Incandescent replacement lamps and health

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Abstract

Incandescent replacement CFL and LED lamps have a larger blue component than red component. Contrary, incandescent lamps have a larger red component than blue component. Our eye has light sensitive cells that connect with the biological clock in the brain, which in turn connects with the pineal gland that controls for a part the rhythm of our hormone metabolism. One therefore wonders whether general domestic evening use of CFL and/or LED lamps can disturb our natural rhythm of hormone metabolism and therefore have negative consequences for our natural body rhythm and our health.

The total non-visual biological effect of light ("biological dose") has been calculated for different light sources on the basis of the biological action spectrum. First, the relative spectral energy distributions are weighted according to the spectral photopic eye sensitivity V_λ in order to arrive at equal lumen output. Our calculations show that CFL and LED lamps with a corrected color temperature of around 4000K and moderate color renderin,g result in a ca. 34% higher biological dose than incandescent lamps. CFL and LED lamps in the range of 2700 – 3000K and good color rendering however result in a slightly lower biological dose than incandescent lamps (1-7% lower). Seen from a health point of view there is therefore no objection against a changeover in the domestic area from incandescent lamps to CFL and/or LED lamps with color temperature 2700–3000K and color rendering 80 or more.

Introduction

Figure 1 shows the spectral sensitivity, B_λ, for non-visual biological effects together with the spectral sensitivity for photopic vision, V_λ. The maximum sensitivity of the novel cell type is obtained for light with short wavelengths (blue light). Light with a large blue component (cool-white light) has therefore a larger non-visual biological effect than light with a large red component (warm-white light).

With the detection in 2002 of a novel photoreceptor cell type in the eye, the non-visual biological effects that light has on human beings can be better understood. The novel cell types are connected via a nerve connection with the biological clock (supra chiasmatic nucleus) in the brain. This clock on its turn is connected with the pineal gland. The non-visual influence of light and dark and thus of time works through the control of the biological clock which amongst others determines the production and suppression of hormones in the pineal gland. The sleep stimulating hormone melatonin is under the influence of this mechanism produced in the evening and night and suppressed in the early morning and during daytime. The hormone cortisol that gives energy to the body is produced in the morning and suppressed in the evening and night. During daytime we need much biological effective light and in the evening light with little biological effectiveness.

Incandescent replacement CFL and LED lamps have a clearly larger blue component than red component. Contrary, incandescent lamps have a larger red component than blue component. We have to ask ourselves therefore whether the domestic use of CFL and LED lamps in the evening disturbs our natural hormone balance and thus our natural body rhythm and health.

The total non-visual biological dose when using different lamps is calculated based on a same light output (same visual dose). The results are compared with those of normal incandescent lamps. Here also the spectral age effect of the elderly is evaluated, both in terms of visual and non-visual biological effectiveness.

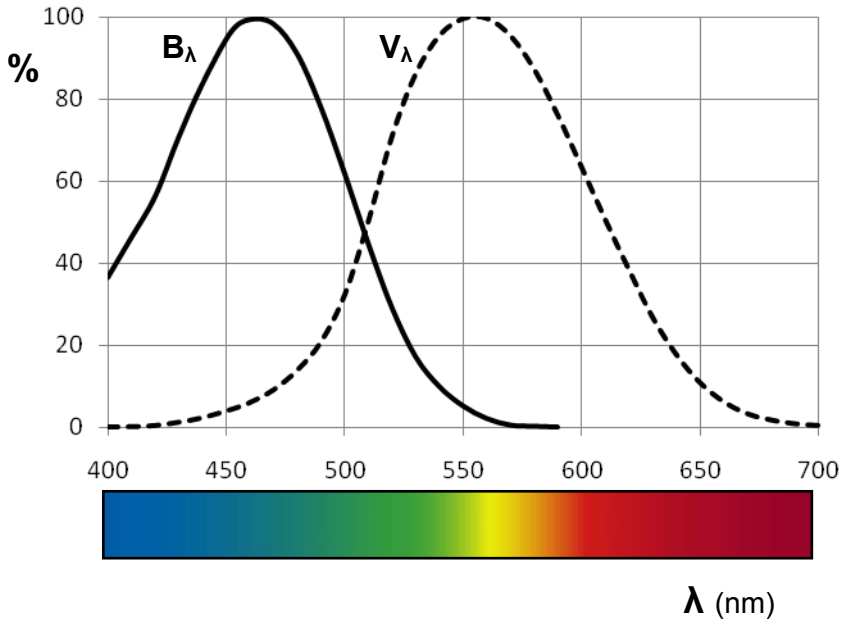

Fig. 1: Relative spectral sensitivity of the eye for photopic vision, V_λ , and for non-visual biological effects, B_λ, (biological action spectrum [1]).

Spectral properties of incandescent, CFL and LED lamps

The light of incandescent lamps is characterized by a continuous spectrum with relatively more red components (large wavelengths) than blue components (short wavelenghths) (Figure 2). Incandescent lamps therefore give warm-white light (correlated color temperature ca. 2700K) with a color rendering index of 100.

CFL lamps give, just as tubular fluorescent lamps, light on the basis of a low pressure mercury gas discharge combined with the fluorescence principle. They don't have a continuous spectrum but one that is characterized by a number of sharp peaks (Figure 2). The choice of the fluorescent powder (phosphor) determines the spectrum and thus color properties. They are available in the color temperature range of 2700K (incandescent lamp color) to 6000K. Color rendering varies in dependence of the type between 65 and ca. 90.

Incandescent replacement LED lamps function on the basis of light generation in semiconductor material combined with the fluorescence principle. In the semiconductor itself blue light with a narrow spectral band around 450 nm is generated. Part of this light is transformed in a more or less continuous spectrum in the shorter wavelength area[1]. With cool-white LEDs (ca. 4000K) the blue peak in the spectrum at ca. 450 nm is still pronounced (Figure 3). With warm-white LEDs of a color temperature of around 2700 – 3000K this peak is reduced and the red component increases.

[1] Latest developments show that it is possible to produce in the semiconductor material itself directly white light so that phosphor powder is not needed. This development has not been taken into account in our present analysis.

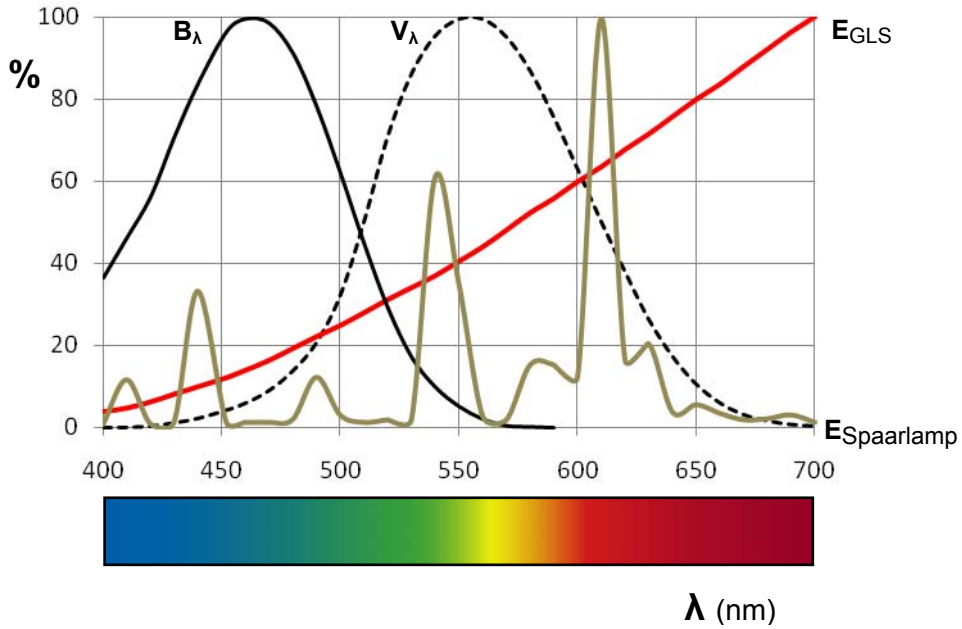

Fig. 2: Relative spectral energy distribution (E) of an incandescent lamp (GLS) and a typical example of a CFL lamp with color temperature 2700K together with the relative spectral sensitivity of the eye for photopic vision, V_λ, and for non-visual biological effects, B_λ, (biological action spectrum).

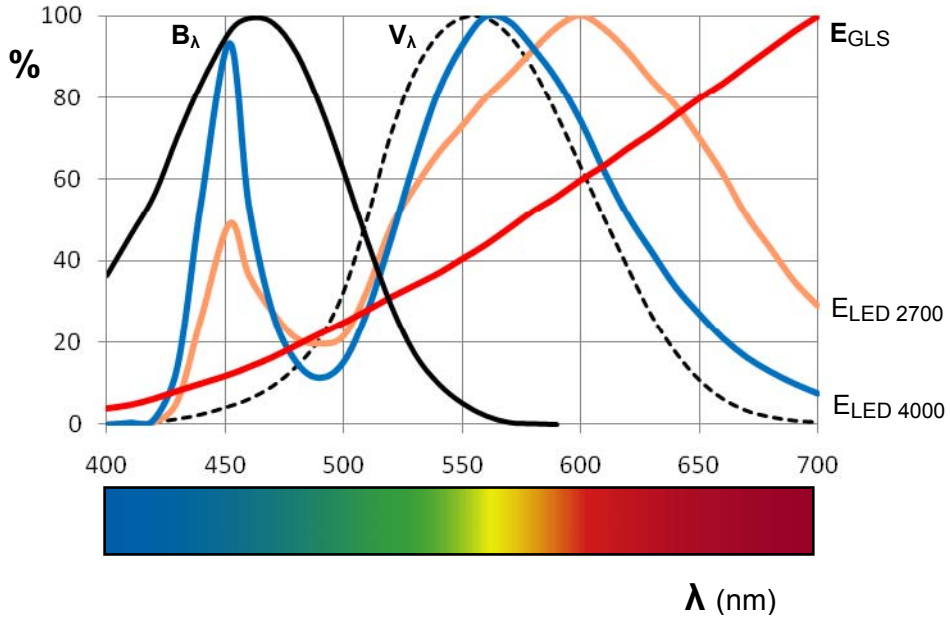

Fig. 3: Relative spectral energy distribution (E) of an incandescent lamp (GLS) and a typical example of a LED lamp with color temperature 2700K and one with color temperature 4000K together with the relative spectral sensitivity of the eye for photopic vision, V_λ , and for non-visual biological effects, B_λ, (biological action spectrum).

Non-visual biological dose

The total non-visual biological effect of light (biological dose) can be calculated from the spectrum of a light source and the non-visual biological action spectrum as determined by Brainard on the basis of melatonin suppression during night [1]. In order to get a correct comparison for different light sources, this dose has to be calculated on the basis of light sources giving the same lumen output[2]. For this purpose the total lumen output is calculated from the relative spectral distributions according to:
LumenOutput (lamp) = $\sum (E_\lambda \text{ (lamp)} \cdot V_\lambda)$.
Next all spectral energy values of a lamp are scaled to give a same lumen output according: E_λ (lamp, same lumen output) = E_λ (lamp) . LumenOutput (GLS) / LumenOutput (lamp).
Figure 4 shows the energy spectra of the incandescent lamp (GLS) and the two LED lamps on basis of a same photopic lumen output. For all other lamps taken into account, a similar calculation has been made.

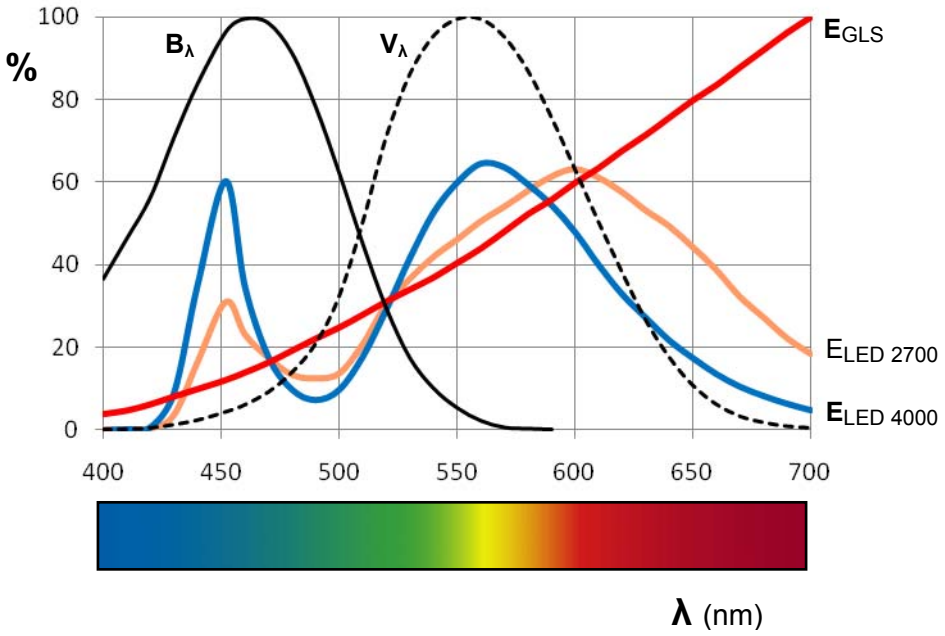

Fig. 4: Relative spectral energy distribution (E) on basis of a same lumen output of an incandescent lamp (GLS) and a typical example of a LED lamp with color temperature 2700K and one with color temperature 4000K together with the relative spectral sensitivity of the eye for photopic vision, V_λ, and for non-visual biological effects, B_λ, (biological action spectrum).

The "same lumen output spectra" are subsequently used to calculate the total relative biological dose according to:
Biological Dose (lamp) = $\sum 100 \cdot (E_\lambda \text{ (lamp)} \cdot B_\lambda) / \sum (E_\lambda \text{ (GLS)} \cdot B_\lambda$.
Table 1 gives the values of the biological dose for the different lamps relative to the dose of an incandescent lamp.

[2] Since this often is not done in analysis described in the popular press, we often see wrong conclusions there solely based on the relative high peak values around the 450 nm area of LED lamps

	Visual dose basis V_λ (%)	Biological dose basis B_λ (%)	Biological dose basis Rea et al (%)
Incandescent lamp GLS	100	100	100
Halogen lamp	100	130,5	122,7
LED 2700K, Ra 80	100	99,0	101,8
LED lamp 2850K, Ra 90	100	92,9	100,0
LED lamp 4000K, Ra 65	100	133,8	137,0
CFL compact lamp 2700K, Ra 80	100	99,1	104,7
CFL compact lamp 4000K, Ra 80	100	134,1	130,1

Table1: Total visual dose (lumen output) and biological dose (%) relative to that of an incandescent lamp at a same lumen output.

Research has shown that Abney's law of additivity that holds for visual effects is not completely valid for the non-visual biological effects [2,3,4]. This means that the above given method to calculate the biological dose is not necessarily fully correct. The expectation however is that deviations because of this are not large. Rea et al [5] published an hypothesis in which they explain the non-additivity through an interaction of the cones, rods and noval photoreceptors in the retina. On the same basis they determined an alternative non-visual biological action spectrum. We have calculated the biological dose also based on this action spectrum and also given in Table 1.
Figure 5 shows the results given in Table 1 as a graph.

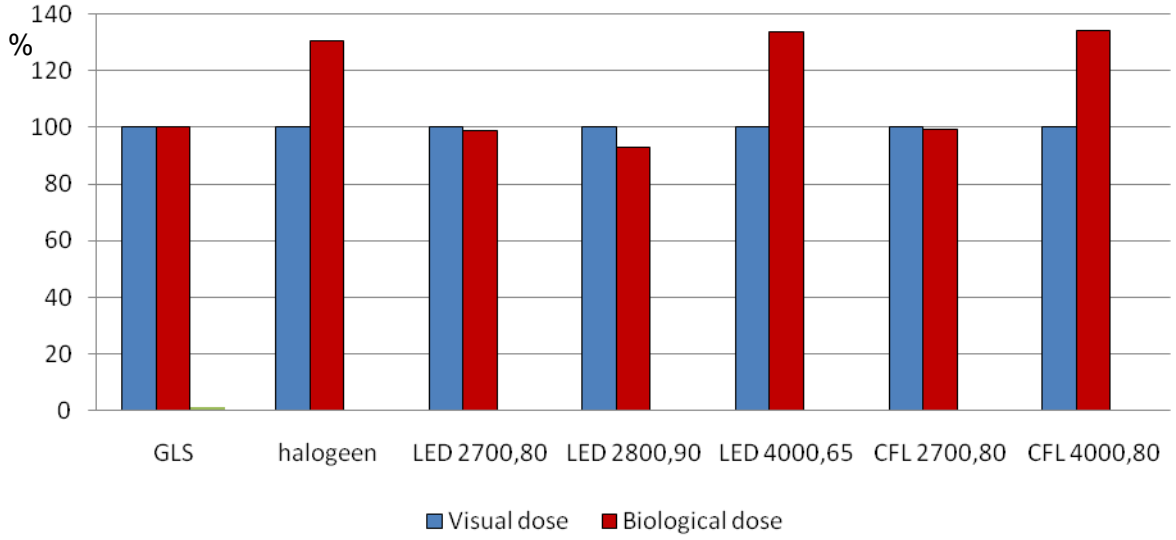

Fig. 5: Total visual dose (lumen output) and biological dose (%) relative to that of an incandescent lamp at a same lumen output.

The conclusion is that the biological dose with the use of warm white CFL and LED lamps of ca. 2700K – 3000K and good color rendering is the same or smaller than the dose obtained when using incandescent lamps. Cool white CFL and LED lamps of ca. 4000K result in a higher biological dose. Interesting to note that use of halogen lamps, results in a clearly higher visual dose than incandescent and CFL and LED lamps of 2700 – 3000K.

Spectral age effects

The clear crystalline eye lens turns yellowish with growing age. Figure 5 gives the transmission of the eye lens for the age group of 60 – 69 year relative to that of the age group of 20 - 29 year in dependence of wavelength. This spectral age effect has influence on both the visual and biological dose. Based on the equal light output lamp spectra the reduction in visual and biological dose for 65 years old persons relative to 25 years old persons has been calculated. Table 2 gives the results.

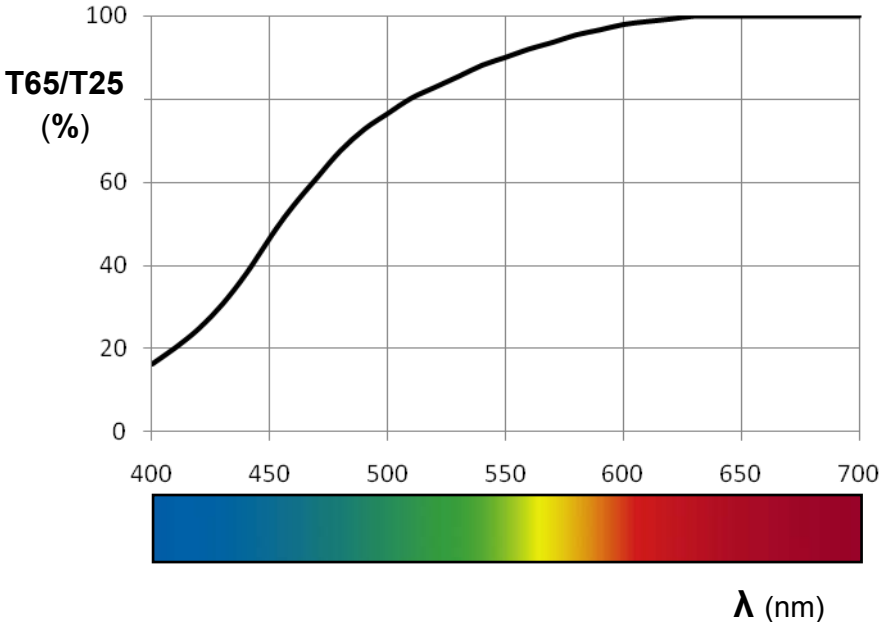

Fig.5: Transmission of the eye of 65 years old persons relative to 25 years old persons, T65/T25, in dependence of the wavelength.

	Visual dose (%)		Biological dose (%)	
	25 yr.	65 yr.	25 yr.	65 yr.
Incandescent lamp GLS	100	92,9	100	64,1
Halogen lamp	100	79,1	130,5	105,0
LED 2700K, Ra 80	100	64,6	99,0	60,8
LED lamp 2850K, Ra 90	100	62,2	92,9	51,3
LED lamp 4000K, Ra 65	100	52,2	133,8	101,4
CFL compact lamp 2700K, Ra 80	100	55,3	99,1	51,4
CFL compact lamp 4000K, Ra 80	100	55,2	134,1	106,4

Table 2: Total visual and biological dose (%) of 25 year old persons and 65 year old persons relative to that of an incandescent lamp at equal lumen output (25 yrs).

Figure 6 shows the results in graphical form.

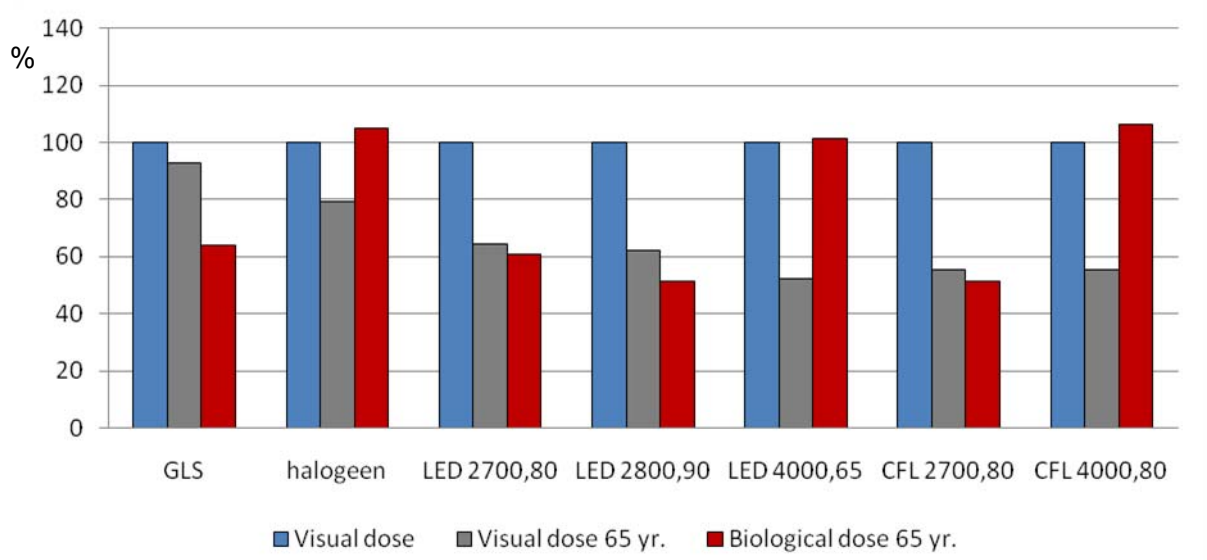

Fig.6: Total visual and biological dose (%) of 25 year old persons and 65 year old persons relative to that of an incandescent lamp at equal lumen output (25 yrs).

The more important effect is the lower visual dose with growing age, which in turn has a negative consequence for the visual possibilities of the elderly. The reduction is least with the incandescent lamp (7%). With the other lamps the reduction, for color temperatures smaller than 3000K, varies from 21 to 38% and for color temperatures around 4000K from 45 to 48%. With the use of incandescent, CFL, and LED lamps of ca. 2700–3000K the reduction of the biological dose is stronger than the reduction of the visual dose. This means that compensation for the visual reduction by using higher output lamps has no negative consequences for the final biological effect.

Conclusions

As indicated earlier the discovery of the noval light sensitive cell that is so important for the non-visual biological effects only dates from 2002. Details of the mechanism behind non-visual biological effects are still being researched. We have for example discussed earlier in this paper that there probably is an interaction between this cell type and the cones and rods. As indicated, such interaction has an influence on the biological action spectrum. Future research results about this interaction and about other details of the mechanism can lead to nuances in the conclusions that we give below.

Effects on body rhythm and health

In the evening we should use biologically ineffective and visual effective light. On the basis of equal lumen output our calculations show that when using warm white CFL and LED lamps of ca. 2700 – 3000K and good color rendering the total biological dose received is equal or smaller than when using incandescent lamps. Changeover from incandescent lamps to these more energy friendly alternatives has no extra disturbing effect on our natural body rhythm and thus not on our health.
Cool white CFL and LED lamps of ca. 4000K do result in a higher biological dose, ca. 34%. Also halogen lamps do result in a higher biological dose, ca. 30%.

Age effect

The spectral age effect reduces the visual dose for elderly which has a negative consequence for their visual capabilities. Where this reduction with an incandescent lamp is ca. 7 % and with an halogen lamp ca. 21%, the reduction with LED lamps of 2700 – 3000K is ca. 35 to 38%. With the use of CFL lamps (both 2700 and 4000K) and the LED lamp of 4000K the reduction is strongest up to 48%. Also the biological dose reduces because of this spectral age effect, in the case of incandescent, CFL and

LED lamps of 2700 – 3000K stronger than the reduction in visual dose. With compensation of the visual loss through the use of higher output lamps, the total biological dose remains under the original 100% (basis: incandescent lamp, young persons). Also for the aging eye the use of CFL and LED lamps of ca. 2700 -3000K is not more harmful than the use of incandescent lamps.

It is still unknown in how far the retina, photo receptors and the brain itself perhaps adapt themselves to the changing transmission of the aging eye.

Acknowledgment

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