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The future of public lighting

Abstract. *Public lighting is now at the beginning of a new era which is expected to a lot of changes. The design of public lighting systems will be increasingly influenced by new technical equipments, legislative measures as well as new conceptual approaches. These changes will be triggered not only by a very fast development in the area of new light sources, optic systems and lighting fittings, but also in the power supply solutions, control and regulation of lighting systems. Equally important will be the impact of the results of visual performance research in the area of mesopic vision.*

Streszczenie. *Oświetlenie publiczne jest na progu nowej ery i oczekuje się wielu zmian. Projektowanie oświetlenia publicznego będzie musiało uwzględniać nowe technologie sprzętowe, regulacje prawne i nowe koncepcje projektowe. Zmiany te będą związane nie tylko z bardzo szybkim rozwojem źródeł światła, układów optycznych i opraw oświetleniowych ale także rozwiązaniami zasilania, sterowania i regulacji systemów oświetleniowych. Wydaje się, że równie ważne będą rezultaty badań dotyczących wydolności wzrokowej w warunkach widzenia mezopowego.* ***(Przyszłość oświetlenia publicznego).***

Keywords: public lighting, light emitting diode (LED), mesopic vision.
Słowa kluczowe: oświetlenie publiczne, diody elektroluminescencyjne (LED), widzenie mezopowe.

Introduction

In the future, new light sources, especially light emitting diodes will, thanks to their technical parameters, influence not only operational cost and energy performance of public lighting systems, but also their durability and reliability. At the same time, the quality of lighting is also expected to improve, which would have an effect on the traffic safety and visual comfort of the road users. Geometric dimensions and character of luminous flux distribution of the new light sources will have influence on the design of lighting fittings and solution of optical systems.

The development of electronic devices utilized for power supply and control will offer new options for power supply, switching and regulation of lighting systems.

Among the many aspects that are expected to influence the future appearance of public lighting systems, this paper focuses on the spectral features of new light sources.

Spectral characteristics of lighting were until recently understood in most cases as a quality parameter which is connected with the luminous efficacy or efficiency of a lighting system to a very little extent. New technologies and processes applied in the production of light sources as well as the knowledge gained in the area of visual perception under conditions of mesopic vision clearly show that spectral characteristics of light sources significantly influence not only qualitative but also quantitative parameters of lighting.

Spectral characteristics and luminous efficacy of light sources

Spectral characteristics of light sources are commonly described with two parameters; general colour rendering index R_a (-) and the colour temperature T_c (K). Colour rendering index is a measure of the degree to which the psychophysical colour of an object illuminated by the test illuminant conforms to that of the same object illuminated by the reference illuminant, suitable allowance having been made for the state of the chromatic adaptation. General colour rendering index value ranges from 0 to 100. Value 0 represents a situation when colours cannot be distinguished at all; value 100 represents a situation with true colour perception.

In general, lighting systems which use light sources with a high colour rendering index of the light have higher energy performance.

Colour temperature T_c, or correlated colour temperature T_{cn}, is characterized by the colour tone of the emitted white light and it is conventionally stated in Kelvins (K). With common light sources, colour temperature ranges between 2 000 K and 6 500 K. Colour temperature of sources with warm white tone is up to 3 300 K, sources with neutral white tone from 3 300 K to 5 000 K and sources with cold white tone more than 5 000 K.

Recent development of technical parameters of light emitting diodes originally helped to point out to the significant dependency of luminous efficacy η (lm/W) on correlated colour temperature of the light.

This pre-assumption then influenced the anticipated development of luminous efficacy of light emitting diodes (figure 1).

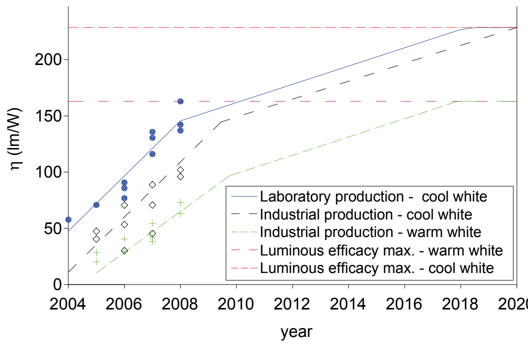

Fig. 1. The anticipated development of luminous efficacy η (lm/W) of light emitting diodes (350mA) for cool or warm white colour of the radiated light published at the beginning of 2009 [1].

With respect of the above stated, new discussion were opened about what colour temperature is acceptable for certain types of roads, and where is the line between the quality characteristics – in this case spectral characteristics, lighting features and energy performance of lighting systems.

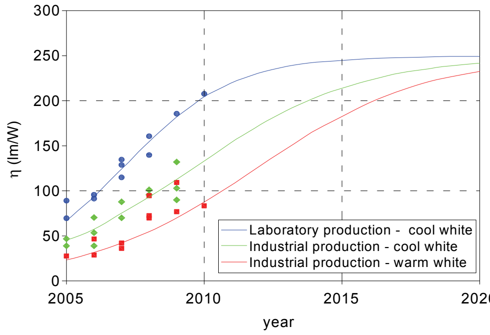

Fig. 2. The anticipated development of the luminous efficacy η (lm/W) of light-emitting diodes (350mA) for cool and warm white hue of the light published at the beginning of 2010 [2].

However, the results of further research and theoretical papers published in 2009 and 2010, which focused on establishing the theoretical maximum values with regard to the luminous efficacy of radiation, and the practically attainable value of the luminous efficacy [3], showed that the above stated maximum values of luminous efficacy of light emitting diodes with various colour temperature of the light may not differ significantly when applying modern production technologies (figure 2).

At the same time, it becomes apparent that the general colour rendering index may also not have a significant influence on luminous efficacy. Table 1 shows the theoretical maximum values and practically attainable values of luminous efficacy for diodes emitting white light which are created by adding together the three basic colour components (RGB). The practically attainable luminous efficacy value, which is related to the conversion efficiency of electric power into luminous energy, corresponds to 67% of the theoretical maximum value [2].

The data contained in table 1 show that provided the colour temperature of emitted light is within the range of 2 700 K to 6 500 K, the practically attainable values of luminous efficacy do not vary more than by 15%. Should the general colour rendering index change from 70 to 90, the practically attainable values of luminous efficacy do not vary more than by 5%. If the white light of light-emitting diodes is produced by transforming the radiation from the area of shorter wavelengths into the area of longer wavelengths while utilizing phosphor, the anticipated value of the attainable luminous efficacy is around 250 lm/W [2].

Table 1. Theoretical maximum values and estimated practically attainable values of luminous efficacy of light emitting diodes depending on the correlated colour temperature and a general colour rendering index. [2].

T_{cn} (K)	Theoretical maximum value η (lm/W)			Practically attainable value η (lm/W)		
	R_a (-)			R_a (-)		
	70	80	90	70	80	90
2700	433	424	416	290	284	279
4100	408	399	390	261	267	261
6500	366	358	349	245	240	234

Reaching the values of the luminous efficacy specified in table 1 is directly related to the spectral composition of the light. The better the spectral distribution of the light source is adapted to the spectral sensitivity curve of a human eye, the higher is the luminous efficacy of the light source (figure 3).

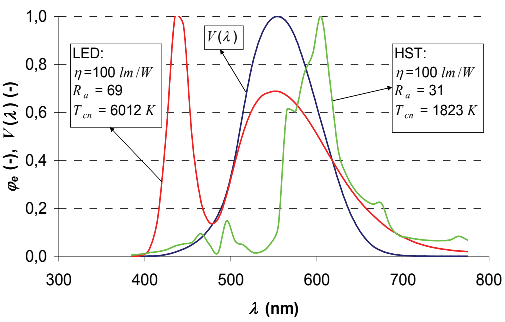

Fig. 3. Spectral luminous efficiency of a human eye for photopic vision V(λ) and the relative spectral distribution of a high pressure sodium lamp (HST) and light emitting diodes (LED).

Current technologies in production of light sources (especially light emitting diodes) make it possible to much greater extent to adapt the emission spectral distribution of the emitted light to the spectral sensitivity of a human eye. In comparison with the existing light sources utilized for public lighting, one can achieve greater luminous efficacy, while preserving very good colour characteristics of lighting.

Mesopic vision and the luminous efficacy of light sources

Apart from technological aspects, the conditions of visual perception at night are fundamentally influenced by adaptation processes. There are two types of photoreceptors in a human eye with a different spectral sensitivity. Their function is directly related to the level of the ambient lighting, i.e. to adaptation luminance. When the adaptation luminance is high (e.g. interior lighting, daylight), retinal cones are activated. Their absolute spectral sensitivity corresponds to the luminous efficacy of radiation of a CIE standard photometric observer represented by the K(λ) curve. On the contrary, when the adaptation luminance is low (e.g. night vision), rods are activated, and their absolute spectral sensitivity is represented by the K´(λ) curve (figure 4).

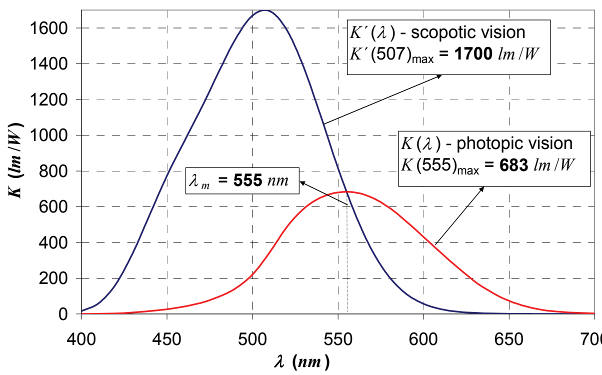

Fig. 4. Luminous efficacy of radiation of a human eye for photopic K(λ) and scotopic vision K´(λ).

Luminous flux of light sources is determined through the assessment of the spectral distribution of luminous flux and the spectral sensitivity of eyes. Given the fact that the spectral sensitivity of a human eye differs in case of photopic and that of scotopic vision (figure 4), the luminous fluxes also differ respectively. In scotopic vision conditions, the spectral sensitivity of a human eye in relation to shorter wavelengths increases (approx.450 nm up to 550 nm), and therefore the spectral components of light from this region of radiation play important role at low adaptation level. The different values of photopic Φ_f and scotopic Φ_s luminous flux are shown in figure 5. This figure captures the ratios of scotopic and photopic luminous flux in various types of light sources (high pressure sodium lamp and light emitting diodes with various spectrum) in relation to the correlated colour temperature T_{cn} of the emitted light.

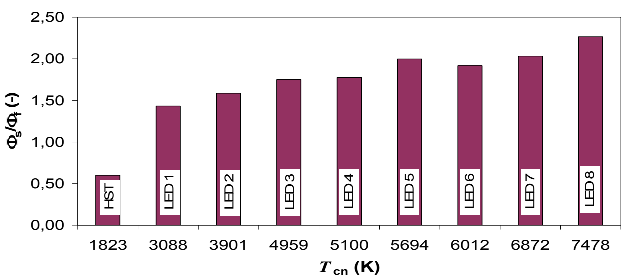

Fig. 5. Relation of the photopic Φ_s and scotopic Φ luminous flux ratio and the correlated colour temperature T_{cn} for high pressure sodium lamp (HST) and light emitting diodes with various spectral components (LED).

With public lighting, we commonly experience a situation when the adaptation luminance varies from 0,03 up to 3,0 cd.m^{-2} and the eyes of observers are in stage of mesopic vision. In this case, the retinal cones as well as rods are activated - each at a certain rate depending on the adaptation luminance of the observer.

As of now, the above described different adaptation conditions haven't been taken into consideration in practice. Even under mesopic vision conditions the photometric values are used as measured by photopic photometry. Although research in mesopic photometry has been conducted since 1970s, it was only recently that a possible solution to the issue of calculating the proportional spectral sensitivity of observer's eyes in mesopic vision conditions was found. During 1990s, two basic methods for describing mesopic photometry were described; They are represented by the European MOVE-system and the American USP-system. Presently, both approaches are used for the proposal of a new method that would be acceptable worldwide. This new method is being prepared by the technical group TC1-58 of the International commission on illumination (CIE).

The results of the research done so far show that the consideration of mesopic photometry and its practical application evidently can influence the quality of visual perception, visual performance, driver's response time as well as energy performance of outdoor lighting systems.

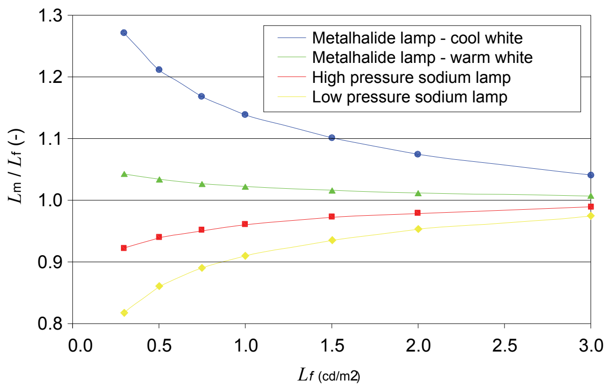

Fig. 6. Dependency of mesopic L_m to photopic L_f luminance ratio on the illumination level expressed by photopic luminance value for light sources with various spectral distribution.

The influence of light sources spectral distribution on the luminous flux under mesopic vision conditions depending on the adaptation luminance is obvious from figure 6 [4].

From the graphs captured in figure 6 it is obvious that in areas with low adaptation luminance there are fairly big differences in the mesopic and photopic luminance ratio, or in luminous flux of various type of light sources. With increasing values of adaptation luminance the described differences decrease significantly.

Conclusion

The results of published research [1,2,3,4] show that spectral characteristics of light source will increasingly have an impact on the design and the final appearance of street lighting systems.

In light source production, there will be a greater emphasis put on the matching of the spectral distribution of luminous flux to the spectral sensitivity of observer's eyes under photopic as well as mesopic vision. This will enable further increase in luminous efficacy of light sources while the quality parameters of lighting which influence visual comfort and visual performance will be preserved.

In the future, mesopic photometry will have an impact on public lighting system solutions, especially on local roads with lower adaptation luminance where the influence of spectral characteristics of utilized light sources is significant.

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