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UNCERTAINTY OF SPECTRAL MISMATCH FACTOR FOR SPOT WHITE (LEDS) AND COMPACT FLUORESCENT LAMPS

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ABSTRACT

The present work focused on analyzed the uncertainty spectral mismatch factor for Spot White Light Emitting Diodes Lamps (LEDs) and Compact Fluorescent Lamps (CFLs) by applied the method of ISO Guide to Expression of Uncertainty in Measurements. The excel program build for calculating the spectral mismatch correction factors and their uncertainties from the spectral power distribution (SPDs). A set up based on National Institute of standards of Egypt (NIS) Spectroradiometer and the photometric bench used for measuring the spectral power distribution of the test lamps against the NIS luminous flux standard lamps. The spectral power distributions (SPDs) diagrams for Spot White Light Emitting Diodes Lamps (LEDs) and Compact Fluorescent Lamps (CFLs) showed typical White LEDs and CFLs responses. The results of spectral mismatch correction factors show that theses mismatch values and their uncertainties could be added to the of luminous flux measurements as correction. The color temperature of the standard lamps varied from 2400 Kelvin to 2750 Kelvin which has effect on the uncertainty.

Keywords: uncertainty, spectral mismatches correction factor, spectral power distribution (SPD), spot white light emitting diodes lamps (LEDs), compact fluorescent lamps (CFLs), human response curve V (λ).

1. INTRODUCTION

In photometry science, the most commonly used comparison device for measuring photometric quantities of a test lamp against a standard calibration lamp, is called a photometer. These comparison devices are designed to correct the spectral distribution of a standard incandescent sources, CIE source A, which is represented of a blackbody source operating at a color temperature of 2856 K so that it matches the CIE standard spectral luminous efficiency function V(λ). If the relative spectral responsivity of the photometer was a perfect match to V(λ), there would be no transfer uncertainties in measuring sources with different spectral distributions. However, this ideal, does not exist and it is necessary to determine spectral mismatch correction factors, which depends upon the spectral differences in the standard calibration source and the test source [1].

The total luminous flux quantity is an important quantity for applied laboratories in the form of standard lamps and detectors as well as calibrated instruments. These standards are used in a calibration laboratory to calibrate secondary standard lamps and detectors as well as instruments to be used in the practical photometric laboratory. The integrating sphere photometer is a device for measuring the total luminous flux quantity for all kind of artificial light sources. The NIS photometer used is LMT U1000 and the integrating sphere used has a diameter of 2.5 meter and is coated internally with a uniform layer of barium sulfate ($BaSO_4$) as shown in Figure-1.The lamps are mounted in a base-up configuration at the center of this sphere into a lamp socket supported from the top of the sphere. The direct exposure of the photometer head is blocked using a small baffle between the lamp and the detector head as shown in Figure-1. When using standard lamps, the test lamp is calibrated against a standard lamp of the same color temperature and the same size. Otherwise, spectral and spatial corrections are needed [2].

Figure-1. The NIS Integrating Sphere Photometer system (2.5meter diameter).

Spectral power distribution (SPD) is used for describing visible spectrum of lighting sources. This quantity shows the radiant power emitted by the source at each wavelength over the visible region (380 to 760 nm). Lamp manufacturers present the SPD curves of specific light sources. The incandescent lamp frequently has high power in the longer wavelengths (above 650 nm) of the visible spectrum and therefore, effectively renders red colors. The light emitting diode lamp has high power in the short wavelength of the visible spectrum (below 450 nm) [3,4].

Compact fluorescent lamps (CFLs) bulbs are an excellent alternative for light bulb. Compact fluorescent lamps (CFLs) are a miniature version of the common fluorescent light, glowing phosphor gas by using an electric current. On comparing with incandescent bulbs, compact fluorescent lamps (CFLs) are approximately four times as efficient. They also possesses high longevity i.e. 10 times longer, meaning that the life of a standard CFL is comparable to 10 incandescent bulbs. But, a CFL gives off light that looks just like a standard incandescent [5,6].

Lamp is usually compounded of two parts. One is plastic cover with holes for pipe and bills. Tube is agglutinated to it. Second much bigger piece has slots for bills from the inner side. Inside is printed circuit board with components and wires from tube. The spectral matching of photometers is important for photometric measurements. However, there is no general estimation for the spectral mismatch correction factor for the measurement of CFLs. According to that, an error occurs when a photometer head measures a light source having the relative spectral power distribution (SPDs) different from the calibrated source. The spectral error can be taken into account through a spectral mismatch correction factor [7-9].

Nowadays, the spot white light emitting diode lamps (LEDs) uses for general illumination applications such as interior lighting in houses and offices. There are many photometric, colorimetric and radiometric metrological problems with LEDs to use as lighting products. For traditional lighting products such as incandescent lamps and compact fluorescent lamps (CFLs), the photometric procedures and standards have been developed and do not work well for LEDs because they have different characteristics especially with their spectral power distributions (SPD). The current state-of-art uncertainties for photometric measurements of LED lighting products are about a factor of 5 poorer than for traditional lamps, based on the results of recent interlaboratory comparisons involving both based upon the results of recent interlaboratory comparisons involving both national measurement institutes (NMIs) and accredited laboratories. [1]. Reducing the uncertainty of these measurements will have a significant impact on society - both on reducing costs due to energy savings, but also on improving overall lighting quality and performance. Solid state lighting products (SSL) such as light emitting diodes (LEDs) are increasingly replacing traditional sources of, which shows the increase in global market penetration of LED lighting over the period 2010 to 2015 and a projected increase by 2020 [1].

Since no photometer perfectly matches the $V(\lambda)$ curve, we need to determine how closely we approach the

$V(\lambda)$ curve. The output of a photometer is a single number; the integration over the spectral range is all done internally and one number comes out. When the photometers measure light sources whose spectral distribution is different from the CIE Illuminant A, an error occurs due to the spectral mismatch of the photometers. This error is corrected by a spectral mismatch correction factor [10]. An error occurs when a photometer measures a light source having a spectral power distribution different from the standard source for which the photometer was calibrated. In order to correct for such spectral mismatch error, the photometer must be characterized for its relative spectral responsivity. The spectral mismatch correction factor SCF is given by [11, 12].

$$SCF = \frac{\int_{360}^{830nm} P_e^T(\lambda) \times V(\lambda)\, d\lambda \int_{all-wavelengths} P_e^S(\lambda) \times R(\lambda)\, d\lambda}{\int_{all-wavelengths} P_e^T(\lambda) \times R(\lambda)\, d\lambda \int_{360}^{830nm} P_e^S(\lambda) \times V(\lambda)\, d\lambda} \quad (1)$$

where

$P_e^T(\lambda)$: is the relative spectral output of the test source.

$P_e^S(\lambda)$: is the relative spectral output of the standard source.

$R(\lambda)$: is the relative spectral responsivity of the photometer.

$V(\lambda)$: is the spectral luminous efficiency function, which defines a photometric measurement

2. UNCERTAINTY ESTIMATION OF SPECTRAL MISMATCH FACTOR

Metrology requires accurate estimates of uncertainties following principles descried in the ISO Guide to the Expression of Uncertainty in Measurement [13]. The Guide has been universally adopted in the national metrology institutes and its use is propagating through to calibration laboratories providing traceable measurements. The Guide provides principles and some examples some related to colour measurement. Uncertainty calculations are difficult for colour parameters. Any measurement of colour is not complete without an estimate of the accompanying uncertainty.

The Guide to the Expression of Uncertainty in Measurement (GUM) gives the Law of Propagation of Uncertainty.

$$u_c^2(y) = \sum_{i=1}^{n}\left(\frac{\partial f}{\partial x_i}\right)^2 u^2(x_i) + 2\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\frac{\partial f}{\partial x_i}\frac{\partial f}{x_j}u(x_i, x_j) \quad (2)$$

which applies for a measurement model of the form

$$Y = f(X_1, X_2, X_3 ...., X_i, ...) \quad (3)$$

where an estimate x_i of quantity X_i has an associated uncertainty $u(x_i)$, the squared combined standard uncertainty (the combined variance) is the sum of two terms in equation (9) [13, 14]. By applying the law of propagation of uncertainty [15] as the following equation:

$$u^2 = \sum_{variable}\left(\frac{\partial f}{\partial\, variable}\right)^2 \times u^2(variable) \quad (4)$$

The square of the standard uncertainty in spectral mismatch factor

$$u^2(SCF) = \delta^2 P_{iS}\left(\frac{\partial SCF}{\partial P_{iS}}\right)^2 + \delta^2 P_{it}\left(\frac{\partial SCF}{\partial P_{it}}\right)^2 + \delta^2 R_i\left(\frac{\partial SCF}{\partial R_i}\right)^2 \quad (5)$$

Where

P_{iS} :the summation of $P_e^S(\lambda)$ within the visible wavelengths range.

P_{it} :the summation of $P_e^T(\lambda)$ within the visible wavelengths range.

R_i : the summation of $R(\lambda)$ within the visible wavelengths range.

Then from equation (5) we have [13, 14,16]

$$u(SCF) = \sqrt{\delta^2 P_{iS}\left(\frac{\partial SCF}{\partial P_{iS}}\right)^2 + \delta^2 P_{it}\left(\frac{\partial SCF}{\partial P_{it}}\right)^2 + \delta^2 R_i\left(\frac{\partial SCF}{\partial R_i}\right)^2}$$

(6)

3. EXPERIMENTS AND MEASUREMENTS

The spectral power distribution measured using the photometric bench and spectroradiometer. Light to be measured is guided into entrance port of spectroradiometer through an optical fiber and the spectrum is output through the USB port to a PC for a data acquisition. An optical fiber that guides light input from lamps allows a flexible measurements setup as shown in Figure-2 [17]. The spectroradiometric measurement of light sources was performed based on CIE 63-1984 method recommended by International Electrotechnical Commission (IEC) [18]. The employed spectroradiometer is periodically calibrated using a standard source of irradiance based on standard method [19]. Measurements were performed in a conditioned dark room and maintaining the temperature at $(25 \pm 2)^0 C$.

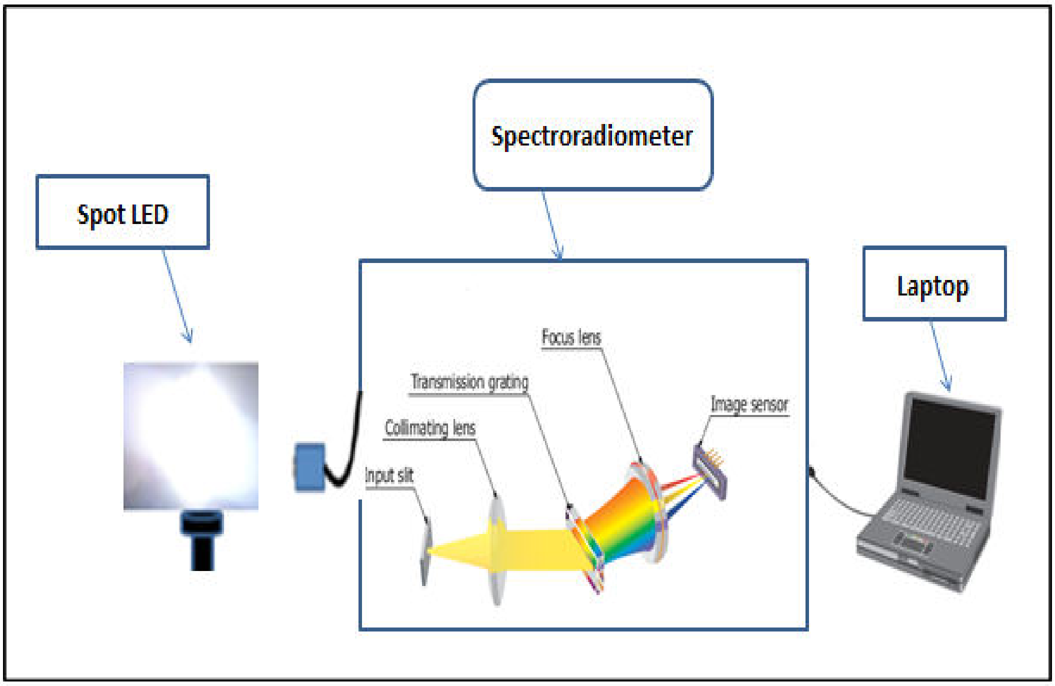

Figure-2. NIS setup for measuring the spectral power distribution.

4. RESULTS AND DISCUSSIONS

The results of measuring the spectral power distribution of the Spot white light emitting diode lamps and compact fluorescent lamps (CFLs) illustrated in Figures 3 and 4. It show the spectral power distribution (SPDs) diagrams for all lamps under study at each wavelength over the visible region compared to the CIE-human response curve V (λ) and NIS photometer. It shows the radiant power emitted by the source at each wavelength over the visible region (400 to 700 nm). In Figure-3, the spectral power distribution (SPDs) diagrams showed typical White Light Emitting Diodes lamps (LEDs) response, with a few narrow spectral peaks. Because of the relativity narrow spectral out put of LEDs lamps, only a small portion of the photometer spectral responsivity is important in measuring their photometric quantities. Also, white LEDs lamps have relatively strong features in the blue and red portions of the spectrum, where the photometer responsivity is low, so even a photometer with a small overall spectral mismatch error can give very large LED measurement errors [1].

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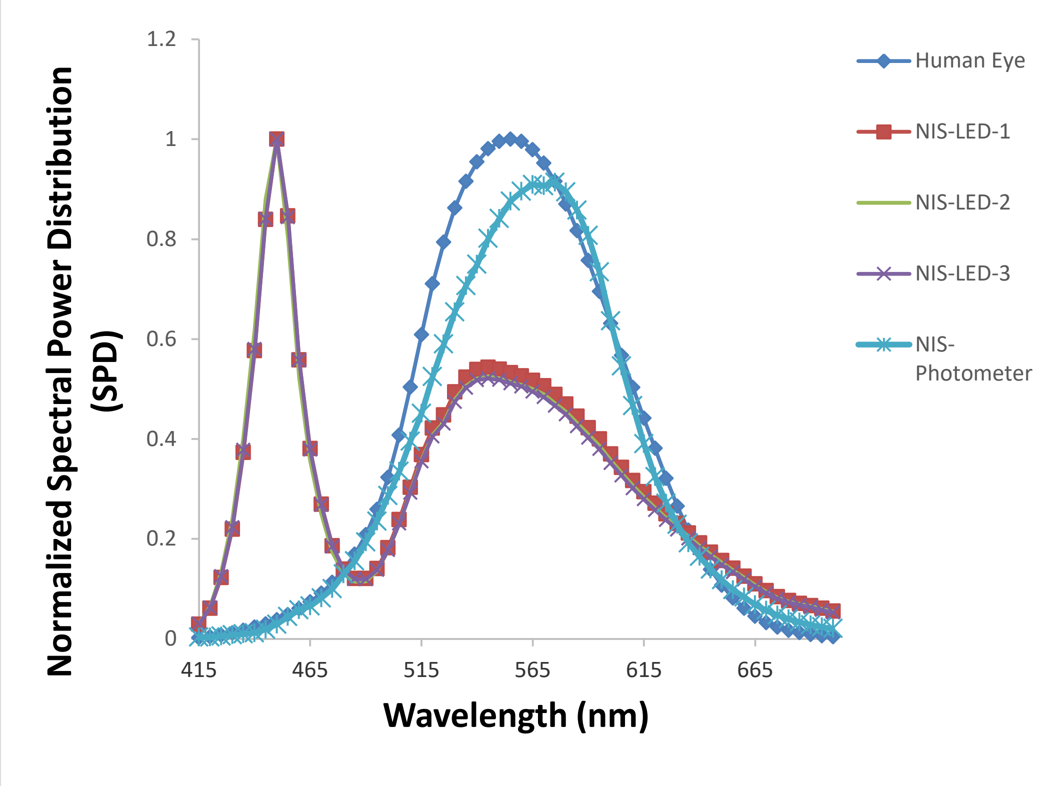

Figure-3. The responsivity of CIE-human eye V(λ) Curve, spectral photometer response, and the spectral power distribution of Spot White Light Emitting Diodes Lamps (LEDs).

In Figure-4, the spectral power distribution (SPDs) diagrams showed typical compact fluorescent lamps (CFLs) response, with a few narrow spectral peaks. It is found that each group of lamps has its own characteristics and they emit their spectrum in the visible region with different spectral distributions for each lamp.

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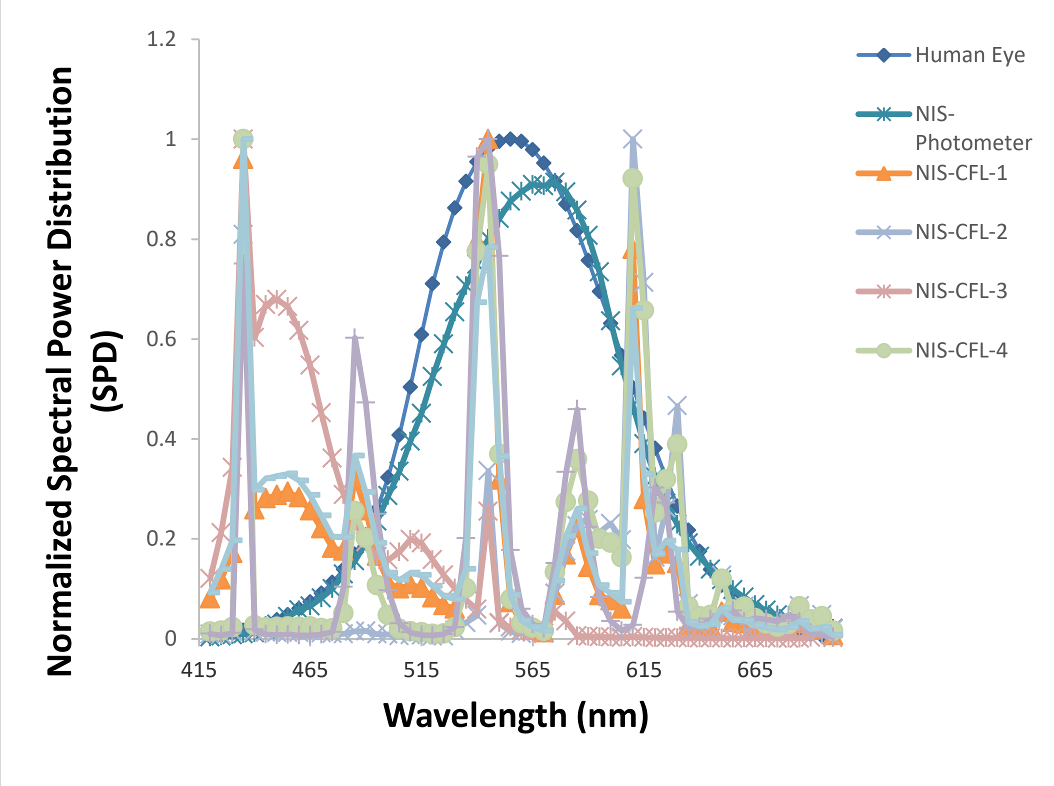

Figure-4. The responsivity of human eye V(λ) Curve, spectral photometer response, and the spectralpower distribution of Compact Fluorescent Lamps (CFLs).

The results of the spectral mismatch factor for spot white light emitting diode lamps (LEDs) against NIS standard lamps are presented in Tables (1) and (2).

Table-1. The Spectral Mismatch Factor of LEDs against NIS standard Lamps (2750 Kelvin)

	NIS-LED-1	NIS-LED-2	NIS-LED-3
NIS-E21	1.211	1.211	1.212
NIS-E22	1.212	1.213	1.212
NIS-E24	1.210	1.210	1.211

Table-2. The Spectral Mismatch Factor of LEDs against NIS standard Lamps (2400 Kelvin)

	NIS-LED-1	NIS-LED-2	NIS-LED-3
NIS-E31	1.195	1.195	1.196
NIS-E32	1.194	1.194	1.194
NIS-E33	1.192	1.192	1.192

The results of the spectral mismatch factor for compact fluorescent lamps (CFLs) against NIS standard lamps are presented in Tables (3) and (4).

Table-3. The Spectral Mismatch Factor of CFLs against NIS standard Lamps (2750 Kelvin).

	NIS-CFL-1	NIS- CFL-2	NIS- CFL-3	NIS- CFL -4	NIS- CFL-5	NIS- CFL-6
NIS-E21	0.990	0.925	0.999	0.959	0.985	0.991
NIS-E22	0.991	0.927	0.998	0.961	0.987	0.992
NIS-E24	0.991	0.927	0.998	0.961	0.987	0.992

Table-4. The Spectral Mismatch Factor of CFLs against NIS standard Lamps (2400 Kelvin)

	NIS-CFL-1	NIS- CFL -2	NIS- CFL-3	NIS- CFL-4	NIS- CFL-5	NIS- CFL-6
NIS-E31	0.988	0.923	0.997	0.957	0.983	0.988
NIS-E32	0.990	0.926	0.997	0.960	0.986	0.991
NIS-E33	0.985	0.921	0.997	0.955	0.981	0.986

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5. THE UNCERTAINTY VALUES

The results of the uncertainty of spectral mismatch factor for spot white light emitting diode lamps (LEDs) against NIS standard lamps are presented in Tables (5) and (6).

Table-5. The Uncertainty of the Spectral Mismatch Factor of LEDs against NIS Standard Lamps (2750 Kelvin).

	NIS-LED-1	NIS-LED-2	NIS-LED-3
NIS-E21	0.00376	0.00376	0.00378
NIS-E22	0.00406	0.00406	0.00408
NIS-E24	0.00403	0.00403	0.00404

Table-6. The Uncertainty of the Spectral Mismatch Factor of LEDs against NIS Standard Lamps (2400 Kelvin).

	NIS-LED-1	NIS-LED-2	NIS-LED-3
NIS-E31	0.00992	0.00992	0.00992
NIS-E32	0.00989	0.00989	0.00988
NIS-E33	0.00978	0.00979	0.00977

The results of the uncertainty of spectral mismatch factor for compact fluorescent lamps (CFLs) against NIS standard lamps are presented in Tables (7) and (8).

Table-7. The Uncertainty of the Spectral Mismatch Factor of CFLs against NIS Standard Lamps (2750 Kelvin).

	NIS-CFL-1	NIS- CFL-2	NIS- CFL -3	NIS- CFL-4	NIS- CFL-5	NIS- CFL-6
NIS-E21	0.01293	0.01039	0.01229	0.01065	0.01328	0.01031
NIS-E22	0.01298	0.01054	0.01189	0.01080	0.01340	0.01037
NIS-E24	0.01299	0.01053	0.01194	0.01079	0.01339	0.01037

Table-8. The Uncertainty of the Spectral Mismatch Factor of CFLs against NIS Standard Lamps (2400 Kelvin).

	NIS-CFL-1	NIS- CFL -2	NIS- CFL-3	NIS- CFL-4	NIS- CFL-5	NIS- CFL-6
NIS-E31	0.01558	0.01349	0.01337	0.01394	0.01624	0.01342
NIS-E32	0.01556	0.01348	0.01334	0.01392	0.01622	0.01340
NIS-E33	0.01557	0.01348	0.01337	0.01393	0.01623	0.01341

6. CONCLUSIONS

The spectral power distribution SPDs at each wavelength over the visible region of three of spot white light emitting diode (LEDs) lamps as the following: NIS-LED-1, NIS- LED -2, and NIS- LED -3 compared to the spectral power distribution of the human response curve V (λ). It is used for describing visible spectrum of lighting sources. This quantity shows the radiant power emitted by the source at each wavelength over the visible region (400 to 700 nm). The spectral power distribution (SPDs) diagrams showed typical White light emitting diode lamps (LED s) response, with a few narrow spectral peaks. The spectral power distribution SPDs at each wavelength over the visible region of tsix of compact fluorescent (CFLs) lamps as the following: NIS- CFL-1, NIS- CFL -2, NIS- CFL -3, NIS- CFL -4, NIS- CFL -5, and NIS- CFL -6 compared to the spectral power distribution of the human response curve V (λ). It is found that each group of lamps has its own characteristics and they emit their spectrum in the visible region with different spectral distributions for each lamp. The results of Spectral Mismatch Factor of all lamps under study depend on their relative spectral power distributions, the spectral power distribution of the human response curve V (λ) and the photometer response. According to Tables (1) and (2), the spectral mismatch correction factor is calculated for all LEDs lamps and found to be from 1.192 when using the 2400 K Standard lamps to 1.213 when using the 2750 K Standard lamps. Depending on these results the spectral power distribution of this type of Spot LEDs lamps does not match perfectly with the spectral power distribution of the human response curve V (λ) and the photometer response. According to Tables (5) and (6), the uncertainty estimation for the spectral mismatch correction factor is calculated for all LEDs lamps and found to be from 0.00376 when using the 2400 K Standard lamps to 0.00992 when using the 2750 K Standard lamps. According to Tables (3) and (4), the spectral mismatch correction factor is calculated for all CFLs lamps and found to be from 0.921 when using the 2400 K Standard lamps to 0.999 when using the 2750 K Standard lamps. Depending on these results the spectral power distribution of this type of Spot LEDs lamps does not match perfectly with the spectral power distribution of the human response curve V (λ) and the photometer response. According to Tables (5) and (6), the uncertainty estimation for the spectral mismatch correction factor is calculated for all CFLs lamps and found to be from 0.01334when using the 2400 K Standard lamps to 0.01299 when using the 2750 K Standard lamps.

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