It should also be stated that the EN 62471 (European Standard, 2006) standard is an integral part of the New Approach Low Voltage Directive (LVD) 2014/35/UE and is listed as a harmonized standard. Therefore, it must be specified in the list of standards of EU declarations of conformity. The EU declaration of conformity is a document issued by the manufacturer or its authorized representative to confirm the product's conformance with the fundamental regulations, namely the New Approach directives. The issue of an EU declaration of conformity allows the manufacturer to apply a CE marking to the product; the CE marking is:

- the manufacturer's responsibility;
- a symbol confirming the conformance of a given product with the relevant European Union directives for this type of products;
- a declaration of observance of the fundamental requirements for health protection and safety and the conformance evaluation procedures;
- a passport permitting the unrestricted flow of goods within the European Union.

Putting the CE marking on goods traded in Poland became mandatory on the day Poland joined the European Union. Although the used of the harmonized standards is voluntary, satisfying the requirements for a given product is of an overriding nature. That means, in practice, that every device with CE marking introduced for trade in the European market has by default been examined for photobiological safety. Additionally, the LVD Directive imposes the requirement of the product being marked in a clear manner.

In the case of photobiological safety, the details on labelling products are specified in the technical report IEC TR 62778 (IEC Technical report, 2014). As per the instructions, products classified in the "0" and "1" risk groups (no risk or low risk) do not have to be marked; lighting equipment in groups "2" and "3" must be labelled.

This means, in practice, that if a product bears the CE marking but no information about the photobiological safety class, every user can expect that the luminaire / light source does not pose any hazard under any conditions or only poses a low hazard (belonging to risk groups "0" or "1").

The publication, in Poland, of Directive 2006/25/EC of the European Parliament and of April 05, 2006 (European Parliament, 2006) and the regulations of the Ministry of Labor and Social Policy dated May 27, 2010 (Journal of Law, 2010) and June 6, 2018 (Journal of Law, 2018), radically changed the treatment of light sources and luminaires as potential sources of a photobiological threat. Both the manufacturers and the consumers must be informed as to under what specific conditions light sources can pose a hazard or none at all, and in the case of the former, what protective measures should be taken. Unfortunately, the technical reports IEC/TR 62471-2:2009 and IEC/TR 62778 (2014) are not part of the group of accepted Polish standards.

The fundamental difference in the position where the measurements are taken between standard EN 62471 (European Standard, 2006) and standards: EN 14255-1 (European Standard, 2005a), EN 14255-2 (European Standard, 2005b) should be noted. The EN 62471 (European Standard, 2006) standard serves to evaluate the risk caused by optical radiation sources and classify the sources according to the risk they pose; therefore it specifies standard measuring distances in order to make a comparison between the sources possible. However, the standards EN 14255-1 (2005), EN 14255-2 (2005) and the Regulation of the Ministry of Labor and Social Policy (May 27, 2010) (Journal of Law, 2010) deal with the hazards that are present in work stations, which means that the measurements should be taken where the employee who is subject to the exposure works – near the eyes or areas of uncovered skin.

Conclusions

It should be stated that the hazards caused by the emission of optical radiation by modern light sources can be identified and eliminated by the correct operation of these sources (maintaining specific distances, correct location in the user's field of vision and using appropriate luminaires).

Based on the literature, it is known that the probability of thermal damage to the retina from non-laser sources is low. Therefore, in case of the radiation from LED sources, the photochemical hazard to eyes caused by blue light can usually be evaluated.

Based on the author's own research (60 LED sources were examined, purchased from DIY stores – 33 LED sources were produced by renowned manufacturers: PHILIPS, OSRAM and 27 were from less well known manufacturers) and the information found in one of the publications (Pawlak & Zalesińska, 2017), it can be said that LED sources (both individual sources and modules) that constitute substitutes for traditional light bulbs, are safe for users in terms of photobiological safety, when used as intended. For a given color temperature, the share of blue light in LED sources does not differ from the share of blue light in sources that use other technologies. Still, users should avoid looking directly at bright, point light sources such as the Sun. However, when a person looks at a bright source of light, a natural aversion response occurs (the eyes close reflexively or are turned away).

Employees often complain about various ailments, in particular of the eyes, which they attribute to improperly illuminated work stations, in particular with the use of various replacements for traditional light bulbs. These complaints do not always stem from the use of the substitutes themselves, but rather the use of poor quality substitutes. In addition, the luminaires that are used should be correctly selected for the type of work being performed. For example, in-line fluorescent lamps should not be replaced with high power LED sources installed inside glass pipes with dimensions equivalent to those of fluorescent lamps, without any lighting and optical systems.

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