Determination of the Optimal Spectral Curve of Emission of LEDs

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Abstract

For illumination of open areas and streets with low requirements of the color rendering, LED based luminaires with high light output can be created. The aim of these luminaires is the decrease of energy consumption and the corresponding expenses of the municipalities. As it is known, the maximum light output depends on the form of the spectral curve and the color rendering index Ra. When the Ra increases, the maximum possible light output decreases and vice versa. So the luminaires, meant to have high light output will be with prevailing emission in one or two parts of the spectrum, low Ra and correlated color temperature in the range 3000 K to 4000 K. Based on these conditions, through optimization, spectral curves, for which the maximal light output is aimed have been created. As an additional condition, it is assumed that the electrical power, consumed by the LEDs is emitted as luminous flux in the visible part of the spectrum.

For maximum efficiency of the street lighting installation it is necessary not only to have light source with high output, but also suitable luminaires. In order to decrease the expenses for electrical energy and maintenance, luminaires with sealed optical systems that do not allow dust and dirt inside them can be created. If such a luminaire is equipped with LEDs with a high light output (380 lm/W), no matter of the low color rendering, a luminance level of about 0,3 cd/m^2 or illuminance of 3 ÷ 5 lx can be achieved only by means of 5 ÷ 7W electrical power per luminaire.

Theorethical Spectral Curves of LEDs

The LEDs, used for indoor and outdoor lighting systems are most often white LEDs with wide continuous spectral distribution, including almost all wavelengths and having high color rendering index Ra > 70÷80. Following the development of the LED technologies in the recent years it is obvious that the manufacturers are getting closer to the maximum possible value of the light output of the white LEDs – 300 lm/W. Currently the value of this index for white LEDs, achieved in laboratory conditions is 274 lm/W [4]. This leads to the assumption that in the near future the technologies will make possible the creation of LEDs with low color rendering index Ra (25 ÷ 35) and light output of 400 lm/W.

The optimal theorethical curves of the relative spectral density, shown below, are part of series of curves, for which emission of LEDs with continous spectrum in the green and yellow part of the spectrum (with wavelengths of 520-580 nm with or without prevailing emission in the part 420-460 nm), is taken in consideration. For the optimization it is assumed that the electrical power is entirely converted to radiation in the visible part of the spectrum.The series of curves for the relative spectral density of the emissions are formed as their correlated color temperatures are devided into ranges – 3000 K to 4500 K and 4500 K to 6500 K, the color rendering indeces Ra are in the range 23 ÷ 43 (estimated according [3]) and the theorethical light outputs are considered from 460 lm/W to 500 lm/W. Some of the results are shown on the figures below in relative values of the spectral density for $\Delta\lambda$=10 nm:

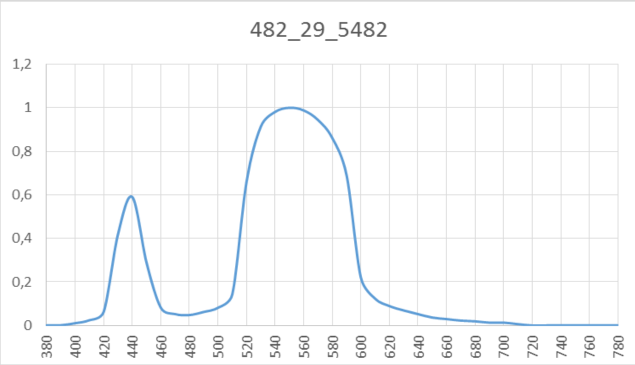

Figure 1 Chromaticity coordinates x=0,334, y=0,480;
Light output 482 lm/W, Ra=29, CCT=5482 K.

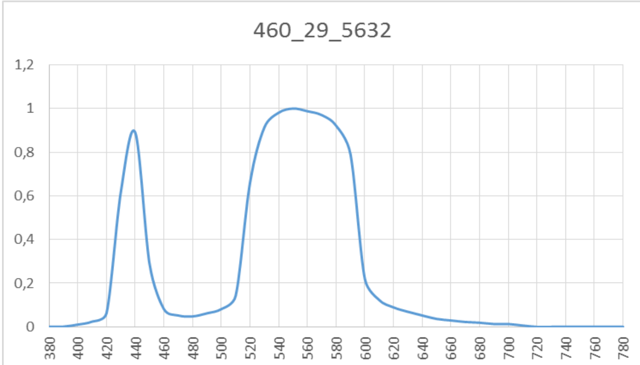

Figure 2 Chromaticity coordinates x=0,328, y=0,450;
Light output 460 lm/W, Ra=29, CCT=5632 K.

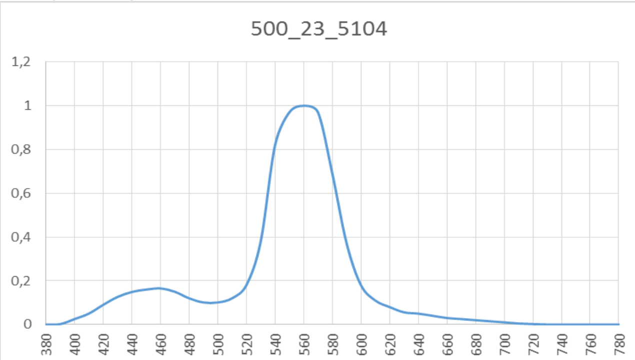

Figure 3. Chromaticity coordinates x=0,353, y=0,505;
Light output 500 lm/W, Ra=23, CCT=5104 K.

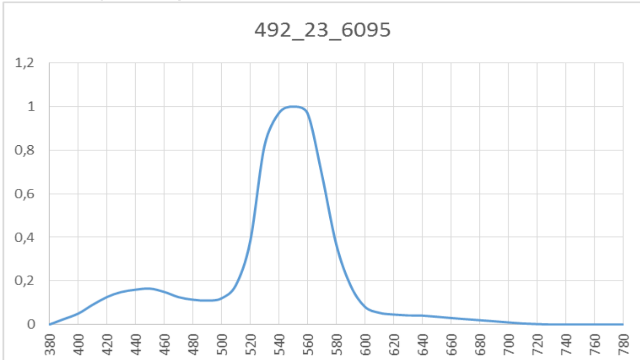

Figure 4 Chromaticity coordinates x=0,328, y=0,450;
Light output 492 lm/W, Ra=23, CCT=6095 K.

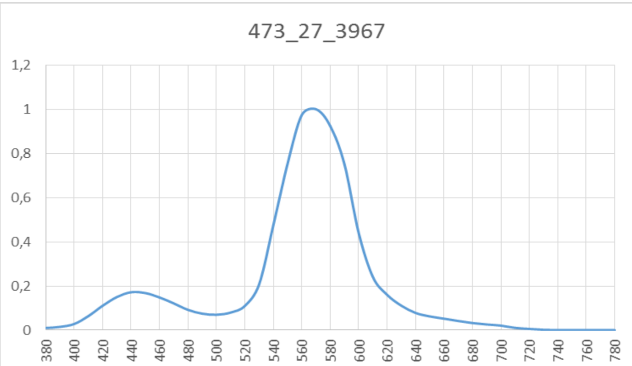

Figure 5. Chromaticity coordinates x=0,406, y=0,466;
Light output 473 lm/W, Ra=27, CCT=3967 K

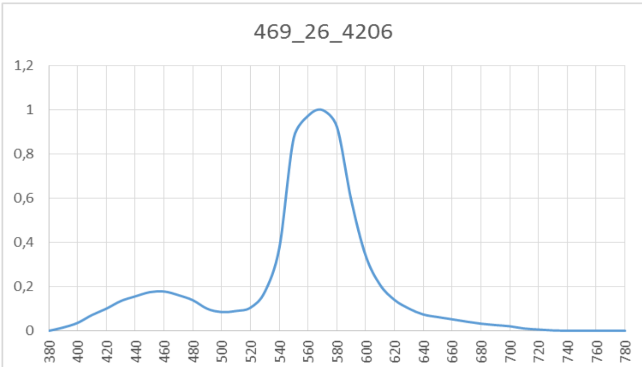

Figure 6 Chromaticity coordinates x=0,393, y=0,464;
Light output 460 lm/W, Ra=26, CCT=4204 K.

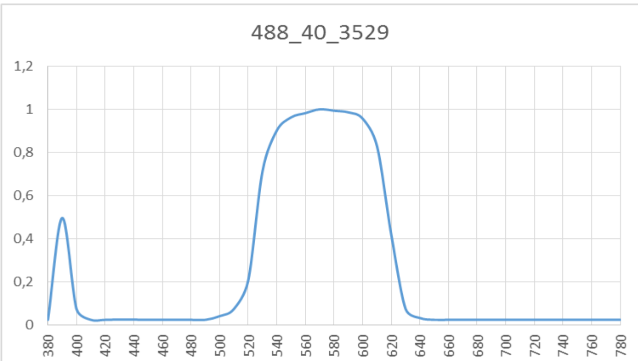

Figure 7 Chromaticity coordinates x=0,452, y=0,522;
Light output 488 lm/W, Ra=40, CCT=3529 K

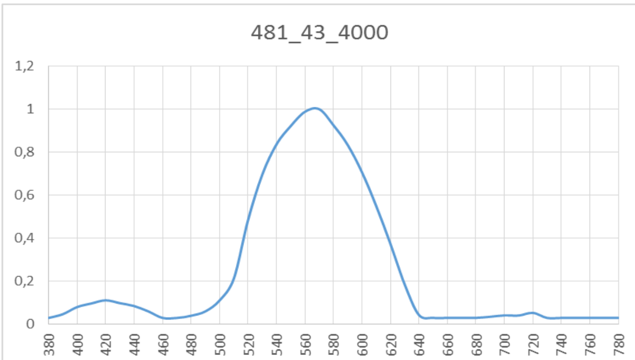

Figure 8. Chromaticity coordinates x=0,420, y=0,521;
Light output 481 lm/W, Ra=43, CCT=4000 K.

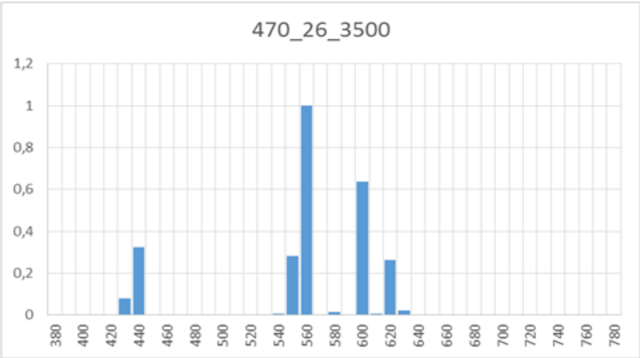

Figure 9 Chromaticity coordinates x=0,424, y=0,441;
Light output 470 lm/W, Ra=26, CCT=3500 K

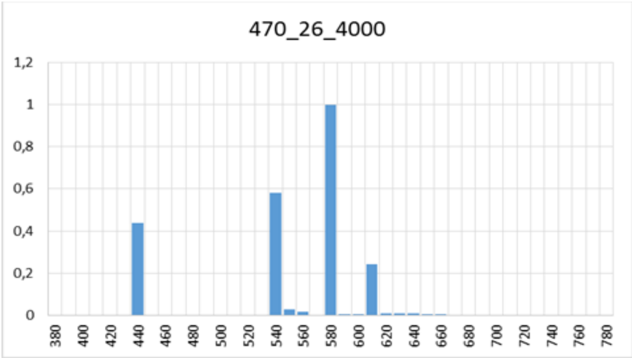

Figure 10 Chromaticity coordinates x=0,420, y=0,521;
Light output 481 lm/W, Ra=43, CCT=4000 K.

During the optimization of the series of curves, it was found that the main contribution for the increase of the light output is that of the radiations with wavelengths from 530 nm to 580 nm, while for the radiations from the rest of the spectrum, the increase of the radiation leads to decrease of the light output. The radiation in the blue part of the spectrum – from 420 nm to 460 nm (Figures 1 and 2) is similar to that of white LEDs, with maximum at wavelength of 440 nm which is 0,6 and 0,9 from the maximum radiation of the LEDs considered in the current publication Figure 11.

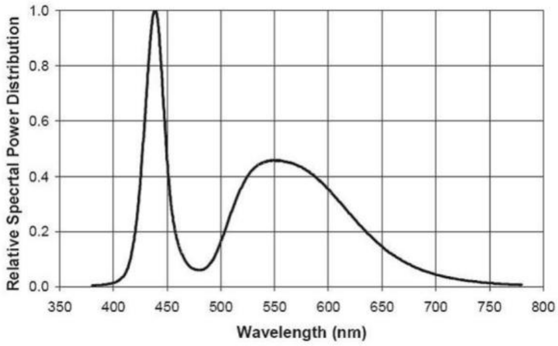

Figure 11 [6]

For the possible real values of the light output, taking in consideration the results obtained, the losses in the LEDs and the change of the light output with the slight changes in the spectrum of the LEDs, it can be assumed, that they will be varying in the range 380 ÷ 400 lm/W with Ra 25 ÷ 35.

Virtual „low-expenses“ luminaire

As it was mentioned before, if LEDs with the above shown spectral distributions are created, it is possible to create LED luminaires with sealed optical systems, with low electricity consumption and maintenance costs.

The maintenance factor MF of such a luminaire can be determined considering the following values:

1.When using LEDs controlled at a constant value of the luminous flux (for the entire exploatation period), the $LLMF_{LED}$ will be equal to 1.

2. The LSF factos LSF = 1, because by law, within 24 hours the burnt light source must be replaced;

3. When using sealed optical system with glass diffuser and individual lenses, filled with gas, having antioxidating action and with pressure equal to that of the enviroment there is no deterioration of optical characteristics due to aging and oxidation of the penetration of contaminants. Contamination of the optical system in this case will be

available only on the outer side of the luminaires, and at medium levels of dusting it can be considered that the LMF_{60Kh} factor will be 0.85 for the lifetime of 15 years;

4. When using individual lenses and convex protective glass, the loss of luminous flux in the optical system will be 4% in the lenses and 4% in the glass, which gives total value of 8%.

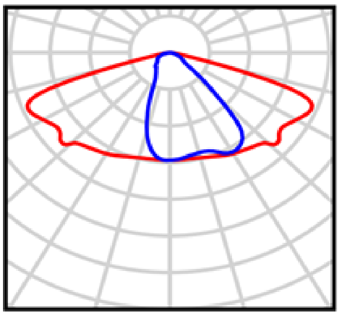

Figure 12 Light distribution of an existing LED luminaire [6]

For determination of the needed luminous flux of the LEDs (for the luminaire conidered), the luminance of the street coating class R3 is calculated. The width of the road is considered 7 m and the light distribution considered is that of a real LED (shown on Figure 12 [6]). The calculations are made considering that the luminaire mounting heigth is 6m; the distance between two poles is 30m; boom length 0.8m; boom angle 3^o; luminous flux of the light source 1800 lm (1530 lm of the luminaire) and MF = 0,85. The average luminance achieved this way is 0,32 cd/m^2, with U0 = 0,43; Ul = 0,41; TI[%] = 12; SR = 0,38, and all the lighting performance requirements for illumination class ME6 [5] are met. So using existing optical systems and with luminous flux of the luminaire 1530 lm all the lighting performance requirements can be met for streets with low illumination requirements.

In accordance with the theorethical light outputs in the range of 480 lm/W – 490 lm/W (Figures 1 ÷ 10), it can be assumed that the possible real light output of the LEDs will be 390÷400 lm/W. Having light output of the LED of 400lm/W and taking into account the lossof luminous flux - 2% from the thermal management and 8% in the optical system, the light output of hte LEDs, brought to te luminaire will be 361 lm/W, and the power, consumed by all the LEDs in the luminaire will be 4,2 W. Adding to this power the value of 0,8 W for electrical losses in the control driver of the LEDs, a total value of 5 W electrical power for feeding the luminaire is obtained.

Using LEDs with high light output, a compact luminaire can be created, that will guarantee good enough cooling of the P-N transition of the LEDs, so that the temperature of the transition and the radiator (luminire) as a whole will not increase above 85^{o}C during the night. Thus good thermal management of the LEDs and stable luminous flux values will be achieved.

Conclusions

Color temperatures above 5000 K, combined with low value of the color rendering index Ra according to the values of the chromaticity coordinates x and y, suggest radiation of light in the green and green-yellow part of the spectrum. The proximity of the wavelengths of the radiations from the blue and green part of the spectrum favor in energy aspect the transformation of the spectral composition of the blue light of LED chip through the phosphor. Besides that, when the LEDs emmit light at the diapasone mentioned, there is an emprovement of the luminance indiactors for mesopic vision conditions – for photopic luminance of 0,3 cd/m^2, the corresponding mesopic luminance is 19 ÷ 24% higher [2]. Thus the needed luminous flux and the corresponding electrical power can be further reduced with 15 - 20%. The lower color temperature and the emissions in the yellow part of the spectrum creates better from psychological point of view visual perceptions of older people.

A basic and hard for decision is the problem with the creation of photoemmitting semiconductors or phosphors, that will allow the realization of the theorethical curves of the relative spectral density, prsented in the current paper.

The low power of the luminaire considered is favourable for reduction of the expenses for lighting in poor countries. The technologies and materials available nowadays allow the creation of constructions of the optical systems, similar to the above described. Also there is an opportunity for reduction of the luminous flux needed with optimization of the light distribution of the luminaires. Thus it can be reduced with 10 ÷ 15% compared to the luminous flux of the above mentioned real luminaire, because there is a significant part of its luminous flux, that remains out of the calulation field.

The problem concerning the low values of the Ra is actually a choice between the good and the bad color rendering. But in situations when there is a lack of resources this problem is easy to deal with in the street lighting. The same is the situation when there is no way to realize street lighting bacause of the lack of power source. When there are luminaires, consuming only 5 -7 W power, it is easy to feed them by means of individual photovoltaic systems or systems with mechanically drived low power generators.

References

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[2] CIE 191:2010.
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[4] www.cree.com
[5] www.dial.de
[6] www.philips.com
[7] http://en.wikipedia.org/wiki/Color_temperature#Approximation, 10.05.2013, 15h 35 min.

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