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Article

Analysis and Measurements of Artificial Optical Radiation (AOR) Emitted by Lighting Sources Found in Offices

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Abstract: In this paper the authors describe in detail the exposure limit values concerning artificial optical radiation due to the main incoherent light sources found in offices. In particular, for some examples of significant sources chosen as case studies, we discuss the results of *in situ* measurements of the exposure values using a broadband photoradiometer. By comparing the measurement results with the exposure limit values specified in the European legislation, the maximum exposure times for workers have been evaluated. From the analysis of the results it can be concluded that the lighting sources typically present in indoor workplaces under usual conditions of use, do not pose a health risks for workers. However, in the case of accidental exposure during work activities or exposure linked to maintenance activities (short exposure distance), values in excess of the limit values have been observed, with decidedly short maximum exposure times.

Keywords: artificial optical radiation; incoherent sources; limit exposure values; lighting sources; indoor work places

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1. Introduction

Electromagnetic radiation in the wavelength range between 100 nm and 1 mm is commonly known as "optical radiation" [1,2]. Optical radiation in the wavelength range between 100 nm and 400 nm is referred to as "ultraviolet" (UV); the UV region is divided into UVA (315–400 nm), UVB (280–315 nm) and UVC (100–280 nm). Optical radiation in the wavelength range between 780 nm and 1 mm is referred to as "infrared" (IR); the IR region is divided into IRA (780–1400 nm), IRB (1400–3000 nm) and IRC (3000 nm–1 mm). Optical radiation in the wavelength range between 380 nm and 780 nm is referred to as "visible light" (VIS) or more simply "light" and it is extensively studied in lighting applications [3,4].

The wavelength range of interest for artificial optical radiation (AOR) risk assessment is between 180 nm and 3000 nm. Within this range, special attention must be paid in the "blue light" range (300–700 nm), where most of the visible light, all the UVA radiation and a portion of the UVB radiation are included.

Among the AOR sources of significant interest some industrial process equipment (e.g., welding, paint drying ovens, melting of metal and glass, *etc.*) and some medical equipment (e.g., laser, neonatal phototherapy lamps, sterilization, surgical lights, *etc.*) are considered. Minor attention has been paid to incoherent sources widely used in offices, e.g., lamps/luminaries, display screen equipment, copiers and scanners, and LED for lighting and signaling. However, for these sources, exposure times (sometimes far higher than the standard working day of eight hours) and values of illuminance higher than the reference values may require careful risk assessment arising from AOR [2,5,6].

In order to achieve sustainable work environments, in which high level of visual comfort and safety are guaranteed during the working activities (especially for those in which demanding visual tasks are required), the risk assessment from AOR exposure should be accompanied by a risk assessment arising from lighting. [7,8]. The risk assessment arising from lighting involves accurate analysis of the artificial lighting systems [4,7] and of the natural lighting conditions [9,10], for both indoor and outdoor work environments. It is also noted that the use of light sources whose emission spectrum is chosen appropriately, in such a way that most of the emitted radiation falls in the visible wavelength range, helps to increase the energy efficiency of the lighting system [3,11] and consequently the environmental sustainability of buildings.

In this paper, using the results of a study of *in situ* measurements, the risks of exposure to sources typically present in offices are analyzed. The measurements were carried out in both customized configurations to reproduce typical work situations and in standard configurations (two source-detectors distances: 20 cm and 100 cm, according to European standards). In particular, the measurement configurations characterized by a short source-detectors distance, even if not realistic, can be representative of special work situations, for example: accidental exposure during work activities (e.g., the handling of portable sources) or exposure linked to maintenance activities (e.g., replacement or repair of lamps and luminaires). It can be noticed that, in these special work situations, knowledge of the potential risks for workers, very often underestimated, has a great importance.

2. Legislative Framework

At an international level [12–19] it is considered necessary to introduce measures protecting workers from the risks arising from AOR, owing to its effects on the health of workers. In Table 1, for each wavelength range of interest, the parts of the body subject to risk and the type of potential hazard are indicated.

Table 1. Artificial optical radiation (AOR) emissions of incoherent sources: interested parts of the body and types of hazards [1,20].

Index	Wavelength (nm)	Electromagnetic Radiation	Part of the Body	Hazard
(a)	180–400	UV (A, B, C)	Eye (cornea, conjunctiva, lens)	Photokeratitis, conjunctivitis, cataractogenesis
			Skin	Erythema, elastosis, skin cancer
(b)	315–400	UVA	Eye (lens)	Cataractogenesis
(c)	300–700	Blue Light	Eye (retina)	Photoretinitis
(d)				
(e)				
(f)				
(g)	380–1400	VIS and IRA		Retinal burn
(h)				
(i)				
(j)	780–1400	IRA		
(k)				
(l)				
(m)	780–3000	IR (A, B)	Eye (cornea, lens)	Corneal burn, Cataractogenesis
(n)				
(o)	380–3000	VIS and IR (A, B)	Skin	Burn

The minimum requirements to protect workers against risks to health and safety that may result from exposure to the AOR at work are specified in the European Directive 2006/25/EC [1,2] on the minimum health and safety requirements regarding the exposure of workers to risks arising from AOR, with special attention to the risks due to adverse effects on the eyes and skin.

The European Directive 2006/25/EC [1,2] has been acknowledged in Italy by the Legislative Decree 81/2008 [20]. In the Italian Legislative Decree, the AOR is listed among the physical agents and treated in Chapter V, "Protection of workers from the risks arising from exposure to artificial optical radiation" (Articles 213–218) and Annex XXXVII (Part I: incoherent sources, Part II: LASER). The content of the European Directive [1] has been fully taken up by the Italian Legislative Decree [20].

In cases in which workers are exposed to AOR, the employer shall assess and (if necessary) measure and/or calculate the maximum exposure levels to which workers are likely to be exposed, additionally evaluating the needed actions to restrict exposure down to the pertinent limits (see Section 4).

3. Technical Standards

The methodology applied in assessment, measurement and calculations of AOR emitted by incoherent sources shall follow the standards of the European Committee for Standardization (see Table 2). All the standards listed in Table 2 were acknowledged in Italy (by UNI, National standardization authority) during the period May 2003–December 2012, especially for the application of the European Directive [1] and the Italian Decree [20].

In exposure situations that are not covered by these standards and recommendations, the assessment, measurement and calculations shall be carried out using available national or international science-based guidelines [2,12–16].

Table 2. Technical standards regarding AOR emissions of incoherent sources.

Title	Number	Year
Photobiological safety of lamps and lamp systems	EN 62471	September 2008
Safety of machinery—Assessment and reduction of risks arising from radiation emitted by machinery—Part 1: General principles	EN 12198-1	September 2008
(…)—Part 2: Radiation emission measurement procedure	EN 12198-2	September 2008
Measurement and assessment of personal exposures to incoherent optical radiation—Part 1: Ultraviolet radiation emitted by artificial sources in the workplace	EN 14255-1	March 2005
(…)—Part 2: Visible and infrared radiation emitted by artificial sources in the workplace	EN 14255-2	December 2005
(…)—Part 4: Terminology and quantities used in UV, visible and IR exposure measurements	EN 14255-4	October 2006
Personal protective equipment—Eye and face protection—Vocabulary	EN ISO 4007	May 2012
Personal eye-protection—Specifications	EN 166	November 2001
(…)—Ultraviolet filters—Transmittance requirements and recommended use	EN 170	October 2002
(…)—Infrared filters—Transmittance requirements and recommended use	EN 171	March 2002

4. Exposure Limit Values

The exposure limit values must be considered as limits on exposure to AOR which are based directly on established health effects and biological considerations [12–19]. Compliance with these limits will ensure that workers exposed to artificial sources of optical radiation are protected against all known adverse health effects [1,20]. The radiometric parameters, which are used to express the exposure limit values for the different wavelength ranges of the optical radiation, are summarized in Table 3 [1,20].

Table 3. AOR emissions of incoherent sources: exposure limit values [1,20].

Index	Wavelength (nm)	Exposure Limit Value	Units	Time	Notes
(a)	180–400	$H_{EFF} = 30$	$J \cdot m^{-2}$	Daily value (8 h)	Equation (1)
(b)	315–400	$H_{UVA} = 10^4$	$J \cdot m^{-2}$		Equation (3)
(c) [1]	300–700	$L_B = 10^6 \cdot t^{-1}$	$W \cdot m^{-2} \cdot sr^{-1}$	$t \leq 10{,}000$ s	Equation (5)
(d) [1]		$L_B = 100$		$t > 10{,}000$ s	
(e) [1]		$E_B = 100 \cdot t^{-1}$	$W \cdot m^{-2}$	$t \leq 10{,}000$ s	Equation (6)
(f) [1]		$E_B = 0.01$		$t > 10{,}000$ s	
(g) [2]	380–1400	$L_R = (2.8 \cdot 10^7) \cdot C_\alpha^{-1}$	$W \cdot m^{-2} \cdot sr^{-1}$	$t > 10$ s	Equation (7)
(h) [2]		$L_R = (5 \cdot 10^7) \cdot C_\alpha^{-1} \cdot t^{-0.25}$		$10\ \mu s \leq t \leq 10$ s	
(i) [2]		$L_R = (8.89 \cdot 10^8) \cdot C_\alpha^{-1}$		$t < 10\ \mu s$	
(j) [3]	780–1400	$L_R = (6 \cdot 10^6) \cdot C_\alpha^{-1}$		$t > 10$ s	Equation (8)
(k) [3]		$L_R = (5 \cdot 10^7) \cdot C_\alpha^{-1} \cdot t^{-0.25}$		$10\ \mu s \leq t \leq 10$ s	
(l) [3]		$L_R = (8.89 \cdot 10^8) \cdot C_\alpha^{-1}$		$t < 10\ \mu s$	
(m)	780–3000	$E_{IR} = 18{,}000 \cdot t^{-0.75}$	$W \cdot m^{-2}$	$t \leq 1000$ s	Equation (9)
(n)		$E_{IR} = 100$		$t > 1000$ s	
(o)	380–3000	$H_{SKIN} = 20{,}000 \cdot t^{0.25}$	$J \cdot m^{-2}$	$t < 10$ s	Equation (10)

Notes: [1] The exposure limit values for indices (c) and (d) are referred to $\alpha \geq 11$ mrad, the exposure limit values for indices (e) and (f) are referred to $\alpha < 11$ mrad; [2] The coefficient C_α for indices (g), (h) and (i) is: $C_\alpha = 1.7$ for $\alpha < 1.7$ mrad, $C_\alpha = \alpha$ for $1.7 \leq \alpha \leq 100$ mrad, $C_\alpha = 100$ for $\alpha > 100$ mrad; [3] The coefficient C_α for indices (j), (k) and (l) is: $C_\alpha = 11$ for $\alpha < 11$ mrad, $C_\alpha = \alpha$ for $11 \leq \alpha \leq 100$ mrad, $C_\alpha = 100$ for $\alpha > 100$ mrad (measurement field of view: 11 mrad). In the previous notes [1–3], α is the angle subtended by an apparent source as viewed at a point in space; apparent source is the real (or virtual) object that forms the smallest possible retinal image.

In the wavelength range 180–400 nm, the radiometric parameter (H_{EFF}), used to express the exposure limit value, is evaluated with the Equation:

$$H_{EFF} = E_{EFF} \cdot \Delta t \tag{1}$$

$$\text{with } E_{EFF} = \sum_{180nm}^{400nm} E_\lambda \cdot S(\lambda) \cdot \Delta\lambda \tag{2}$$

where: E_λ ($W \cdot m^{-2} \cdot nm^{-1}$) is the radiant power incident per unit area upon a surface (spectral irradiance); Δt (s) is the duration of the exposure (t, time); $\Delta\lambda$ (nm) is the bandwidth of the pertinent wavelength range; $S(\lambda)$ is the spectral weighting (dimensionless). In particular the function $S(\lambda)$ takes into account the wavelength dependence of the health effects of UV radiation on eyes and skin (see Figure 1). The exposure limit value for H_{EFF} is indicated in Table 3 (index a).

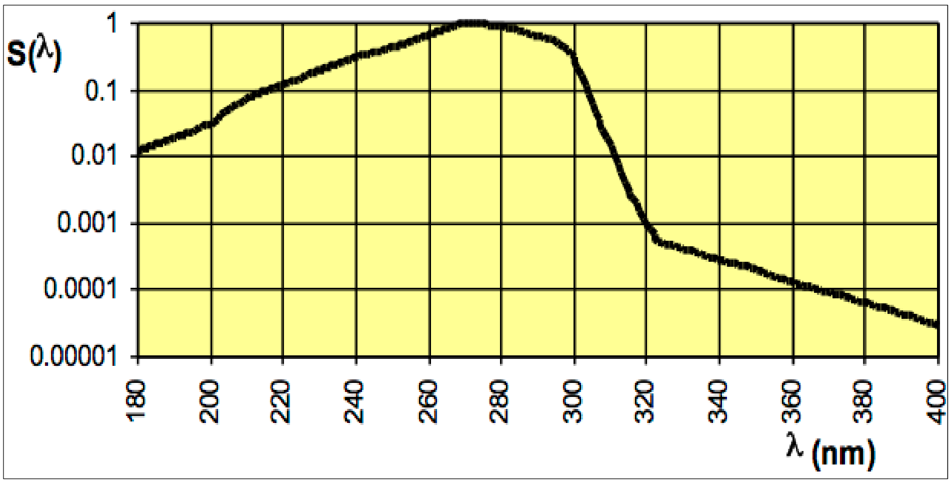
In the wavelength range 315–400 nm, the radiometric parameter (H_{UVA}), used to express the exposure limit value, is evaluated with the Equation:

$$H_{UVA} = E_{UVA} \cdot \Delta t \tag{3}$$

$$\text{with } E_{UVA} = \sum_{315nm}^{400nm} E_\lambda \cdot \Delta\lambda \tag{4}$$

The exposure limit value for H_{UVA} is indicated in Table 3 (index b).

Figure 1. The spectral weighting S(λ), see also Equation (2).



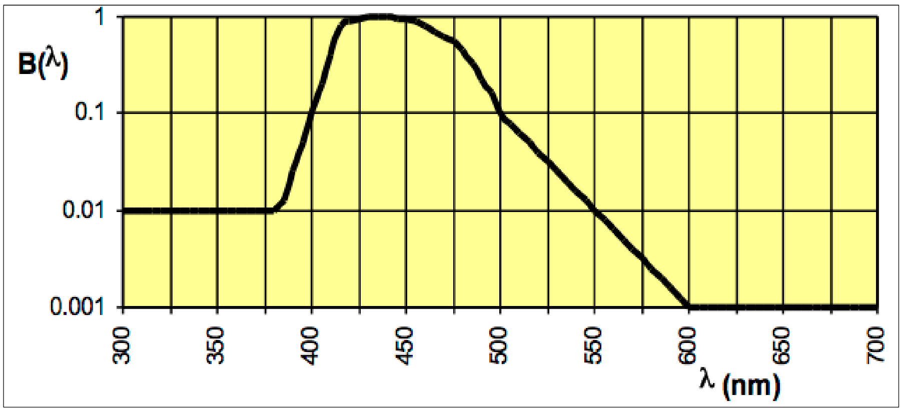
In the wavelength range 300–700 nm, the radiometric parameters (L_B and E_B), used to express the exposure limit values, are evaluated with the Equations:

$$L_B = \sum_{300nm}^{700nm} L_\lambda \cdot B(\lambda) \cdot \Delta\lambda \qquad (5)$$

$$E_B = \sum_{300nm}^{700nm} E_\lambda \cdot B(\lambda) \cdot \Delta\lambda \qquad (6)$$

where: L_λ ($W \cdot m^{-2} \cdot sr^{-1} \cdot nm^{-1}$) is the spectral radiance of the source; B(λ) is the spectral weighting (dimensionless). In particular the function B(λ) takes into account the wavelength dependence of the photochemical injury caused to the eyes by Blue Light radiation (see Figure 2). The exposure limit values for L_B and E_B are indicated in Table 3 (indices c–f, see also note [1]).

Figure 2. The spectral weighting B(λ), see also Equations (5) and (6).



In the wavelength range 380–1400 nm, the radiometric parameter (L_R), used to express the exposure limit values, is evaluated with the Equations:

$$L_R = \sum_{380nm}^{1400nm} L_\lambda \cdot R(\lambda) \cdot \Delta\lambda \qquad (7)$$

$$L_R = \sum_{780nm}^{1400nm} L_\lambda \cdot R(\lambda) \cdot \Delta\lambda \quad (8)$$

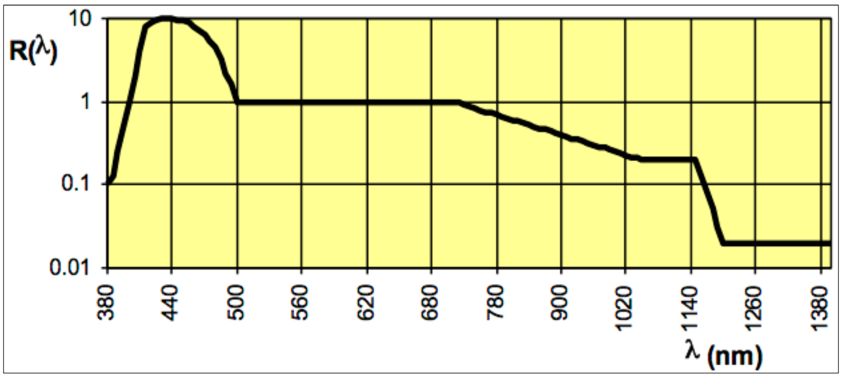
In this case, the function R(λ) takes into account the wavelength dependence of the thermal injury caused to the eye by visible and IRA radiation (see Figure 3). The exposure limit values for L_R evaluated with Equation (7) are indicated in Table 3 (indices g–i, see also note [2]). The exposure limit values for L_R evaluated with Equation (8) are indicated in Table 3 (indices j–l, see also note [3]).

In the wavelength range 780–3000 nm, the radiometric parameter (E_{IR}), used to express the exposure limit values, is evaluated with the Equation:

$$E_{IR} = \sum_{780nm}^{3000nm} E_\lambda \cdot \Delta\lambda \quad (9)$$

The exposure limit values for E_{IR} are indicated in Table 3 (indices m–n).

Figure 3. The spectral weighting R(λ), see also Equations (7) and (8).



Finally, in the wavelength range 380–3000 nm, the radiometric parameter (H_{SKIN}), used to express the exposure limit value, is evaluated by the Equation:

$$H_{SKIN} = E_{SKIN} \cdot \Delta t \quad (10)$$

$$\text{with } E_{SKIN} = \sum_{380nm}^{3000nm} E_\lambda \cdot \Delta\lambda \quad (11)$$

The exposure limit value for H_{SKIN} is indicated in Table 3 (index o).

Functions S(λ), B(λ) and R(λ) are reported as data lists in the European Directive [1], in Figures 1–3 this data is plotted in graphical form. The international definitions of the spectral weighting functions S(λ), B(λ) and R(λ) are based on extensive research activity in medical science whose results have been published by the International Commission on Non-Ionizing Radiation Protection [12–19].

The exposure limit values, shown in Table 3, can be graphically interpreted [5]. The graphical interpretations of the exposure limit values can be used as a practical tool by the staff assigned to assess the risks arising from AOR exposure in the workplace.

5. Examples of AOR *in situ* Measurements

In this Section, some results obtained from *in situ* measurements of AOR emitted by incoherent sources typically found in offices are shown and discussed. The results reported in this paper are some examples of a wider research carried out by the authors on the artificial optical radiation emitted from light sources in offices and from medical equipment [5]. This research is currently being continued with *in situ* measurements on a sample representative of LED lamps used in offices.

The incoherent sources typically found in offices, and for which the results of *in situ* measurements are reported in this section, are shown in Figure 4 (sources 1–5). In order to obtain useful comparisons, in addition to emissions of sources found in the offices, the authors have carried out AOR measurements for some sources that have significant emissions in specific wavelength ranges (e.g., UV, Blue Light, IR). In this regard, some typical medical equipment, sources 6–8 in Figure 4, has been chosen. This are characterized respectively by IR, UV and Blue Light significant emissions and for these sources, specific activities of analysis and monitoring of emissions are required in order to protect the safety and health of workers [5].

Figure 4. Examples of AOR incoherent sources (A: source number; B: type of source; C: manufacturer and model) typically found in offices (sources 1–5) and examples of medical equipment (sources 6–8).

The measurements have been carried out by the authors during the period between April 2013 and January 2014. The measurement activity has been developed in some offices of the Department of Energy Engineering, Systems, Territory and Constructions of the University of Pisa, for the sources found in offices and in the Medical Hospital of Pisa, for the medical equipment.

The measurements were carried out by using a portable broadband photoradiometer (Type Delta Ohm model HD2402, with DeltaLog13 software used to set measurement parameters and to perform post-elaborations of the acquired data). The broadband photoradiometer is equipped with: four radiometer detectors, a photometer detector and a thermopile detector, which are able to make measurements of irradiance over the entire range of AOR wavelengths (180–3000 nm). The photoradiometer has an internal processor which, by combining the electrical signals coming from the different detectors and taking into account the spectral weighting functions S(λ), B(λ) and R(λ), allows estimation of the parameters required for the risk assessment according to the European Directive 2006/25/EC [1]. The measure of the radiance is indirectly obtained, starting from: the values of the irradiance measured by the detectors, the size of the effective surface of emission and the geometric characteristics of the measurement configuration (e.g., viewing distance and viewing angle, set by the operator).

For all the sources shown in Figure 4, the measurements were carried out in both standard configurations (two source-detectors distances: 20 cm and 100 cm, with view directions orthogonal to the emitting surface of the source) and customized configurations (in order to reproduce usual work situations). For the sources 1 and 8, the measurements at a distance of 20 cm were replaced with measurements at a distance for which illuminance values of 500 lx and 10^5 lx respectively were detected (EN 62471, see Table 2). The activity measurement was carried out according to a standard procedure, divided into the following phases:

- positioning of the radiometric detector in the measurement configuration chosen;
- geometric relief of the measurement configuration and of the size of the emission source;
- lighting of the source and beginning of the radiometric data acquisition;
- waiting for the achievement of stabilized emission (condition considered to be reached when the illuminance measured values remained constant over time);
- acquisition of the radiometric data, with sample rate of 1 s for a total time of 300 s;
- interruption of the measurement and turning-off of the source;
- post-processing of the acquired data and verification of the maximum exposure times;
- preparation (printing) of the certificate of measurement.

From the results of the *in situ* measurements carried out by the authors, it can be noticed that, for most of the incoherent office sources, if the usual conditions of use are considered, the limit values fixed in the European Directive 2006/25/EC [1] are not exceeded. However, the risk from exposure to these sources cannot be directly excluded because an exposure duration longer than 8 h, exceeding that indicated in [1], or an exposure in other than usual conditions (e.g., maintenance operation of the source) can lead to exposure limit values being exceed, with consequent risks for the health of the worker.

A graphical interpretation of the exposure limit values has been used in order to discuss the results of *in situ* measurements of AOR. In this regard, in Figures 5–7, for the wavelength ranges: UV (180–400 nm), Blue Light (300–700 nm) and IR (780–3000 nm), the results obtained for the sources indicated in Figure 4 are shown. The results are referred to the measurement configuration characterized by a source-detectors distance equal to 20 cm (with the direction of view orthogonal to the source), in which measured values exceed often the exposure limit values for different sources.

Figure 5 shows the trend of the radiant exposure H_{EFF} (180–400 nm) as a function of time for source 2 (see Figure 4), the only source among those examined for the offices which has significant emissions in the UV wavelength range. This trend, see Equation (1), is obtained having measured a value of irradiance E_{EFF} = 1.77 W/m^2. The emission of source 2 in the UV range is comparable to that of source 7 (Hand-Foot UV lamp), used for therapeutic purposes because of its UV emission. For source 7, in the specified measurement configuration, a value of irradiance E_{EFF} = 1.58 W/m^2 has been measured. As a useful comparison between sources 2 and 7, in Figure 5 the trend of the radiant exposure H_{EFF} is also shown. From the analysis of Figure 5 it is possible to notice how, in the specified measurement configuration, the radiant exposure limit value is reached in 17 s and 19 s for sources 2 and 7 respectively. These times are to be interpreted as a maximum time of continuous exposure.

Figure 5. Trends of radiant exposure H_{EFF} (180–400 nm) and maximum exposure times for sources 2 and 7 (see Figure 4).

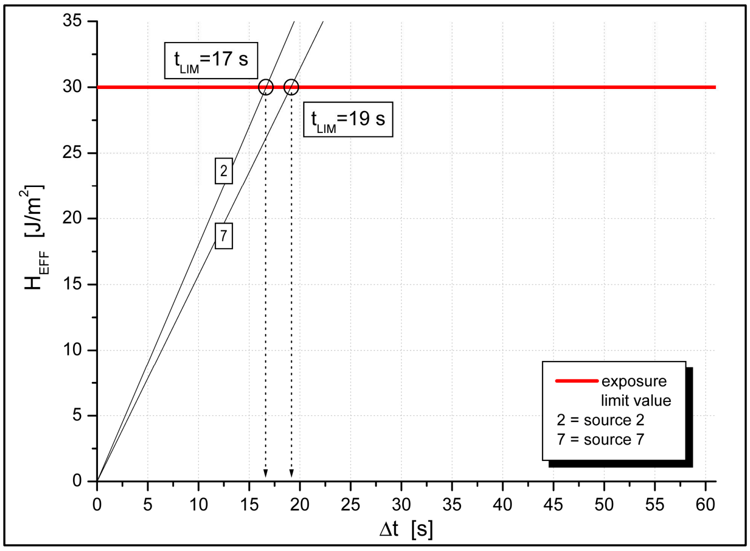


Figure 6 shows the values of the radiance L_B (300–700 nm) for all the sources of Figure 4. As can be seen from the comparison of the values obtained for L_B in the measurement configuration with the corresponding exposure limit values, for sources 2, 3 and 5 it is clear that the exposure limit is exceeded. The emissions of sources 2, 3 and 5 in the range of Blue Light are comparable to the emissions of source 8 (Scialytic lamp), characterized by high emission levels necessary to perform the visual task in the operating room. The maximum exposure times vary from 9174 s (about 2.5 h) for source 8 (Scialytic lamp) down to 56 s for source 5 (video projector).

Figure 6. Measured values of the radiance L_B (300–700 nm) and maximum exposure times for sources 1–8 (see Figure 4).

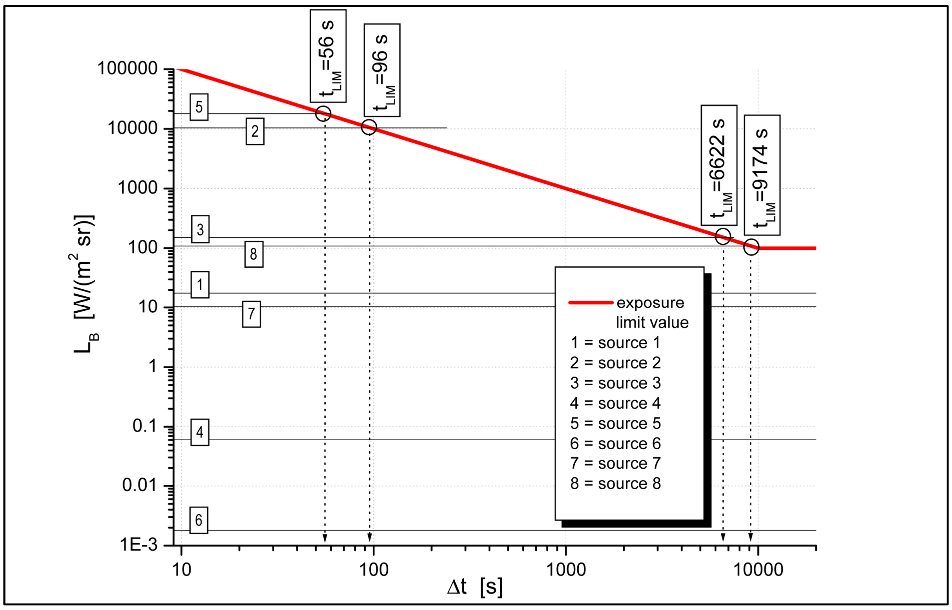
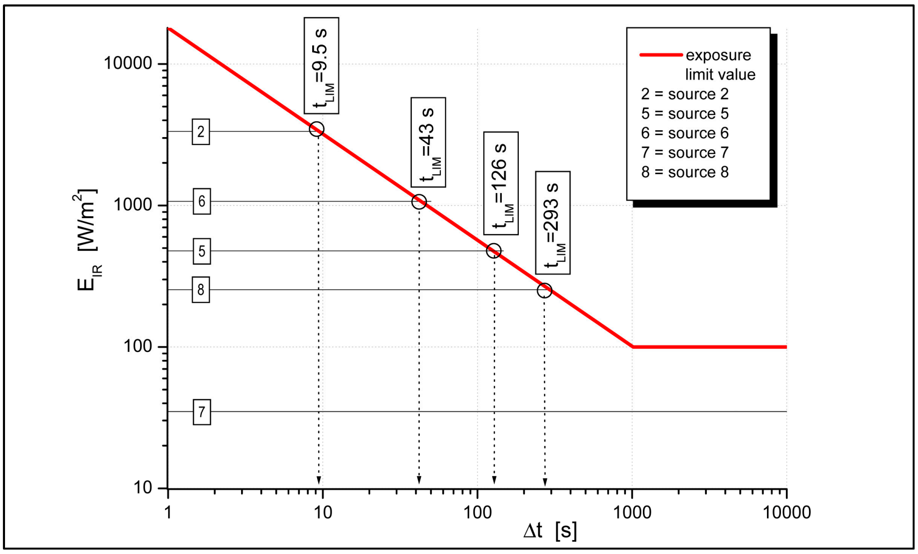


Figure 7 shows the values of irradiance E_{IR} (780–3000 nm) for sources 2 and 5 in comparison with source 6 (Infant warmer IR), whose significant emissions are used in neonatal therapies. In Figure 7, for completeness, the values of irradiance for sources 7 and 8 are also shown. As can be seen from the comparison of the values obtained for E_{IR} in the measurement configuration with the corresponding exposure limit values, for sources 2, 5, 6 and 8 it is clear that the exposure limit is exceeded. The maximum exposure times vary from 293 s for source 8 (Scialytic lamp) down to 9.5 s for source 2 (Spot light).

Figure 7. Measured values of the irradiance E_{IR} (780–3000 nm) and maximum exposure times for sources 2, 5–8 (see Figure 4).



6. Conclusions

The problem of risk assessment from exposure to artificial optical radiation (AOR), both for coherent and incoherent sources, has long been analyzed by the international scientific community, as demonstrated by the numerous technical reports and guidelines that are present in the technical literature. The minimum requirements to protect workers against risks to health and safety that may result from exposure to the AOR at work are specified in the European Directive 2006/25/EC; in Italy, the content of the European Directive has been fully taken up by the Legislative Decree 81/2008.

Among the incoherent sources, special attention has been paid to industrial process equipment and medical equipment, while minor attention has been paid to incoherent sources widely used in offices. In this paper, using the results of a study of *in situ* measurements, the risks of exposure to sources typically present in offices have been analyzed. The measurements were carried out in both customized configurations to reproduce usual work situations and in standard configurations (two source-detectors distances: 20 cm and 100 cm, according to European standards).

From the analysis of the results of *in situ* measurements it can be concluded that the lighting sources typically present in indoor workplaces under usual conditions of use do not pose a health risks for workers. However, for the measurement configuration characterized by a source-detectors distance equal to 20 cm (direction of view orthogonal to the source), values in excess of exposure limit values have been observed, with decidedly short maximum exposure times (in some cases less than 20 s).

This configuration (which is suitable in order to determine the AOR emission of the sources according to EN 62471) can be representative of special work situations, for example: accidental exposure during work activities or exposure linked to maintenance activities. It can be noticed that in these special work situations (e.g., handling of portable sources, replacement or repair of lamps and luminaires) the knowledge of the potential risks for workers, very often underestimated, has a great importance.

Finally, the graphical interpretation of the exposure limit values proposed by the authors could be used as a practical tool for the staff assigned to assess the risks arising from AOR exposure in the workplace within the Occupational Health and Safety assessment procedures.

Author Contributions

The authors have contributed in equal parts to the realization of all stages of the work, beginning with the design of the research activity, finishing with the writing of the manuscript, including the important stages inherent to the measurements activity and the data analysis. All authors have read and approved the final manuscript.

Nomenclature

λ	wavelength (nm);
$B(\lambda)$	spectral weighting function in the wavelength range 300–700 nm (dimensionless);
E_λ	spectral irradiance ($W \cdot m^{-2} \cdot nm^{-1}$);
E_B	effective irradiance in the wavelength range 300–700 nm ($W \cdot m^{-2}$);
E_{EFF}	effective irradiance in the wavelength range 180–400 nm ($W \cdot m^{-2}$);
E_{IR}	effective irradiance in the wavelength range 780–3000 nm ($W \cdot m^{-2}$);
E_{SKIN}	effective irradiance in the wavelength range 380–3000 nm ($W \cdot m^{-2}$);
E_{UVA}	effective irradiance in the wavelength range 315–400 nm ($W \cdot m^{-2}$);
H_{EFF}	radiant exposure in the wavelength range 180–400 nm ($J \cdot m^{-2}$)
H_{SKIN}	radiant exposure in the wavelength range 380–3000 nm ($J \cdot m^{-2}$);
H_{UVA}	radiant exposure in the wavelength range 315–400 nm ($J \cdot m^{-2}$);
L_λ	spectral radiance ($W \cdot m^{-2} \cdot sr^{-1} \cdot nm^{-1}$);
L_B	effective irradiance in the wavelength range 300–700 nm ($W \cdot m^{-2} \cdot sr^{-1}$);
L_R	effective irradiance in the wavelength range 380–1400 nm ($W \cdot m^{-2} \cdot sr^{-1}$);
$R(\lambda)$	spectral weighting function in the wavelength range 380–1400 nm (dimensionless);
$S(\lambda)$	spectral weighting function in the wavelength range 180–400 nm (dimensionless);
t	time (s).

Conflicts of Interest

The authors declare no conflict of interest.

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