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Photometry of LED sources

***Abstract**. In this article each luminous intensity curve of LED sources, measured in different photometric distances were compared. It also compares the luminous efficacy, luminance and illuminance provided with LED sources compared to fluorescent sources. It also compares the energy demands of different sources to achieve equivalent illumination.*

Streszczenie.** W artykule porównano rozsyły światłości diod świecących, mierzone w różnych odległościach fotometrowania. Również porównano skuteczności świetlne, luminancje i natężenia oświetlenia uzyskane od źródeł LED w odniesieniu do wyników uzyskanych dla świetlówek. Również porównano charakterystyki energetyczne różnych źródeł w celu osiągnięcia równoważnego natężenia oświetlenia. **(Fotometrowanie źródeł LED)

Keywords: LED sources, photometry, illuminance.
Słowa kluczowe: źródła LED, fotometria, natężenia oświetlenia.

Introduction

In the context of Regulation No. 244/2009 of 18th March 2009 of the European Commission based on the directive of the European Parliament and Council Directive 2005/32/EC relating to eco-design requirements for omni-directional light sources for households [4] in the EU since 1st September 2009 gradually the import and production of incandescent light sources according to their power are banned, until they are completely stopped on the 1st September 2016. By this step the European Commission plans, provided on the substitution of incandescent light sources with compact fluorescent lamps, to save 40 TWh of electrical power annually (equivalent to average annual electrical energy consumption of 11 million European households in 2008) [1,7].

Efficiency of electrical energy conversion of the first banned (but most effective) 100 W incandescent light source is with the luminous flux Φ = 1350 lm, approximately 2 % (derived from the maximum theoretical efficacy of 683 $\text{lm}\cdot\text{W}^{-1}$). Therefore, they are gradually replaced by more efficient light sources, whether based on low-pressure mercury lamps in the form of compact fluorescent lamps, or induction discharge lamps, or lately quite modern light sources with LEDs [3]. Using of a large number of small point semiconductor sources in a single unit makes the last mentioned sources specific due to their luminous flux distribution. Therefore the photometry of LED sources should be performed very precisely to avoid unnecessary errors at the evaluation of lighting systems equipped with these sources.

Type of LED sources

LED sources as replacements of incandescent light bulbs with E27 socket are produced in casings resembling the shape of the bulb. Size of these replacements is in comparison with a conventional light bulb, which has dimensions Φ56x97 mm, due to the need of the use of electronics slightly larger, typically Φ56x126 mm [12]. An important fact is that construction of the source (Fig. 1) leads to a different shape of the resulting luminous intensity curve, when used in classic luminaire. On the market there are also offered sources with different design where the LEDs are hidden under the opaque material (Fig. 2.).

Fig.1. An example of replacement of classic bulb [10]

Fig.2. An example of replacement of opaque bulb [10]

Using this type of replacement eliminates particularly the function of luminaire reflector, because the light source is down-light type and reflective surface of the luminaire is actually useless. This may lead to a significant price reduction of luminaires designed specifically for LED sources in the future, because they will no longer need quality reflective surface and the luminaire will only serve to prevent glare, to connect source with the power network and also to the aesthetic function.

The most important parameter that should be crucial at choosing the replacement of incandescent bulb is the luminous flux Φ declared in the unit Lumen *(lm)*, not the power *P* in Watts *(W)*. Luminous flux is closely linked to the luminous efficacy M_z declared in Lumens per Watt $(\text{lm}\cdot\text{W}^{-1})$, which expresses how much luminous flux can be obtained from one Watt. A brief overview of specific luminous efficacies can be found in [9]. It is also clearly elaborated in the article [6], which provides an illustrative comparison of replacements of classic bulbs with alternative light sources. In this article there is presented the following table Table 1.

Table 1. Overview of replacements of classic bulbs in terms of the corresponding flux

Light source	**Power (W)**					
classic bulb	15	25	40	60	75	100
halogen bulb	-	18	28	42	51	70
compact fl. lamp	4-5	5-7	8-10	14-15	18	23
compact LED	3-4	6-7	7-8	12	-	-
induction dis. lamp	-	-	-	15	-	23
Luminous flux (lm)	**90**	**200**	**400**	**700**	**900**	**1300**

Producers of LED sources do not offer replacements only for the sockets E27. For sockets E40 can also be found many LED light sources of various shapes, see Fig. 3 and Fig. 4

The question is how much these sources replace classical sources, or they are made as originally designed sources.

Fig.3. LED source PAR 55 with refractor for sockets E40

Fig.4. LED source PAR 55 with spherical flask for sockets E40

In addition to light sources with Edison sockets there are presented on the market replacements of linear low-pressure mercury lamps (fluorescent lamps) mostly for the type T8. Even here, most of LED tubes are designed as a down-light lamp. Replacement lamps can be connected as the classic tube, but they should be verified before connecting to the voltage, whether it is necessary to replace the starter with a jumper, or remove it completely. You can meet two different types of LED tubes, each of them requires different connection to the circuit. Original inductive ballast should be bridged in all cases to avoid unnecessary losses.

Fig.5. Preview of linear LED sources

Each producer in an effort to achieve the best and most effective replacement of conventional fluorescent tubes tries to integrate different placement of chips equipped with diffusers or simple reflectors to achieve the final adjustment of the luminous intensity curve.

Fig.6. Preview of linear LED sources [13]

Each arrangement carries its own advantages and disadvantages, and it depends on the customer, what kind of replacement he would choose. Specific luminous efficacy of conventional LED tubes is about 80-90 $\mathrm{lm\cdot W^{-1}}$. For comparison, the specific luminous efficacy of standard T8 tubes is also around 80-100 $\mathrm{lm\cdot W^{-1}}$. The advantage of LED over traditional tube stands in average 2-3 times longer life (approximately 35 000 h).

Photometry of LED sources

A very important parameter for designing the lighting system with LED sources is naturally luminous intensity curve. Luminous intensity curve measurement is performed with goniophotometer and with illuminance meter placed in sufficient photometric distance. Luminous intensity is then calculated according to equation (1)

$$I = E \cdot r^2 \tag{1}$$

where: I - is luminous intensity *(cd)*, E - is illuminance *(lx)*, r - is photometric distance *(m)*.

Selecting suitable photometric distance at the measurement has subsequently effect on the accuracy of lighting system evaluation. If considered that none of the sources (LED linear tube or bulb replacement for the E27 and E40 socket) is purely point source, the errors are caused at the luminous intensity curve measurement, if the non-point source is considered as a point source. If the photometric distance is 5 times longer than the longest dimension of the light active surface, when using equation (1), the deviation becomes less than 1 %. If this distance is eg 10 m, a linear light source of dimension 2 m can be considered as a point source. If this light source is placed in the lighting system in a typical height of 2 m from the reference area, it cannot be considered as a point source and we commit errors in the lighting evaluation, because we use the luminous intensity curve measured at 10 m as a point source. Large or small photometric distance during the measurement of luminaire or light source with narrow luminous intensity curve can distort the results and thus it can bring unnecessary errors into the evaluation. This claim was verified at the light sources of Fig. 3 and Fig. 4 when photometric distances were 8,76 m and 0,79 m. Distance 0,79 m corresponded to 5x longer distance than the longest dimension of the light active area. Distance 8,76 m is the maximum photometric distance that can be achieved in light laboratory of the Department of electrical power engineering of Brno University of Technology.

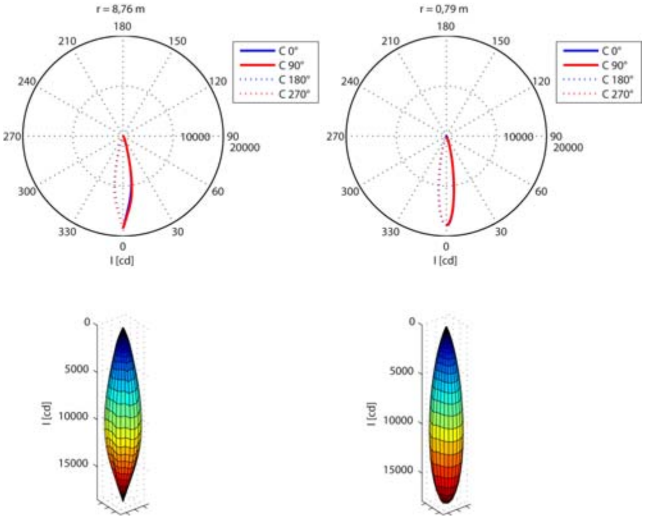

Fig.7. Luminous intensity curves of LED source PAR 55 for photometric distances 8,76 m and 0,79 m

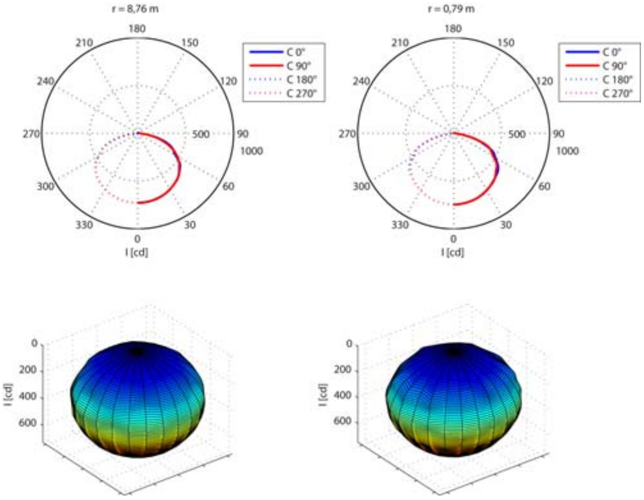

Fig.8. Luminous intensity curves of LED source PAR 55 with spherical bulb for photometric distances 8,76 m and 0,79 m

Fig. 7 can safely deduct that the same step of 5° in both measurements leads to different shapes of the luminous intensity curve. The measurement results illustrated in Fig. 8 present slightly different shape of luminous intensity curve. This corresponds with conclusions already published in [5], where the deviation luminous intensity curve also depends on its shape.

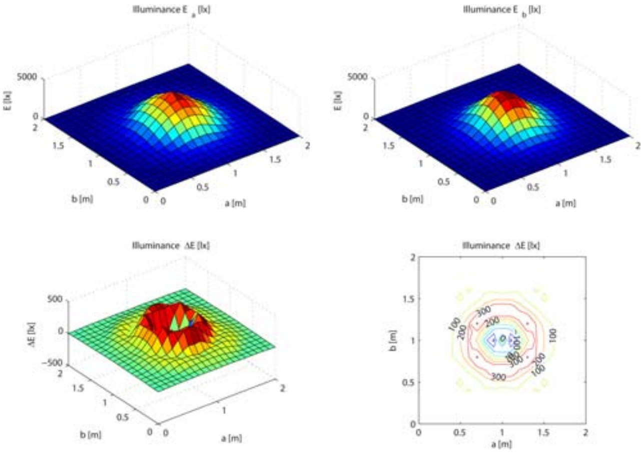

Fig.9. Illuminance from LED source PAR 55 for using different luminous intensity curves E_a (r = 8,76 m), E_b (r = 0,79 m)

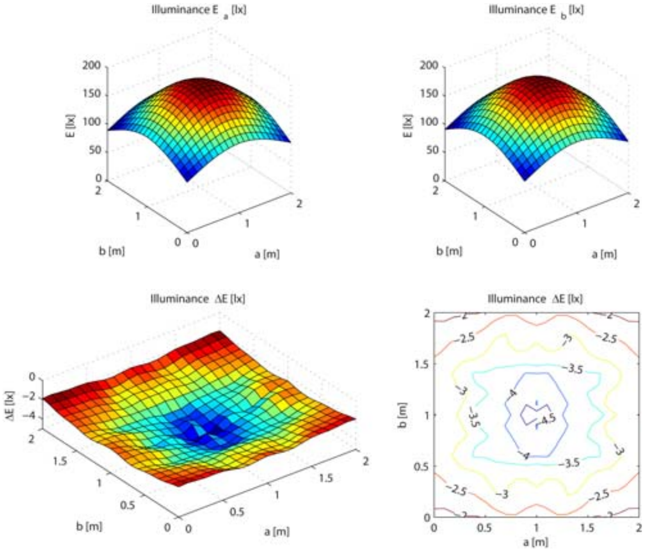

Fig.10. Illuminance from LED source PAR 55 with spherical bulb for using different luminous intensity curves E_a (r = 8,76 m), E_b (r = 0,79 m)

The difference in illuminance level on the comparative surface of size 2x2 m with photometric distance from the light source 2 m is shown for both sources in following figures Fig. 9 and Fig. 10.

In the Fig. 9 it can be seen that with using the luminous intensity curves measured at different distances the deviation between illuminance levels at some places can rise up to 400 lux. Compared with the maximum level of 4500 lx the error is approximately 8 %. In Fig 10 the deviation between illuminance levels is minimal (about 2.5 %), as well as the luminous intensity curve differences are negligible.

Unfortunately, these calculations are flawed, because for correct illuminance calculation of the real sources it is necessary to have a luminous intensity curve measured in photometric distance corresponding to the distance between the light source or luminaire and illuminated point. It is often unrealistic in practice and during the design of lighting systems it should be expected that the actual value of the illuminance is different from the calculation.

Luminance analyses of LED sources

It is almost certain that from the terms of the glare LED sources without diffuser have very bad parameters. This is unfortunately given with the fundamental construction of PN junction, when the luminous flux is produced from very small surface. Reducing the risk of glare can be achieved at the expense of decrease of flux with using the diffuser, see Fig 2. More sophisticated solution is to increase the number of diodes on the surface of luminaire to fully cover most of the light source surface. This step reduces the contrast between the foreground and background and significantly decreases the risk of glare. Unfortunately, this option is still quite problematic, because the blanks are used for soldering and connecting the supply voltage and there is no other place for more LEDs. A complicating factor at this solution is heat dissipation from the LEDs. In terms of the luminance distribution ratios on active lighting area the values can be as follows.

With the help of our self-developed LumiDISP luminance analyzer [8] it can be said that the luminance of presented LED sources reach the order of millions $cd \cdot m^{-2}$.

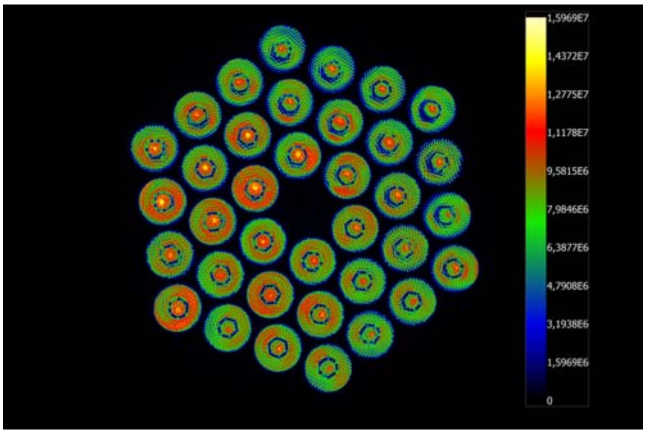

Fig.11. Luminance analysis of LED source PAR 55 in straight direction

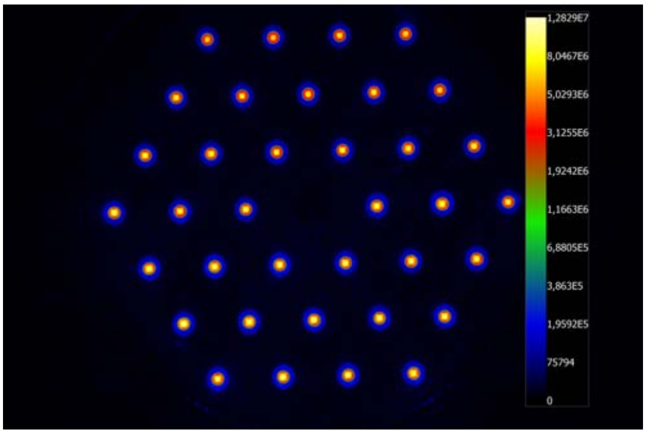

Fig.12. Luminance analysis of LED source PAR 55 with spherical bulb in straight direction

Color rendering index (CRI)

Evaluation of color rendering index of LEDs is quite debatable. As a reference source the current methodology consider to the color temperature of 5000 K black body (heat source, incandescent lamp), and from 5000 K some of the daily light D [2]. In the first case the evaluation is quite debatable, because R_a is affected with the spectral distribution (red color), which can be seen by the human eye only limitedly Fig. 13.

Therefore, the subjective assessment of quality of color rendering index of illuminated object color can seem very natural but according to the methodology it has significantly worse results.

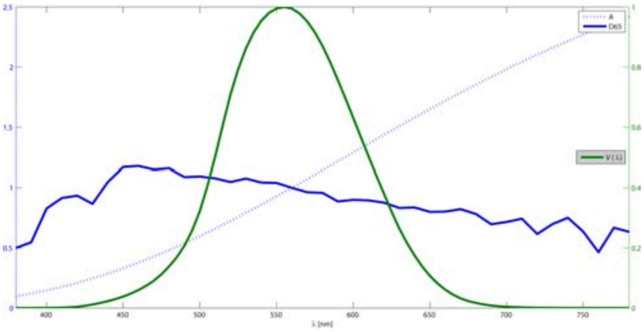

Fig.13. Spectral distribution of normalized light A, D65, and spectral sensitivity of the normal photometric observer V(λ)

Conclusion

Generally it can be said that before replacing the bulb it must be considered especially the luminous flux and the directional distribution of luminous flux.

Measurements and subsequent analysis showed that the LED source have a specific photometry mainly influenced by the number of elementary luminous points (each LED). Due to their high luminous flux when designing lighting systems with these types of sources it is necessary to consider the deviation of actual illuminance from the evaluated values, which are calculated from a finite photometric distance and the shape of the luminous intensity curve. It can be assumed that the deviation in illuminance calculation will be greater the narrower there is the luminous intensity curve.

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