Marek BÁLSKÝ[1], Rudolf BAYER[1]

Dept. of Electrical Power Engineering, Faculty of Electrical Engineering, Czech Technical University in Prague (1)

Comparison of real street lighting with sodium lamps and LEDs

***Abstract.** The paper presents the comparison of luminous and electrical properties of modern LED-based luminaires with properties of the conventional luminaires with high pressure sodium lamp. It collects available product information of compared luminaires with measured luminous and electrical properties of them to allow a reader to take a view of mentioned luminaire properties. The most important values of the luminaire samples compared are the luminous efficacy, color rendering index, startup process characteristics, spectral distribution of the light sources, etc.*

Streszczenie.** W artykule przedstawiono porównanie wielkości świetlnych i elektrycznych nowoczesnych opraw LED z konwencjonalnymi oprawami do lamp sodowych wysokoprężnych. Zawarto dostępne informacje dotyczące porównywanych opraw z pomierzonymi parametrami świetlnymi i elektrycznymi w celu pełnego przedstawienia czytelnikom cech porównywanego sprzętu. Porównano m.in. następujące parametry opraw: skuteczność świetlna, wskaźnik oddawania barw, charakterystyki początkowe, rozkład widmowy źródeł światła. **(Porównanie systemów oświetlenia drogowego sodowego i LEDowego).

Keywords: road lighting, light emitting diodes, high pressure sodium lamp, luminaire.
Słowa kluczowe: oświetlenie dróg, diody elektroluminescencyjne, lampy sodowe wysokoprężne, oprawa oświetleniowa.

Introduction

In the late 1990s first white light emitting diodes applicable in lighting were developed. Luminous efficacy of the first power LEDs was similar to the luminous efficacy of common incandescent tungsten bulbs. Luminous characteristics of white LEDs are increasing progressively up to the current situation when white LEDs have luminous efficacy similar or higher than conventional light sources used in road lighting, e.g. high pressure sodium discharge lamps (see fig. 1). Therewithal LEDs features much higher color rendering index then conventional light sources used in road lighting. Consequently there is a need to compare luminous and electrical characteristics of two sample types of luminaire, one fitted with conventional and the other with modern light source.

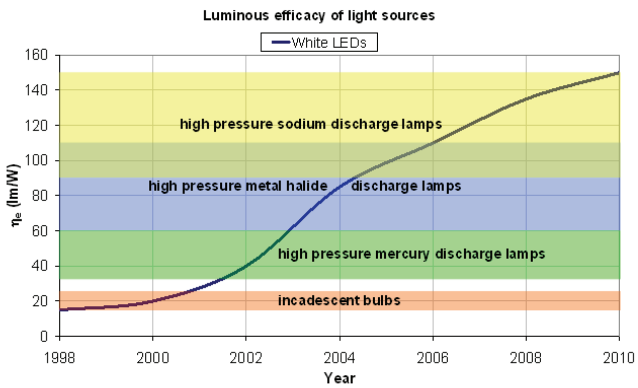

Fig. 1. Increase of white LEDs luminous efficacy since 1998 [5].

LED-based luminaire characteristics

The first compared luminaire is LED-based luminaire (see fig. 2) fitted with 84 Osram Golden Dragon Plus diodes. Further description and nominal characteristics are summarized in Tab. 1 and hereinafter.

Fig. 2. Sample of a LED-based luminaire for road lighting [4]

Table 1. Nominal characteristics of the LED-based luminaire sample [4, 5].

Light source	LED
Light source manufacturer	Osram
Light source type	Golden Dragon Plus
Number of light sources in the luminaire	84
Power consumption of 1 light source (W)	1,2
Luminous flux of light source (lm)	120
Luminous efficacy of light source (lm/W)	100
Color temperature (K)	6 012
Color rendering index (-)	69
Luminous flux of all light sources in luminaire (lm)	10 080
Output luminous flux of the luminaire (lm)	6 417
Optical system efficacy ($\%$)	63,7
Power consumption of the luminaire (W, including balast consumption)	108
Luminous efficacy of the luminaire (lm/W)	59.4

In order to draw up the chromaticity classification, spectral analysis of the LED-based luminaire light was elaborated in The Laboratory of Photometry at FEE CTU in Prague. Based on the spectral analysis several significant characteristics have been evaluated: color rendering index (see Tab. 1), color temperature (see Fig. 6), spectral distribution of radiant flux (see fig. 3) and spectral distribution of luminous flux for photopic vision (under well light conditions, e.g. in the daytime) and for scotopic vision (under low light conditions, e.g. at night) – see fig. 5.

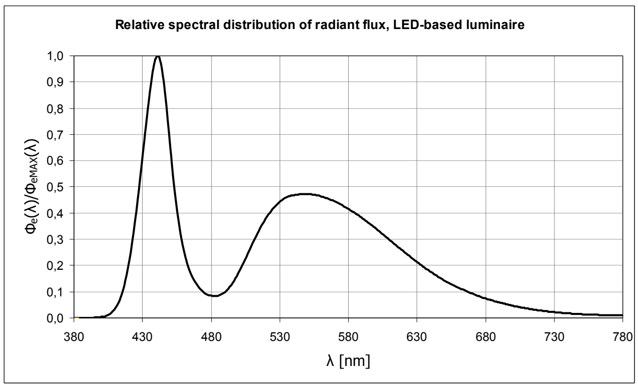

Fig. 3. Relative spectral distribution of radiant flux of LED based luminaire sample [5]

Spectral distribution of luminous flux for photopic and scotopic vision shown in fig. 5 is calculated using equations (1) and (2).

Luminous flux for photopic vision [1]:

(1) $$\Phi(\lambda)=\Phi_e(\lambda)\cdot K_m\cdot V(\lambda)$$

where: $\Phi(\lambda)$ is luminous flux according to wavelength λ, $\Phi_e(\lambda)$ is radiant flux according to wavelength λ (fig. 3), K_m is absolute maximum of human eye spectral sensitivity for photopic vision (K_m = 683 lm/W at λ = 555 nm), $V(\lambda)$ is relative photopic spectral sensitivity of human eye (fig. 4).

Luminous flux for scotopic vision [1]:

(2) $$\Phi'(\lambda)=\Phi_e(\lambda)\cdot K'_m\cdot V'(\lambda)$$

where: $\Phi'(\lambda)$ is luminous flux according to wavelength λ, $\Phi_e(\lambda)$ is radiant flux according to wavelength λ (fig. 3), K'_m is absolute maximum of human eye spectral sensitivity for scotopic vision (K_m = 683 lm/W at λ = 555 nm), $V'(\lambda)$ is relative scotopic spectral sensitivity of human eye (fig. 4).

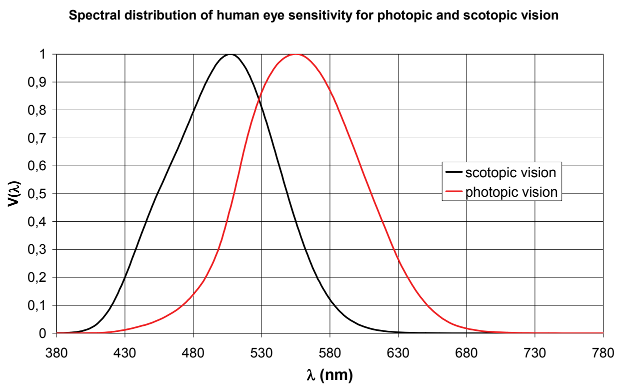

Fig. 4. Spectral distribution of human eye sensitivity for photopic and scotopic vision [5].

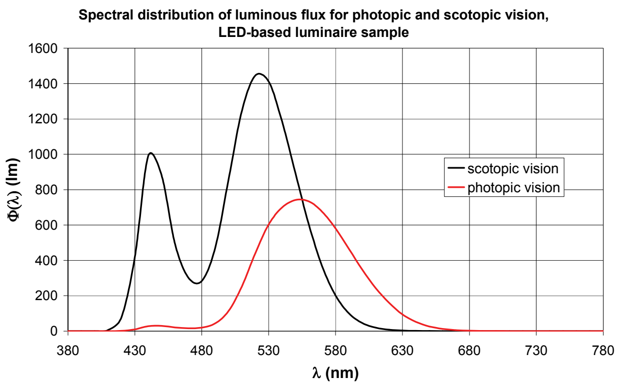

Fig. 5. Spectral distribution of luminous flux of LED based luminaire sample, photopic and scotopic vision [5].

The total luminous flux of the luminaire for photopic vision Φ (or analogically for scotopic vision Φ') could be calculated using equation (3) [1]:

(3) $$\Phi = K_m\cdot\int_0^\infty\left(\frac{d\Phi_e(\lambda)}{d\lambda}\right)_\lambda\cdot V(\lambda)d\lambda$$

where the physical values are described by equation (1).

Particular values of luminous flux of LED-based luminaire sample are calculated in table 2.

Table 2. Total luminous flux of LED-based luminaire sample.

Vision	Luminous flux
Photopic	Φ = 6 417 lm
Scotopic	Φ' = 12 308 lm

Based on spectral distribution of radiant flux measurements (Fig. 3) the color temperature and x, y coordinates of CIE 1931 color space have been evaluated: x = 0.3210; y = 0.3455. These values correspond with color temperature T_c = 6012 K (see Fig. 6).

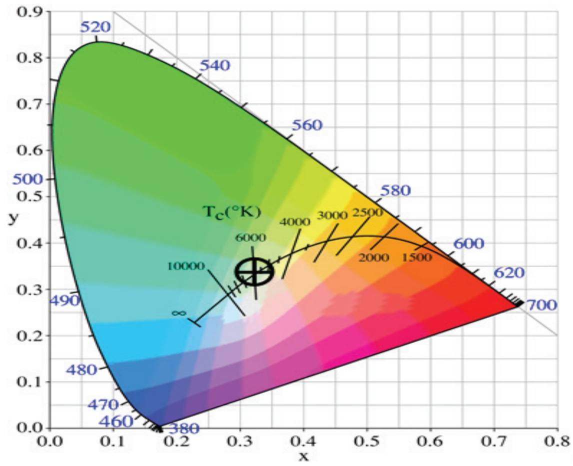

Fig. 6. CIE 1931 Color space with figured x, y coordinates of LED-based luminaire light [5].

In order to review startup process of sample luminaires several characteristics have been measured after luminaire switch-on during two hours with the step of one minute in the beginning (30 minutes) and 15 minutes latter. Significant startup characteristics – the temperature of LED cooler, electric current (relative to stabilized value), power consumption (relative to stabilized value) and luminous flux (relative to stabilized value) – are shown in figure 7.

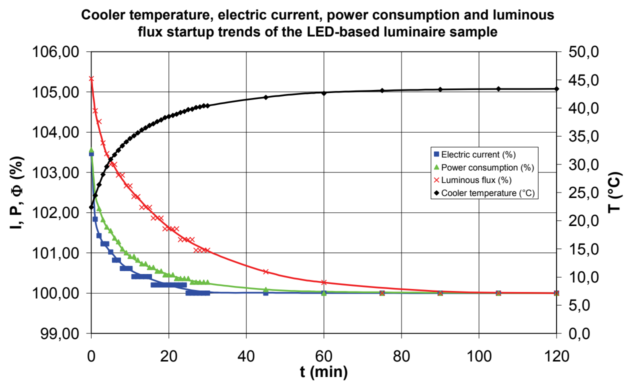

Fig.7. Cooler temperature, electric current, power consumption and luminous flux startup trends of the LED-based luminaire sample [5].

The stabilized luminous and electrical values (two hours after luminaire switch-on) corresponds with values in table 1.

Conventional luminaire characteristics

The second tested luminaire is the conventional one for road lighting (see Fig. 8) fitted with high pressure sodium discharge lamp.

This type of luminaire is widely used in road lighting all over Czech Republic. Typically it can be found in big cities like Prague, where this type of luminaire predominates. Nominal characteristics of the second sample are summarized in the table 3. Further significant characteristics of the conventional luminaire fitted with high pressure sodium discharge lamp are described analogically as in the section „LED-based luminaire characteristics” by following figures (9, 10, 11, 12).

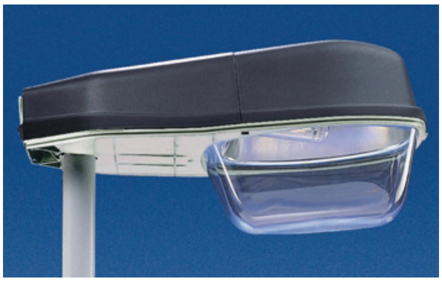

Fig. 8. Sample of a conventional luminaire for road lighting [3].

Table 3. Nominal characteristics of the conventional luminaire sample [2, 3, 5].

Light source	High pressure sodium discharge lamp
Light source manufacturer	Osram
Light source type	NAV-T 100
Number of light sources in the luminaire	1
Power consumption of 1 light source (W)	100
Luminous flux of light source (lm)	9 000
Luminous efficacy of light source (lm/W)	90
Color temperature (K)	1 823
Color rendering index (-)	31
Luminous flux of all light sources in luminaire (lm)	9 000
Output luminous flux of the luminaire (lm)	7 290
Optical system efficacy ($\%$)	81
Power consumption of the luminaire (W, including balast consumption)	122
Luminous efficacy of the luminaire (lm/W)	59.8

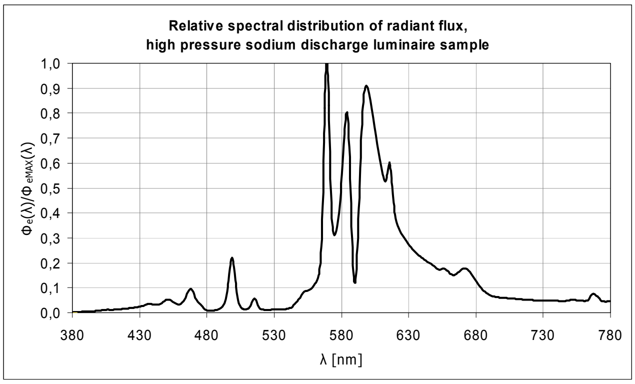

Fig.9. Relative spectral distribution of radiant flux of high pressure sodium discharge luminaire sample [5].

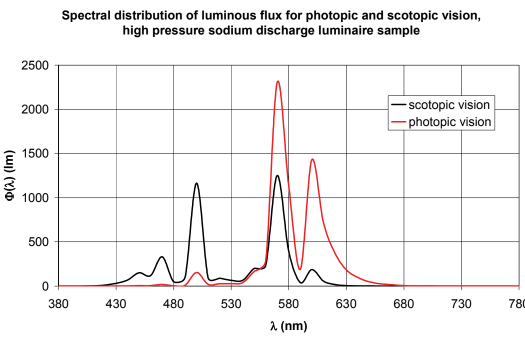

Fig. 10. Spectral distribution of luminous flux of high pressure sodium discharge luminaire sample, photopic and scotopic vision [5].

Table 4. Total luminous flux of high pressure sodium discharge luminaire sample.

Vision	Luminous flux
Photopic	Φ = 7 290 lm
Scotopic	Φ' = 4 347 lm

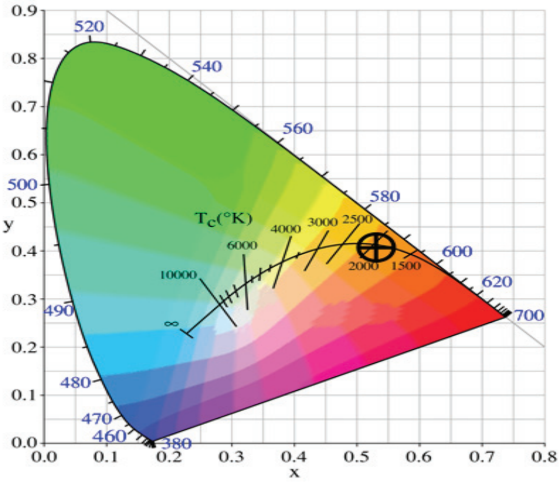

Fig.11. CIE 1931 Color space with figured x, y coordinates of high pressure sodium discharge light; x = 0.5397; y = 0.4004 [5].

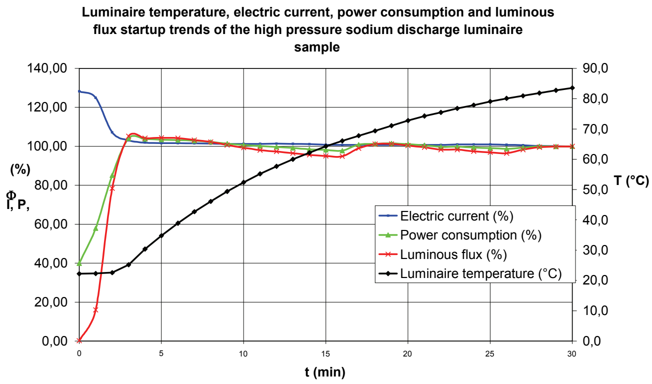

Fig.12. Luminaire temperature, electric current, power consumption and luminous flux startup trends of the high pressure sodium discharge luminaire sample [5].

Summary

LED-based luminaire sample has better parameters than high pressure sodium discharge luminaire ones for use in road lighting applications. The LED-based provides better color rendering, far higher scotopic luminous flux (important especially at night) and better startup stability with approximately the same luminous efficacy of the whole luminaire. In the yellow light of high pressure sodium discharge lamp with low color temperature colors are worse distinguishable. Taking into account the progressive development of LED-based luminaires it can be expected that they will be widely used for road lighting soon.

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Authors: *Ing. Marek Bálský, Ing. Rudolf Bayer, both PhD. students at Czech Technical University in Prague, Department of Electrical Power Engineering at Faculty of Electrical Engineering, Technická 2, CZ 166 27 Praha, E-mail: balskmar@fel.cvut.cz , bayerrud@fel.cvut.cz .*