doi: 10.4302/plp.v16i3.1286 PHOTONICS LETTERS OF POLAND, VOL. 16 (3), 52-54 (2024)

The Role of Standard and Supplementary Observers in Accurate Illuminance Measurements

Maciej Listowski*

Faculty of Electrical Engineering, Bialystok University of Technology, Wiejska 45d, 15-351 Bialystok

Received June 25, 2024; accepted September 24, 2024; published September 30, 2024

Abstract—Typically, the sensitivity V2 (λ) for a 2° standard observer is used for photometric measurements. Nevertheless, the light reaches the human eye from a wider field of view. This fact motivated the *International Commission on Illumination* to introduce the 10° supplementary observer with sensitivity $V_{10}(\lambda)$. This paper analyzes the impact of the transition from $V_2(\lambda)$ to $V_{10}(\lambda)$ on measured pc-LEDs illuminance values. The results indicate that the maximum difference is 2% for 3000 K pc-LEDs, 4% for 4000 K pc-LEDs, and 6% for 6500 K pc-LEDs.

Photometry is a science used to describe visible light parameters such as luminous flux, luminous intensity, illuminance, and luminance. It is crucial to consider the spectral sensitivity of the human eye when evaluating these parameters, as the human eye is not equally sensitive to all wavelengths of radiation [1, 2]. In 1924, the *International Commission on Illumination* (CIE) proposed using the spectral sensitivity of the human eye V(λ). This curve was designed to standardize light measurement [1, 2]. The experiment assumed that the sensitivity of the human eye is optimal in photopic vision and that the light reaches the human eye within a 2° field of view (FoV) [1, 2]. The light to the human eye may also reach from broader viewing angles [3, 4]. This was the motivation for the CIE to introduce a supplementary observer with 10° FoV in 1964. [5, 6]. Based on extensive research described in the literature [7–13], the CIE in 2015 proposed spectral sensitivities of the human eye ($V_2(\lambda)$ and $V_{10}(\lambda)$) based on cone-fundamental for 2° and 10° FoV photometric observers (Fig. 1) [14].

Despite the CIE recommendation, the photometers currently manufactured and used for measurements have spectral responses designed for a 2° FoV observer [15]. In the complex process, the filters are selected for the detector to obtain the spectral response of the photometer that is the most consistent with the sensitivity of $V_2(\lambda)$ (Fig. 1) [16–18]. However, the difference in sensitivity between the $V_2(\lambda)$ and $V_{10}(\lambda)$ is significant at short wavelengths (380 nm – 500 nm) (Fig. 1). For specific wavelengths, the discrepancy is approaching 65%. This difference in sensitivity affects the measurements [19], particularly for the light sources currently used for lighting purposes.

* E-mail: maciej.listowski@pb.edu.pl

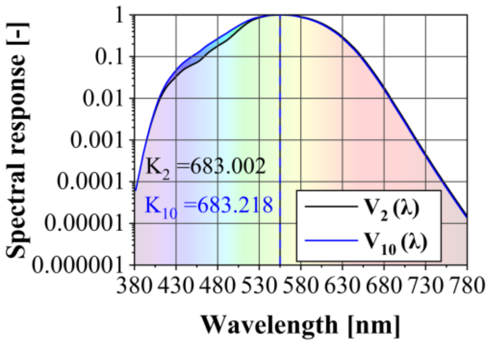

Fig. 1. The spectral sensitivity of the human eye (black line for $V_2(\lambda)$ and blue line for $V_{10}(\lambda)$).

The low luminous efficiency and relatively short lifespan of the incandescent lamp result in its infrequent use [20]. To mitigate the environmental impact of fluorescent lamps, the European Union has enacted legislation prohibiting their use in new and modernized lighting installations [21, 22]. The high luminous efficiency of LEDs is the primary reason for their widespread use in lighting applications [20, 23]. The emission of white light by LEDs is contingent upon the specific technology type [23]. However, phosphor-converted LEDs (pc-LEDs) are the most commonly used commercially. The white light is based on combining blue diode radiation and excited phosphor radiation [23–25]. The application of this technology results in the emission of significant quantities of radiation in the short-wave range (this is demonstrated by the orange zone in Fig. 2). A photometer whose spectral response is consistent with $V_2(\lambda)$ will yield disparate measurement values, than when its spectral response is consistent with $V_{10}(\lambda)$. Consequently, a relation index (RI) should be established that represents the ratio of the photometric value for $V_2(\lambda)$ to the photometric value for $V_{10}(\lambda)$ when the measurement value is for the same LED source. The disparity in sensitivity between $V_2(\lambda)$ and $V_{10}(\lambda)$ affects the illuminance value through the luminous flux. This is demonstrated by equations (1)–(5), with the same surface area (S); the intensity value is contingent upon the luminous flux (Φ_2 and Φ_{10}). The calculation of the luminous flux requires the K factor to be included. K_2 for $V_2(\lambda)$ is 683.002 lm/W [1, 2]. Two solutions are possible in the case of K_{10} for $V_{10}(\lambda)$. The literature indicates that using the constant value of K (K = 683 lm/W) in the calculation is a valid solution [26]. Alternatively, K_{10} can be determined in a similar manner to that used for K_2. Consequently, a more precise luminous flux result will be obtained, with K_{10} equaling 683.218 lm/W.

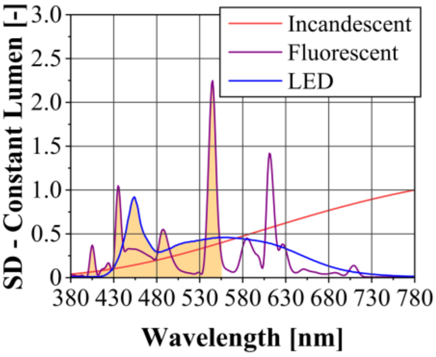

Fig. 2. The SD of white light sources: incandescent (red line), fluorescent (violet line), LED (blue line).

$$E_2 = \frac{\Phi_2}{S} \tag{1}$$

$$E_{10} = \frac{\Phi_{10}}{S} \tag{2}$$

$$\Phi_2 = K_2 \cdot \int_{380}^{780} SD(\lambda) \cdot V_2(\lambda)\, d\lambda \tag{3}$$

$$\Phi_{10} = K_{10} \cdot \int_{380}^{780} SD(\lambda) \cdot V_{10}(\lambda)\, d\lambda \tag{4}$$

$$RI = \frac{E_2}{E_{10}} = \frac{\Phi_2}{\Phi_{10}} \tag{5}$$

The 845 psc. of commercially available pc-LEDs [27,28] are included in this study. These data were collected from European projects (project EMPIR 15SIB07 PhotoLED [27]) and American projects (Real Light Source SPDs and Color Data for Use in Research [28]). Spectral distributions of pc-LEDs were classified into three groups (Fig. 3), in accordance with the ANSI C78.377 [29,30]. The study only included pc-LEDs with a Color Rendering Index (CRI) ≥ 60, corresponding to light sources used in general and road lighting. The tested spectral distributions are shown in Fig. 3: a) 3000 K (485 pcs.), b) 4000 K (272 pcs.), c) 6500 K (88 pcs.). For the specified SDs, chromaticities were plotted on the CIE 1976 (*u'*,*v'*) diagram. The chromaticities of pc-LEDs were distributed evenly throughout the area defined by the ANSI C78.377 7-step Quadrangles for individual CCT (3000 K (Fig. 4a), 4000 K (Fig.5a), 6500 K (Fig.6a)). Consequently, the study encompassed the various pc-LED types that the consumer may encounter. Equations 3-4 were used to determine the luminous flux for each pc-LED's SD (Fig. 3). To assess the effect of the selection of the spectral sensitivity of the human eye on the given measure value of the illuminance, the index (RI) was determined from (Eq. 5).

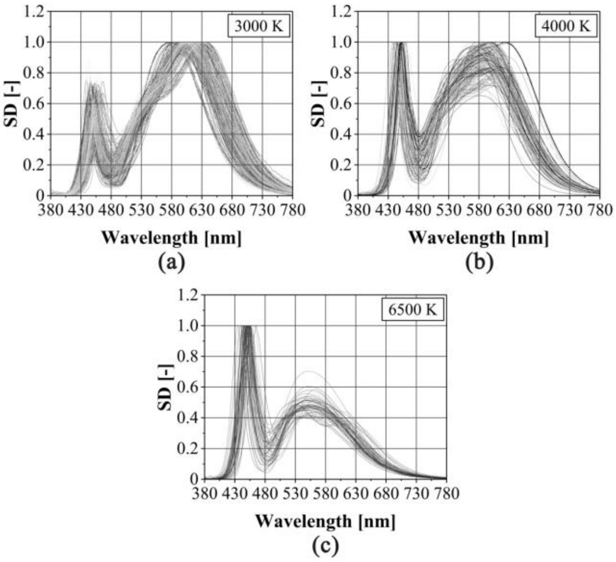

Fig. 3. The spectral distributions of the tested pc-LEDs for different CCTs: a) 3000 K (485 pcs.), b) 4000 K (272 pcs.), c) 6500 K (88 pcs.).

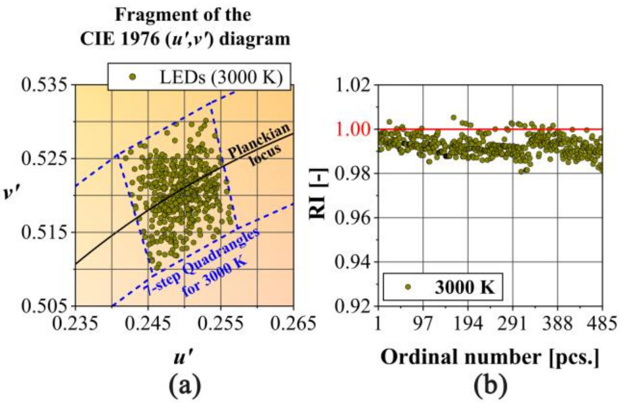

Fig. 4. (a) Fragment of the CIE 1976 diagram with pc-LEDs chromaticities for 3000 K and (b) the relation index RI for tested pc-LEDs.

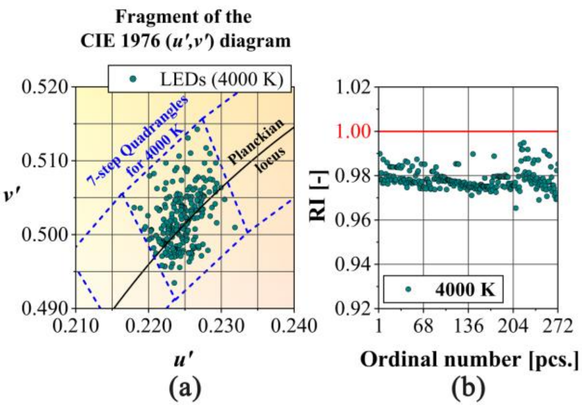

Fig. 5. (a) Fragment of the CIE 1976 diagram with pc-LEDs chromaticities for 4000 K and (b) the relation index RI for tested pc-LEDs.

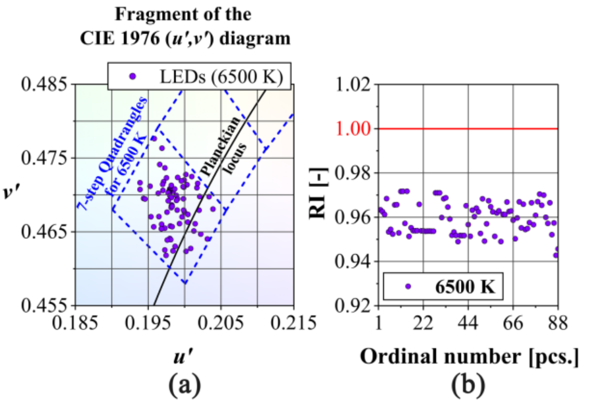

Fig. 6. (a) Fragment of the CIE 1976 diagram with pc-LEDs chromaticities for 6500 K and (b) the relation index RI for tested pc-LEDs.

The results illustrate that for the light sources in the tested groups (3000 K, 4000 K, 6500 K), the transition of the spectral sensitivity of the human eye (from $V_2(\lambda)$ to $V_{10}(\lambda)$) is reflected in the measured values. The relation index RI indicates that the maximum of the difference is 2% for warm pc-LEDs (3000 K) (Fig. 4b), 4% for neutral pc-LEDs (4000 K) (Fig. 5b), and 6% for cold pc-LEDs (6500 K) (Fig. 6b).

This work was funded by the Minister of Science in Poland at the Bialystok University of Technology under research subsidy No. WI/WE-IA/3/2022

References

[1] K.S. Gibson, E.P.T. Tyndall, Scientific Papers of the Bureau of Standards **19**, 131 (1923).

[2] E.P. Hyde, W.E. Forsythe, Journal of the Franklin Institute **185**, 829 (1918). https://doi.org/10.1016/S0016-0032(18)90370-4.

[3] I. Fryc, M. Listowski, R. Supronowicz, Opt. Expr. **31**, 38666 (2023) https://doi.org/10.1364/OE.504818.

[4] R. Supronowicz, J. Fan, M. Listowski, A. Watras, I. Fryc, , Photon. Lett. Poland **13**(2), 31 (2021). https://doi.org/10.4302/plp.v13i2.1098.

[5] W.S. Stiles, J.M. Burch, Optica Acta: Intern. J. Optics **6**, 1 (1959). https://doi.org/10.1080/713826267.

[6] CIE 165:2005 CIE 10 Degree Photopic Photometric Observer, (2005).

[7] J. Nathans, D. Thomas, D.S. Hogness, Science **232**,193 (1986). https://doi.org/10.1126/science.2937147.

[8] A. Roorda, A.B. Metha, P. Lennie, D.R. Williams, Vision Research **41**, 1291 (2001). https://doi.org/10.1016/S0042-6989(01)00043-8.

[9] H. Hofer, J. Carroll, J. Neitz, M. Neitz, D.R. Williams, J. Neurosci. **25**, 9669 (2005). https://doi.org/10.1523/JNEUROSCI.2414-05.2005.

[10] C.A. Curcio, K.R. Sloan, R.E. Kalina, A.E. Hendrickson, J. Comparative Neurology **292**, 497 (1990). https://doi.org/10.1002/cne.902920402.

[11] D. Mustafi, A.H. Engel, K. Palczewski, Progress in Retinal and Eye Research **28**, 289 (2009). https://doi.org/10.1016/j.preteyeres.2009.05.003.

[12] E.M. Wells-Gray, S.S. Choi, A. Bries, N. Doble, Eye 30, 1135 (2016). https://doi.org/10.1038/eye.2016.107.

[13] S. Bara, M.A. Bonmati-Carrion, J.A. Madrid, M.A. Rol, J. Zamorano, Photon. Lett. Poland **11**(3), 60 (2019). https://doi.org/10.4302/plp.v11i3.920.

[14] CIE 170-2:2015 Fundamental Chromaticity Diagram with Physiological Axes – Part 2: Spectral Luminous Efficiency Functions and Chromaticity Diagrams, (2015).

[15] I. Fryc, T. Dimitrova-Grekow, 2016 IEEE Lighting Conference of the Visegrad Countries (Lumen V4), IEEE, Karpacz, Poland, 2016: pp. 1–4. https://doi.org/10.1109/LUMENV.2016.7745526.

[16] I. Fryc, Proc. SPIE **3820**, 343 (1999). https://doi.org/10.1117/12.353083.

[17] H. Wright, C.L. Sanders, D. Gignac, Appl. Opt. **8**, 2449 (1969). https://doi.org/10.1364/AO.8.002449.

[18] S. Winter, D. Lindner, A. Sperling, G. Sauter, S. Brown, T. Larason, Y. Zong, Y. Ohno, Proceedings of the 9th International Conference on New Developments and Applications in Optical Radiometry (NEWRAD), Davos 2005.

[19] I. Fryc, P. Tabaka, Optica Applicata **XLIX**, 345 (2019). https://doi.org/10.5277/oa190214.

[20] U.S. Energy Information Administration, Commercial Buildings Energy Consumption Survey (2021).

[21] United Nations Environment Programme (2013). Minamata convention on mercury: text and annexes, (2013). https://wedocs.unep.org/20.500.11822/8541.

[22] M. Listowski, R. Supronowicz, Photon. Lett. Poland 14(3), 56 (2022). https://doi.org/10.4302/plp.v14i3.1159.

[23] J. Cho, J.H. Park, J.K. Kim, E.F. Schubert, Photonics Reviews 11, 1600147 (2017). https://doi.org/10.1002/lpor.201600147.

[24] K. Bando, K. Sakano, Y. Noguchi, Y. Shimizu, J. Light Vis. Env. **22**, 2 (1998). https://doi.org/10.2150/jlve.22.1_2.

[25] M. Listowski, Przegląd Elektrotechniczny **1**, 59 (2022). https://doi.org/10.15199/48.2022.06.10.

[26] W. Song, D. Durmus, Buildings **12**, 2220 (2022). https://doi.org/10.3390/buildings12122220.

[27] S. Jost, A. Thorseth, T. Poikonen, P. Blattner, T. Gerloff, A. Kokka, P. Dekker, M. Smid, A. Ferrero, T. Kubarsepp, P. Gal, S. Källberg, A. Klej, G. Brida, T. Reiners, K. Ludwig, M. Schneider, L. Hui, EMPIR 15SIB07 PhotoLED - Database of LED product spectra (2021). https://doi.org/10.11583/DTU.12783389.V2.

[28] M. Royer, Real Light Source SPDs and Color Data for Use in Research (2023). https://doi.org/10.6084/M9.FIGSHARE.12947240.V2.

[29] ANSI C78.377 Electric Lamps - Specifications for The Chromaticity of Solid-State Lighting Products, (2017).

[30] Y. Ohno, LEUKOS **10**, 47 (2014). https://doi.org/10.1080/15502724.2014.839020.

