Aging of the Human's Ocular Media and Blue Light Effects from Different LED Sources

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Abstract: The human eye is adapted to function in conditions of optical radiation. This radiation not only enables vision, but influences important physiologic functions. But along with its many beneficial effects, light exposure can also bring harm to both skin and eyesð not all of the wide range wavelengths spectrum of optical radiation have favorable impact. Retinal changes associated with age have significant influence over the potential for photodamage. The current paper presents quantitative estimation of these changes depending on the observerðs age with the use of calibrated measurements of the optical radiation from LED lighting sources with different spectrum.

Keywords: spectral sensitivity of the eye, aging of the ocular media, LED lighting sources

Introduction

The electromagnetic spectrum consists of three bands of optical radiation: ultraviolet (with wavelengths in the range from 100 nm to 380 nm), visible (from 380 nm to 780 nm) and infrared radiation (from 780 to 10000 nm), fig.1. The radiation in the short-wavelength visible spectrum is characterized by the highest amount of photon energy. It includes harmful blue-violet (415-455 nm) and beneficial blue-turquoise radiation (465-495 nm), involved in the proper functioning of the metabolism in humans (circadian rhythms and endocrine activities) [1,13].

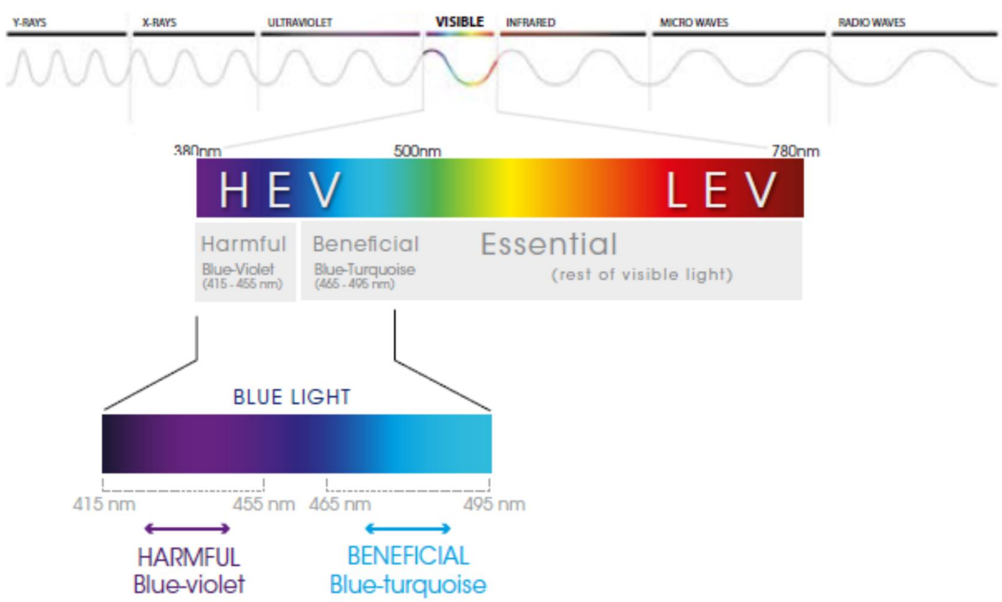

Fig. 1 Electromagnetic spectrum and optical radiation [13]

The human eye is subject to harmful and positive effects, both acute and long-term exposure to optical radiation from the sun, artificial light sources and digital devices.

Radiation in the ultraviolet (UV) and visible part of the spectrum have been researched for decades and found that they can lead to photochemical damage of the retinal photoreceptors and retinal pigment epithelium cells. The composition of the radiation is filtered by the cornea or the crystalline lens. They absorb ʘlarge portion of the UV and IR radiation. In adult eyes only 1% to 2% of incoming UV and IR radiation with wavelength shorter than 980 nm is transmitted to the retina, fig.2. [2]. The healthy human eye has a natural protection against UV radiation, but in terms of radiation in the visible part of the spectrum there aren't available natural defense mechanisms.

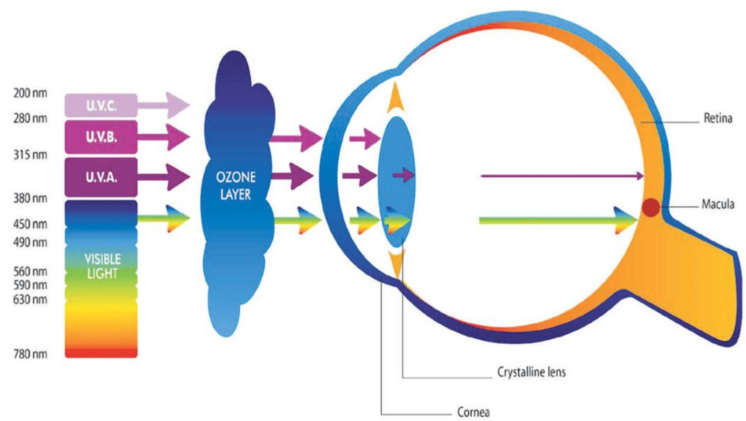

Fig. 2 Absorbtion and transmission of solar radiation in the eye [1]

Influence of the radiation in the blue part of the spectrum

Photochemical damage and toxication of the retina can appear both acute and long term exposure to solar radiation and artificial lighting sources, in particular to radiation in the blue part of the spectrum [1, 7, 8, 9]. The radiation with wavelengths from 300 to 500 nm possesses highest energy photon levels and contribute the most to the retinal photochemical damage. The photon energy is inversely proportional to the wavelength of the radiation [7, 8, 10].

On the other hand, radiation in the blue part of the spectrum is important not only for the color perception, but for many non-visual processes. They include circadian entrainment, melatonin regulation, pupillary light reflex, cognitive performance, mood, locomotor activity, memory,and body temperature [4, 5, 9]. Studies have shown that pupil constriction, the eye's natural defense against exposure to strong light,is wavelength-dependent and peaks at 480 nm [1].

In recent years, there is a huge development in the use of filtering optical devices that reduce the harmful effects of "blue light". There are some theoretical studies which show the potential negative effects from the filtering of radiation in the blue part of the spectrum. However, it should be considered that this radiation provides 35% of the scotopic vision, 53% of the melanopsin reaction, 55% of the circadian and 35% of the s-cone photoreception. Filtering by using lenses can eliminate 27-40% of the incident blue light depending on the optical properties of the used optical elements. This reduction in the photoreception of blue light can produce deterioration of the color and the scotopic vision, as well as modifications in the circadian rhythm in the individuals [9]. When optical devices for prevention of degenerativ¿ action of blue light are used is very important to ensure their correct selection and selective action. Some research on color lenses give analyses of biological effects, showing the balance between photoprotection and photoexposition at 445 nm. There are some positive results of the use of clear lenses from patients with dry eyes, especially when associated with prolonged use of digital devices and intense light exposure [10,11].

It is necessary to reduce the risk factors for retinal damage from the presence of blue light, while not neglecting its positive impact on the circadian rhythms [12,13].

Sources of optical radiation in the blue part of the spectrum

The spectral distribution of the radiated power, typical of the various sources, differs in terms of the share of the blue light emission spectrum, fig. 3. The share of the emitted radiation in the blue part of the spectrum from the sun is from 25 to 30%, depending on its typical characteristic features. For the artificial light sources this share ranges widely: from 3% for the filament lamps to 35% for LED sources with cold white light [3, 13]. For the CFL it is around 26%. The trend towards the use of energy-efficient lighting sources determined light environment with increasing exposure to artificial blue light.

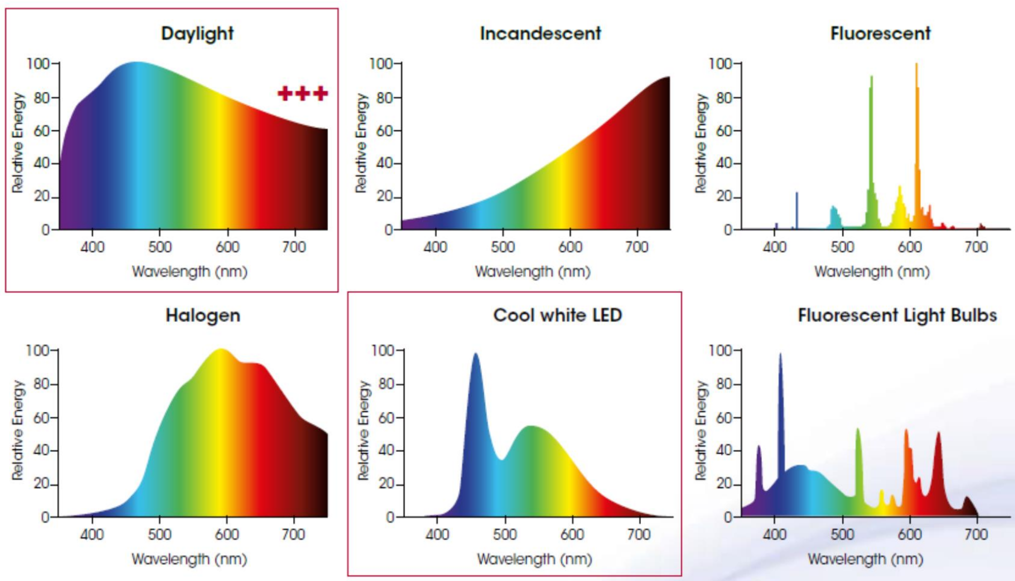

Fig. 3 Emission spectrum of various light sources including cold-white LED [13]

The change in the population daily habits from an early age requires taking into account of other sources of optical radiation, especially screens with LED background illumination. Recent surveys in different countries reported that in some regions 90% of individuals questioned use a computer and/or watch TV on a daily basis, while 70% of participants use a smartphone, almost all of whom use it daily. In addition, the duration of the use of these devices is increasing with each passing year. Beyond these changing behavioral habits, long-term exposure is increasing as exposure to LED-backlit screens is starting from an earlier age with each passing year. Another fact, which generally receives insufficient attention is that night time viewing of screens and the intensity of LED lighting is likely to affect the extent of pupil dilation, which is important in terms of potential harm to the retina [13].

Mechanisms of retinal damage and phototoxicity

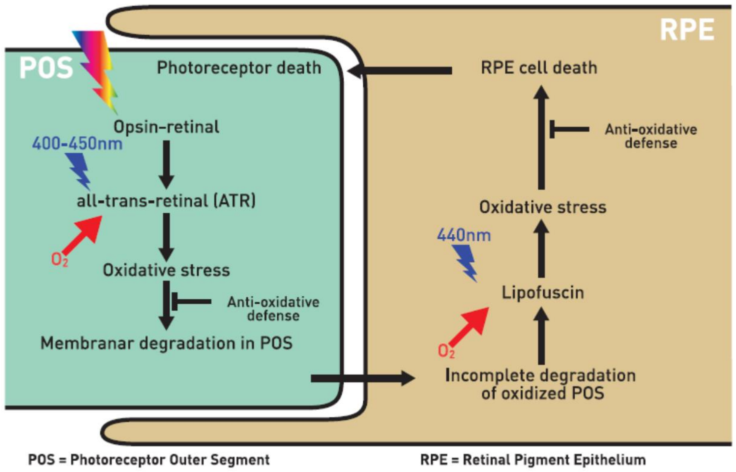

Fig.4 Phototoxicity mechanisms in outer retina [1]

Blue light can cause photochemical damage to retinal photoreceptors and retinal pigment epithelium cells, fig. 4. The reason is accumulation of the waste product lipofuscin in the granules of retinal pigment epithelium cells. Lipofuscin (also known as age pigment) accumulates with increasing age, and also in certain diseases of the retina.

Aging and optical radiation transduction of the ocular media

Age-related changes of the retina have a significant impact over the photodamage potential. As the eye ages, light transmission and absorption change, primarily owing to the gradual yellowing of the crystalline lens. As a result, the aging lens transmits less visible light overall, with a disproportionate drop in transmission of blue light due to yellow discoloration of the lens, fig. 5. Lipofuscin starts to accumulate in the earlier ages and becomes visible in the retinal pigment epithelium cells of a healthy 10 years old human being, fig. 6.

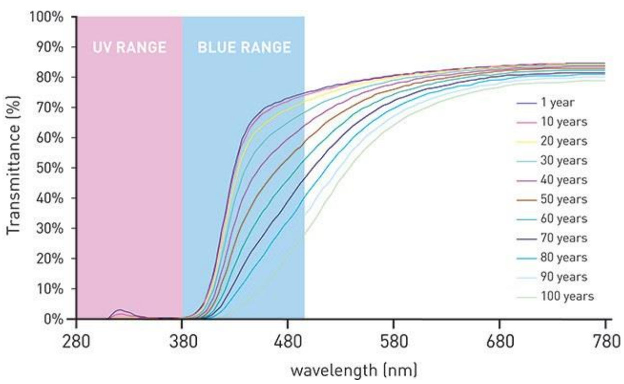

Fig.5A: Total transmittance of clear ocular media of aging human eye. Fitted from the CIE 203:2012 data [14]

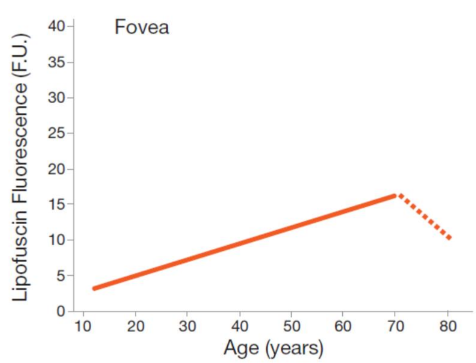

Fig.5B Lipofuscin levels in the human fovea increase with age[15]

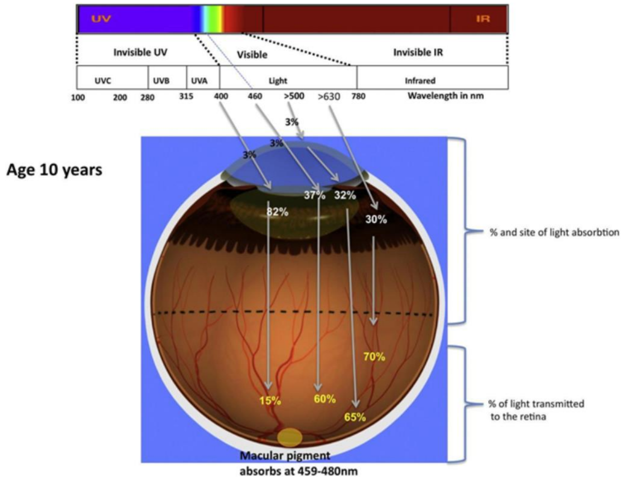

Fig.6: Interaction of visible light (www.sciencedirect.com, Behar-Cohen et al. (2011) [2].

Research on the influence of age on the transmission of optical radiation in the blue part of the spectrum

The purpose of the study is to assess the impact of age-related changes in the characteristics of the ocular media on the possible risks from radiation in the blue part of the spectrum from LED sources different spectrum. On the other hand, of particular interest are comparative analysis of the non-visual influence on the melanopsin photoreceptors reaction, which is connected with a direct impact on the circadian rhythms.

The object of the research are different types of LED lighting sources, Table 1.

Experimental survey of the radiated spectrum has been done with calibrated radiometer Stellar Black Comet (wavelength range 200-1100 nm) and complying with EN 62471 and IEC/TR 62778 [16,17].

For comparison reasons the results from the research are represented for equal illuminances over the measurement plane and the corresponding field of views, defining the angular subtense of the lighting sources. The specific characteristics of the products have been taken into account. The luminance of the sources is defined according p.5.2.2.2 of EN 62471.

Table 1 Measured LED lighting sources

No	Description		Power	CCT, defined from measured spectrum	L_B, W/(m^2.sr)
1	LED retrofit bulb		7 W	3026 K	12,03
2	LED recessed luminaire with glass optics		29 W	3510 K	23,91
3	LED recessed luminaire frosted		100 W	5256 K	41,91
4	LED retrofit bulb		7 W	5744K	70,23

For evaluation of the potential age-related blue light hazard is defined by the radiance L_B(Ǚ, weighted with the standard blue light spectral sensitivity function B(ə), fig. 7A, and the age-related functions of total transmittance of the ocular media Ű(ə) [14, 16].

Melanopic irradiance quantity $E_{E,ə}(\tau)$ is defined by the irradiance from the sources, weighted with the spectral sensitivity function of the intrinsically photosensitive retinal ganglion cells s_z(ə), fig. 7B, and the age-related functions of total transmittance of the ocular media Ű(ə) [14, 17].

The influence of the age-related changes in the ocular media and the corresponding coefficients of total transmittance of optical radiation are adopted from the data, shown on fig. 5ϕ.

Numeric values for L_B(Ǚ, W/(m^2.sr), for the different age groups are calculated from:

$$L_B(\tau) = \sum_{300}^{700} L(\lambda).B(\lambda).\tau(\lambda).\Delta\lambda, \qquad (1)$$

where *L(λ)* is the spectral radiance, W/(m^2.sr.nm); *B(λ)* is the blue light hazard weighting function; *τ(λ)* is the age-related total transmittance function of the ocular media and Δ*λ* is the bandwidth, nm

Numeric values for age-related spectrally weighted melanopic irradiance $E_{E,ə}(\tau)$, εW/cm^2, are calculated from:

$$E_{E,z}(\tau) = \sum_{300}^{700} E_{E,\lambda}(\lambda).s_Z(\lambda).\tau(\lambda).\Delta\lambda, \qquad (2)$$

Where $E_{E,ə}$(ə) is the spectralirradiance, εW/(cm^2.nm); s_z(ə) is the spectral sensitivity function of the intrinsically photosensitive retinal ganglion cells; Ű(ə) is the age-related total transmittance function of the ocular media and æə is the bandwidth, nm.

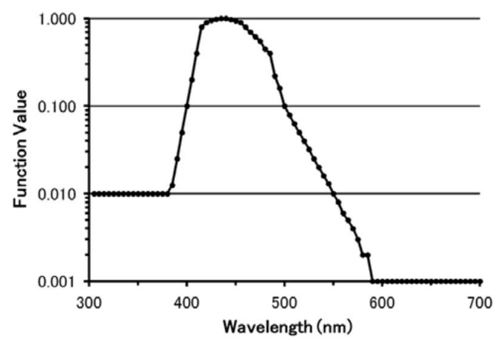

Fig.7A: Spectral weighting function for blue light retinal hazard B(λ) [16]

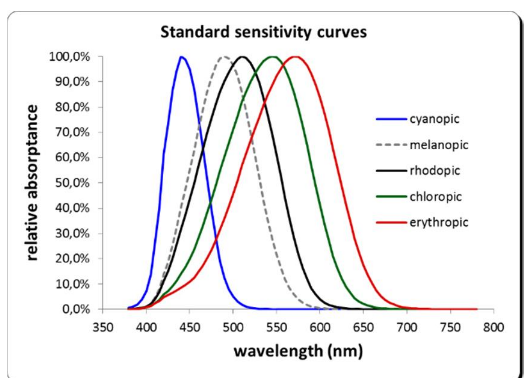

Fig.7B Standard sensitivity curves for the different human retinal photopigments[17]

The received results for the different samples are represented on figures 8, 9, 10 ɖ 11.

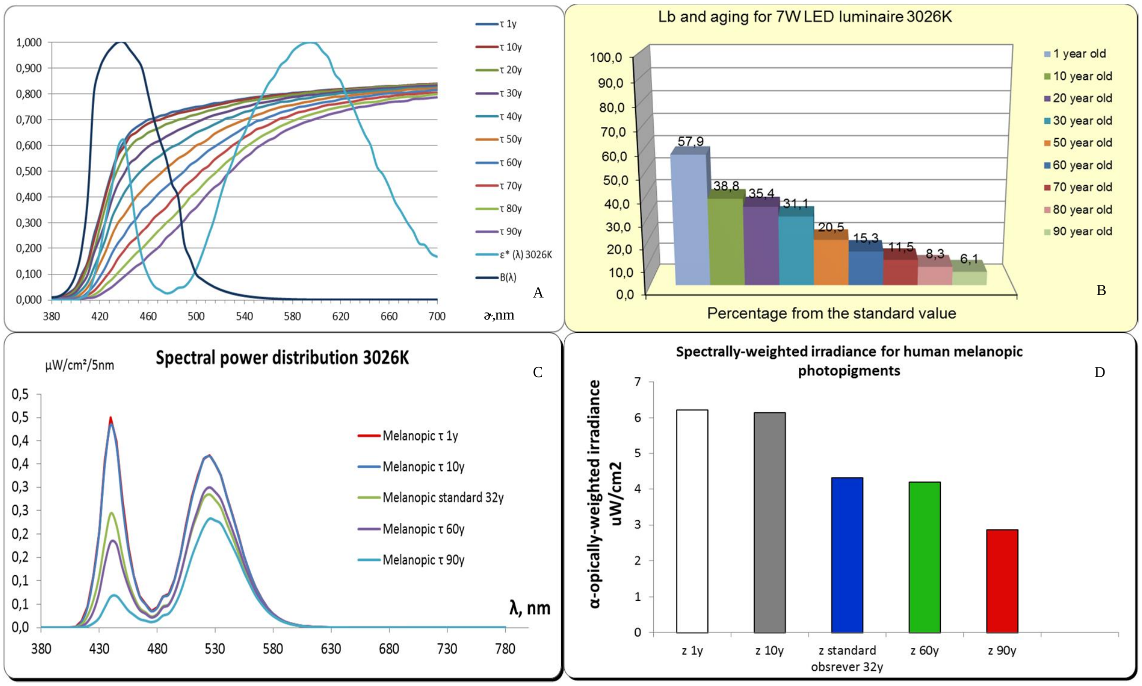

Fig. 8 Results for LED retrofit bulb with radiation spectrum, corresponding to CCT 3026K

A. Relative values for the measured irradiance from the LED source Ů(ə), B(ə) and age-related Ű(ə)
B. Age-dependency of the determined values for L_B
C. Age-related spectral power distribution weighted for human melanopic photopigments
D. Age-related spectrally weighted irradiance for human melanopic photopigments

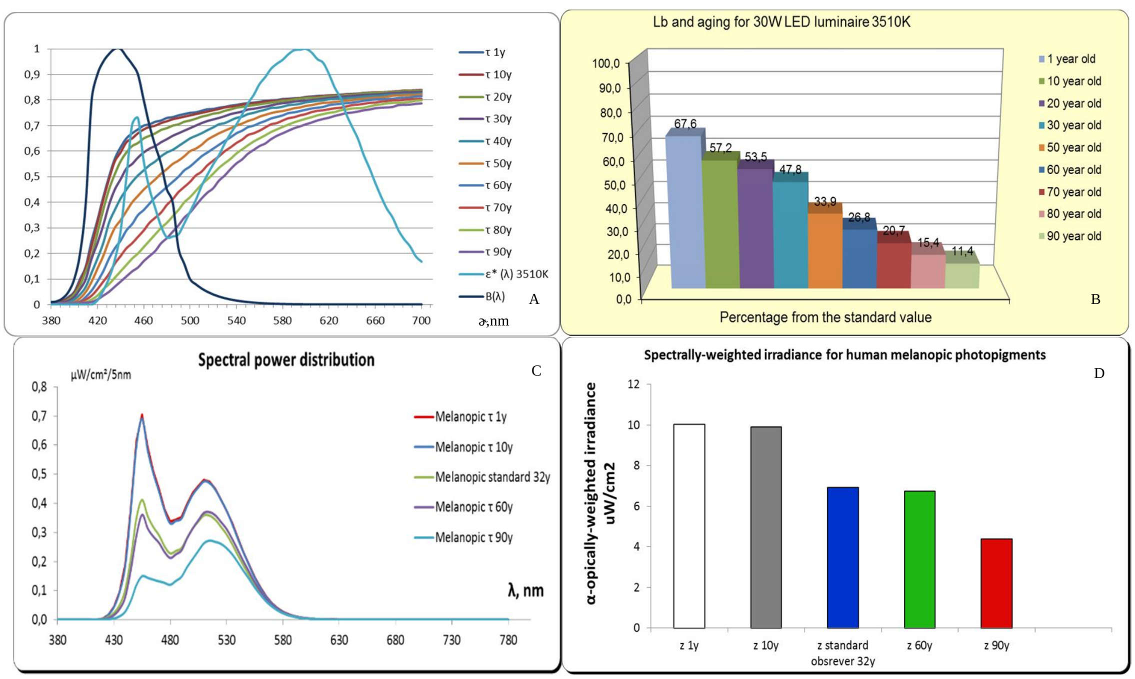

Fig. 9 Results for LED recessed luminaire with glass optics and radiation spectrum, corresponding to CCT 3510K

A. Relative values for the measured irradiance from the LED source Ů(ə), B(ə) and age-related Ű(ə)
B. Age-dependency of the determined values for L_B
C. Age-related spectral power distribution weighted for human melanopic photopigments
D. Age-related spectrally weighted irradiance for human melanopic photopigments

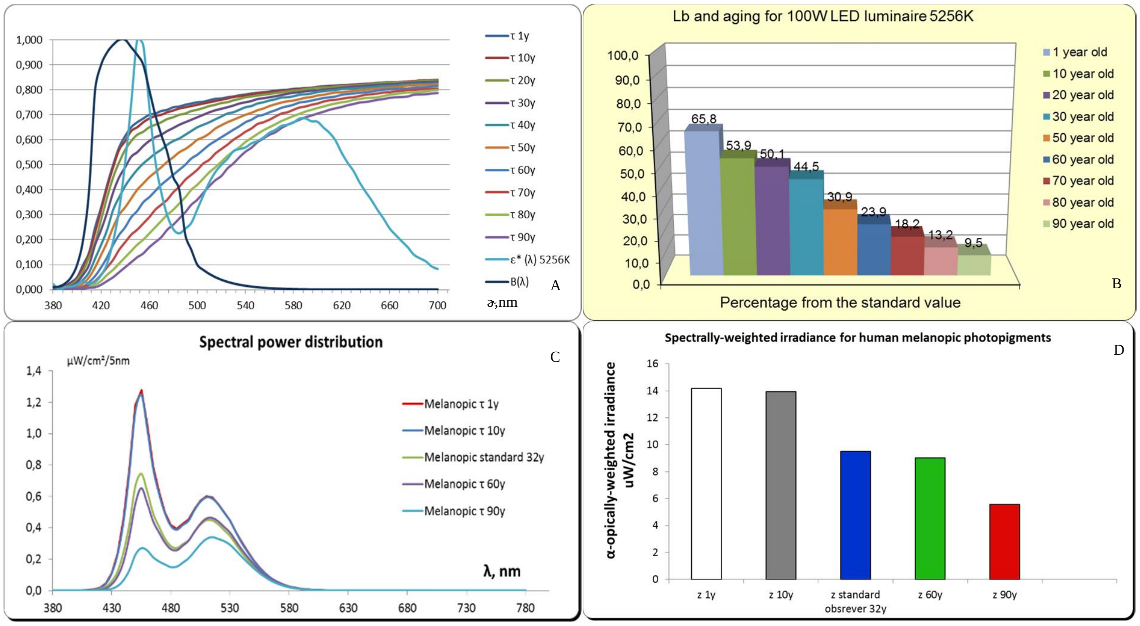

Fig. 10 Results for LED recessed luminaire, frosted with radiation spectrum, corresponding to CCT 5256K

A. Relative values for the measured irradiance from the LED source Ů(ə), B(ə) and age-related Ű(ə)
B. Age-dependency of the determined values for L_B
C. Age-related spectral power distribution weighted for human melanopic photopigments
D. Age-related spectrally weighted irradiance for human melanopic photopigments

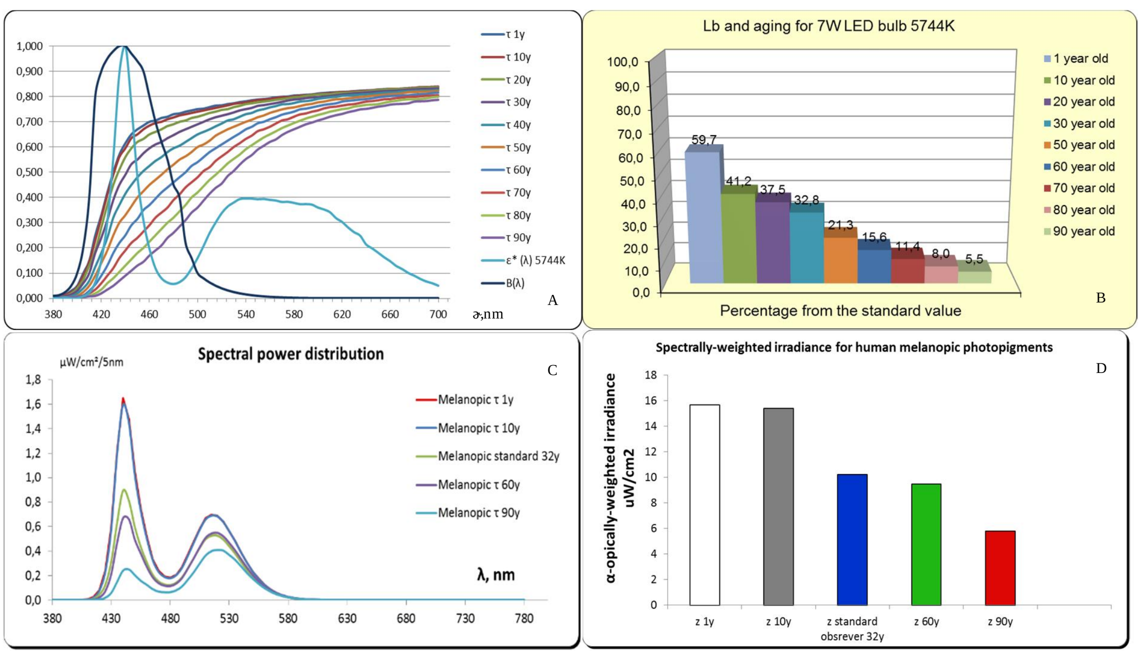

Fig. 11 Results for LED retrofit bulb with radiation spectrum, corresponding to CCT 5744K

A. Relative values for the measured irradiance from the LED source Ů(ə), B(ə) and age-related Ű(ə)
B. Age-dependency of the determined values for L_B
C. Age-related spectral power distribution weighted for human melanopic photopigments
D. Age-related spectrally weighted irradiance for human melanopic photopigments

Conclusions

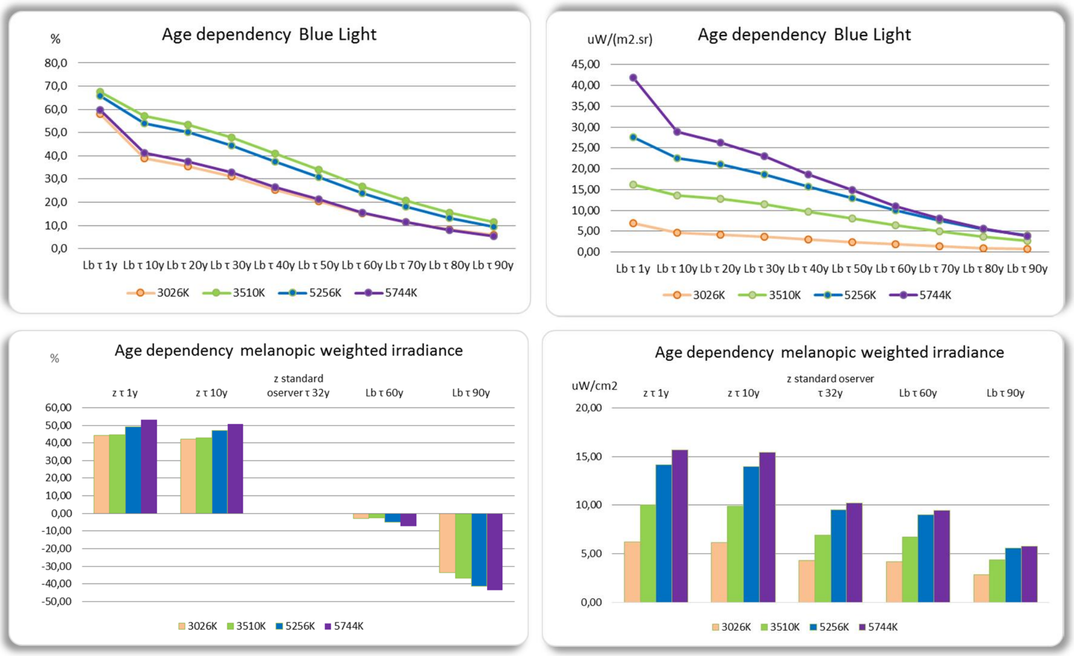

Fig. 12 Influence of age related transmission of ocular media and spectral distribution of different LED light sources on the quantitative determination of blue light hazard and the melanopic weighted irradiance

Age-related changes of the total transmittance of the human ocular media have significant impact over the non-visual processes ocuring in the retina, fig.12. Younger people are more sensitive, both in terms of the retinal damage due to the presence of radiation in the blue-violet part of the spectrum, and the melanopsin reactions by radiation in the blue-turquoise part of the spectrum.

The quantitative determination of the potential blue light hazard at equal illuminance levels shows that the retina of an 1 year old child receives from 58 to 68% from the measured radiation, which contributes the determined quantitative indices. The amount of the reaching blue light with increasing age decreases non-linearly as for the 90 year old people it is only 6 to 11% from the measured quantities. Age-related changes also lead to reducing differences in the effective values for the blue light radiance (assessed with the function of spectral sensitivity of the retina) in various sources. Over 40 years these differences do not exceed 7%. For the studied LED sources with spectral radiated power, defining CCT 3026 ş and 5774 ş, there is a similarity of the age-dependency function in percentages for the received from the retina effective radiation. Analogical similarity of the functions is observed for LED sources with radiation spectrum, corresponding to CCT 3510 ş and 5256 ş. These percentage similarities are applicable only for the measured concrete optical radiation spectrum of the studied sources.

In terms of the melanopic irradiance there are also significant age-related variations. For 10 year old child the melanopic irradiance is from 42 to 50 % higher than the defined for the standard 32 year old observer, depending on the radiation spectrum of the measured lighting sources. There are no considerable differences in the effective radiation for the observers up to 60 year old compared with the standard one. They are up to 8% lower depending on the spectrum of the radiation sources.

After this age there is a significant drop. For 90 year old observer the defined melanopic irradiance for LED retrofit bulb with radiated spectrum, corresponding to CCT 5744 K, is with 43,5% lower than the melanopic irradiance, calculated for the standard observer.

To obtain a more precise estimation of the non-visual effects of optical radiation is useful to be reported all available data when calibrated measurements of the spectrum of radiation sources is performed. Defining of spectrally weighted biological quantities is appropriate to carry out not only for the specific lighting conditions but for known age groups of the observers.

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