Original scientific paper

UDK 537.563.2:72.033.5
DOI 10.7251/COMEN2401009T

MEASUREMENT AND ANALYSIS OF THE SPECTRAL EMISSION OF DIFFERENT TYPES OF DOMESTIC LAMPS IN THE BLUE LIGHT HAZARD WAVELENGTH RANGE

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Abstract: In recent years, research on the photobiological impact of light on humans has been expanding and deepening. A significant part of this research is aimed at harmful effects such as the blue light hazard (BLH) on the retina of the human eye, for which there are standardized indicators in international normative documents. The current research presents laboratory measurements and results for the spectral emission in blue light hazard wavelength range for several domestic lamps: conventional tungsten filament lamps, halogen and metal halide lamps, compact fluorescent lamps, and state-of-the-art LED lamps. The measurements are conducted in a specialised laboratory in the Technological Park of the Technical University - Gabrovo using a photometer with a spectroradiometer in an integrating sphere and are processed with specialised software. Graphical comparisons of the spectral distributions of lamps in the visible part of the electromagnetic spectrum with the dangerous blue light wavelength range are shown. Data on the main photometric and colour characteristics - luminous flux, light efficacy, chromaticity coordinates, colour temperature, colour rendering index, and indicators for assessing the presence of dangerous blue light - blue light (weighted power) and blue light hazard factor (weighted power/ lux), for the different types of lamps, are shown in tables. Conclusions and recommendations regarding the choice of the type of domestic lamp and its colour characteristics to limit the level of dangerous blue light are made.

Keywords: blue light hazard, domestic lamp, light-emitting diode, spectral distribution of lamp, spectroradiometer measurement.

1. INTRODUCTION

In recent years, the widespread adoption of artificial lighting in domestic settings has revolutionized our lives, enhancing productivity, safety, and comfort during nighttime hours. However, with the rapid proliferation of energy-efficient light sources, particularly light-emitting diodes (LEDs), concerns have arisen regarding their potential adverse effects on human health. Of particular interest is the blue light emitted by these lamps, which has been identified as a potential hazard due to its impact on the circadian rhythm and ocular health.

One of the significant direct potentially harmful effects of radiation from light sources is the Blue Light Hazard (BLH), which has a relatively strong photochemical effect in retinal tissues. [1,2] Specific measurement methods and BLH level control indicators are systematized and defined in international normative documents. [3,4] The relevance of the BLH problem is confirmed by modern scientific books and publications by authoritative scientists. [1,5,6,7]

Fig. 1 shows a comparison of photopic eye sensitivity, actinic UV, blue light and thermal hazard spectrums according to IEC 62471 Photobiological Safety of Lamps and Lamp Systems. [2]

The human eye is sensitive to light across a broad spectrum, ranging from ultraviolet (UV) to visible and infrared light. Blue light, with wavelengths between approximately 400 to 500 nanometers, lies at the higher-energy end of the visible spectrum and plays a crucial role in regulating our sleep-wake cycle. In natural settings, exposure to blue light during the day is essential for maintaining proper circadian rhythms, alertness, and mood. However, excessive or untimely exposure to blue light, especially during evening hours, can disrupt the natural sleep-wake cycle, leading to various health issues. [8]

Domestic lamps, including LEDs, compact fluorescent lamps (CFLs), and traditional incandescent bulbs, have replaced conventional lighting sources in households due to their energy efficiency and longer lifespan. LEDs, in particular, have gained popularity due to their low energy consumption and versatile applications. Nonetheless, their high blue light content has raised concerns regarding their potential impact on human health.

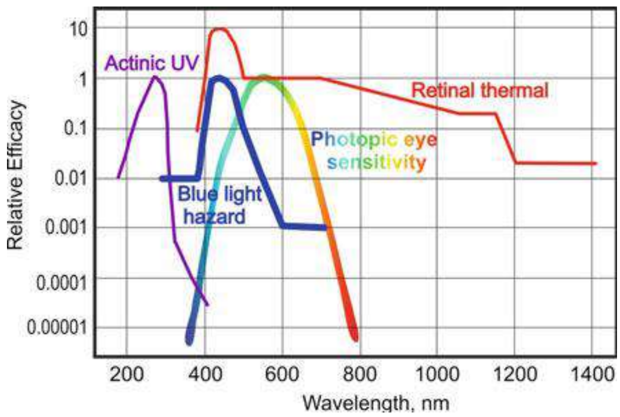


Figure 1. *Photopic eye sensitivity, actinic UV, blue light and thermal hazards spectrums. [2]*

In contemporary indoor lighting lamps, light-emitting diodes (LED) based on a Blue LED + Yellow phosphor are mainly used. In both cases, the presence of a blue LED emitting in a narrow wavelength range with a maximum close to that of the blue light hazard wavelength range of (400÷500) nm, makes it highly likely that the eye-safe levels of blue light will be exceeded. Fig. 1 shows a typical spectrum of Blue LED + Yellow phosphor technology LED. Blue light is directly emitted by the GaN-based LED luminescence (peak at about 465 nm) and the more broadband Stokes-shifted light emitted by the Ce3+:YAG (Yttrium aluminium garnet—Y3Al5O12) phosphorescence, which emits at roughly 500–700 nm. [2,9]

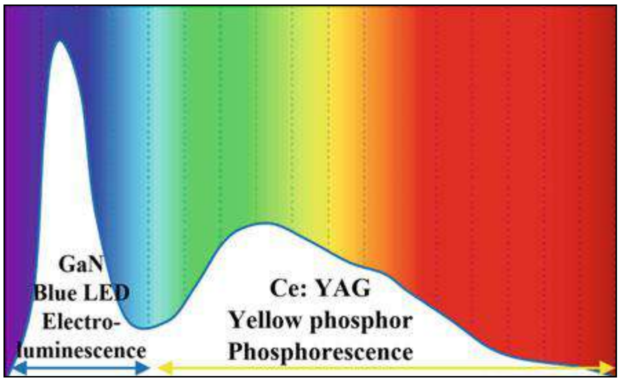


Figure 2. *Spectrum formation of Blue LED + Yellow phosphor technology LEDs*

Studies have shown that prolonged exposure to blue light, especially during the evening, can suppress the production of melatonin, a hormone responsible for regulating sleep. This disruption can lead to sleep disturbances, insomnia, and even contribute to the development of chronic health conditions, including obesity, diabetes, and cardiovascular diseases. Moreover, blue light exposure can cause eye strain, visual discomfort, and in extreme cases, retinal damage, leading to an increased risk of age-related macular degeneration (AMD).

One of the quantitative indicators giving information about the potential danger of the spectrum of a given light source is the blue light hazard efficacy of luminous radiation $K_{B,V}$ [10,11,12], expressed in (W/lm), with a mathematical definition:

$$K_{B,V} = \frac{\int \phi_\lambda(\lambda) \cdot B(\lambda) \cdot d\lambda}{K_m \cdot \int \phi_\lambda(\lambda) \cdot V(\lambda) \cdot d\lambda} \tag{1}$$

where: $\Phi_\lambda(\lambda)$ is the radiometric spectral power distribution of the white light source (W/nm); λ is the wavelength variable (nm); $B(\lambda)$ is the blue light hazard weighting function defined in IEC 62471; K_m is the photopic luminous efficacy of radiation for a monochromatic source with a 555 nm wavelength (683 lm/W); $V(\lambda)$ is the luminous efficiency function of the human eye.

The watts in the dimension *W/lm*, calculated using formula (1), are the blue light hazard weighted optical watts of the source, designated as W_B. Another possibility for the analytical representation of $K_{B,V}$ in IEC 62471 is through illuminance or luminance of the light sources - formula (2):

$$K_{B,V} = \frac{E_B}{E} = \frac{L_B}{L} \quad (2)$$

where E_B (W_B/m^2) and L_B ($W_B/(sr.m^2)$) values are used for calculation of $K_{B,V}$ value [1,11,13]. In the present study, according to the definition proposed by EN 62471 for for $K_{B,V}$ via illuminance, a (μW/cm²/lux) dimension is used.

2. LABORATORY SETUP FOR MEASUREMENTS

The measurements of the spectral power distribution (SPD) in range (380÷780) nm, electrical, photometric and colourimetric parameters and efficacy of the lamps studied are performed using a CCD spectroradiometer system Lisun LMS-9000B with an integrating sphere in Gabrovo Tech Park (Fig. 3). [14] The power supply with pure sinewave rated voltage and measurement of the electrical, photometric and colourimetric parameters and efficacy of the domestic lamps studied are realized by the specialized software product LMS-9000 Lisun CCD Spectroradiometer, shown in Fig. 4.

In LMS-9000 Lisun CCD Spectroradiometer software, the spectral power distribution data (W/nm) in the wavelength range (380÷780) nm of the domestic lamps studied are exported and recorded in CSV file format, shown in Fig. 5. Then spectral power distribution data are processed in f.luxome-

Figure 3. *Measurement of the spectral emission of the studied domestic lamps with a CCD spectroradiometer system*

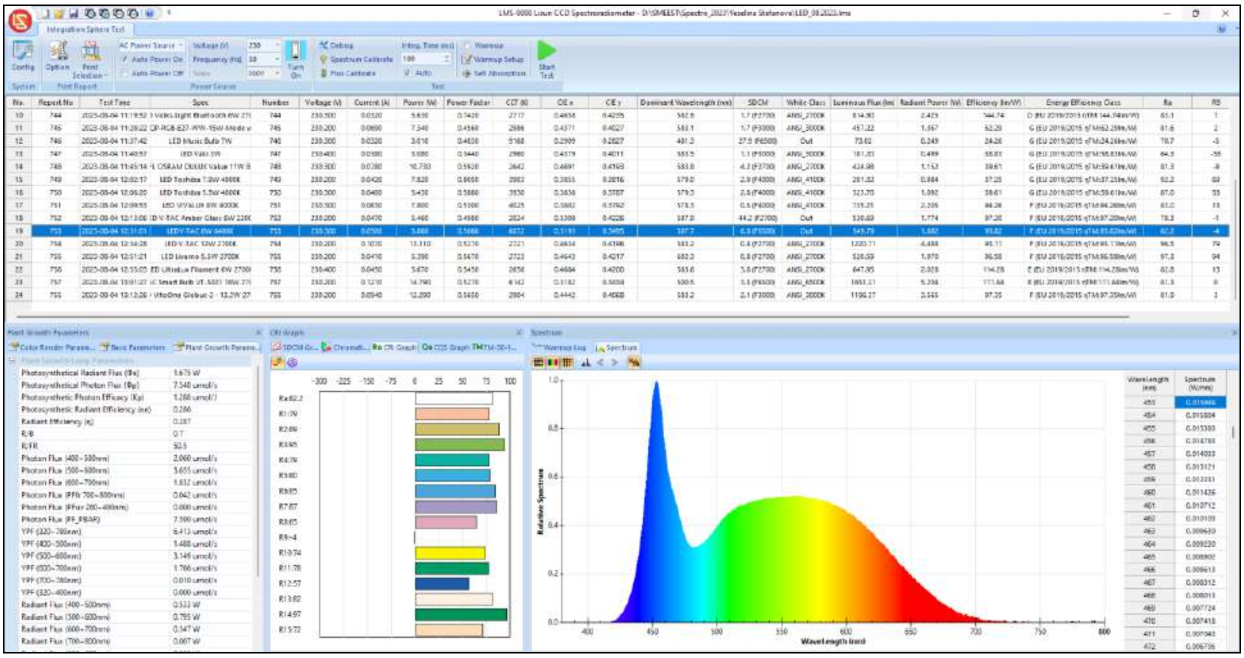
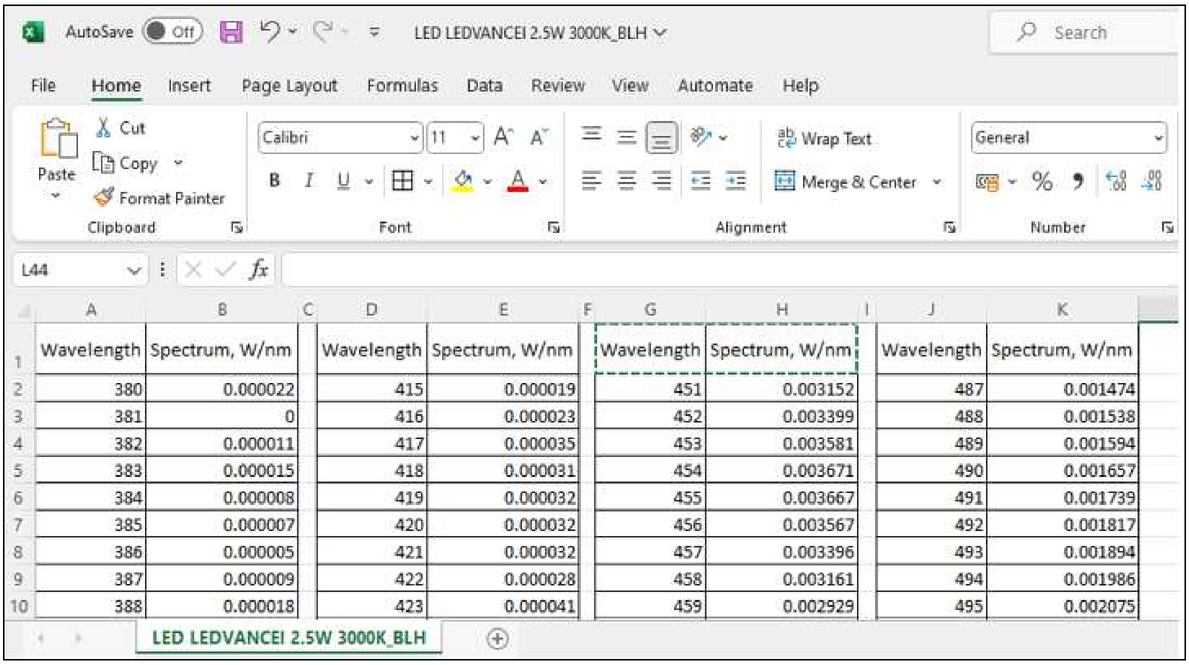


Figure 4. *LMS-9000 Lisun CCD Spectroradiometer software used to control the measurement process*

ter™ online application and service, shown in Fig. 6. [15]

Eighteen domestic lamps with different power and correlated colour temperature: two incandescent lamps, three halogen lamps, six compact fluorescent lamps (CFL), two metal halide lamps (MHL), two xenon lamps, and three LED lamps, are studied. Fig. 7 shows part of the domestic lamps studied.



Wavelength	Spectrum, W/nm	Wavelength	Spectrum, W/nm	Wavelength	Spectrum, W/nm	Wavelength	Spectrum, W/nm
380	0.000022	415	0.000019	451	0.003152	487	0.001474
381	0	416	0.000023	452	0.003399	488	0.001538
382	0.000011	417	0.000035	453	0.003581	489	0.001594
383	0.000015	418	0.000031	454	0.003671	490	0.001657
384	0.000008	419	0.000032	455	0.003667	491	0.001739
385	0.000007	420	0.000032	456	0.003567	492	0.001817
386	0.000005	421	0.000032	457	0.003396	493	0.001894
387	0.000009	422	0.000028	458	0.003161	494	0.001986
388	0.000018	423	0.000041	459	0.002929	495	0.002075

Figure 5. *Recording spectral power distribution data in CSV file format*

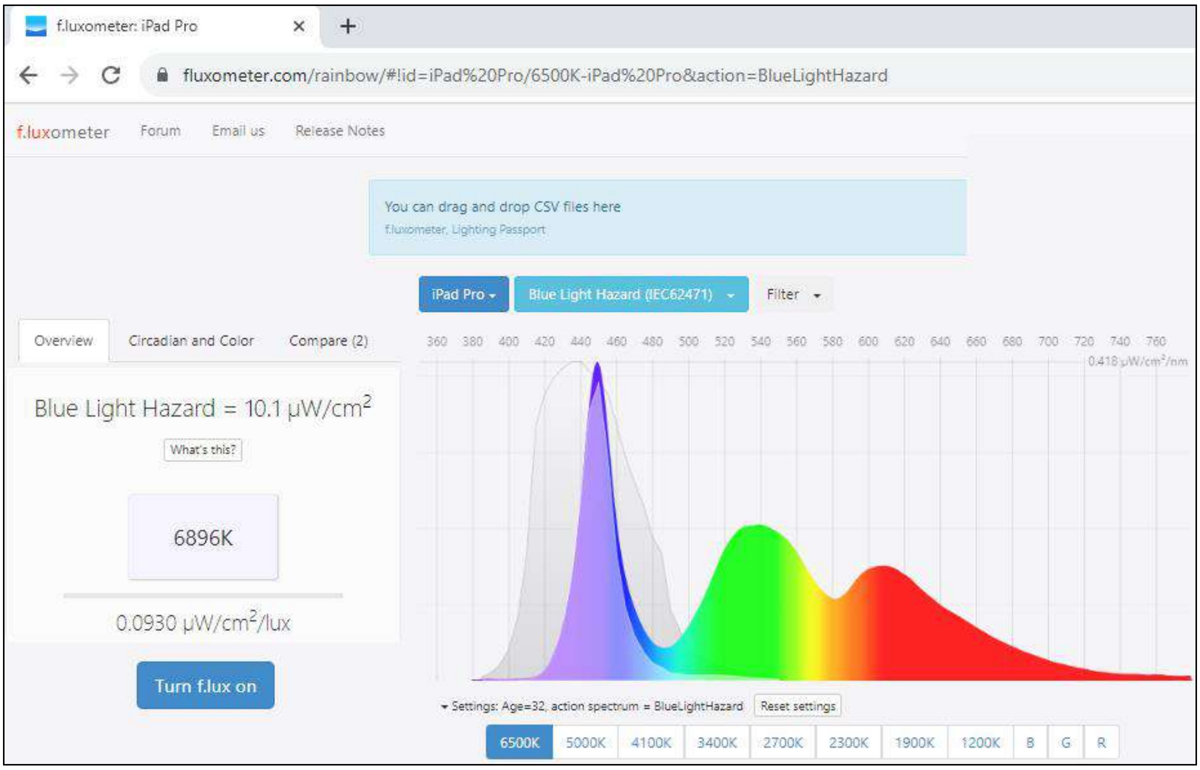
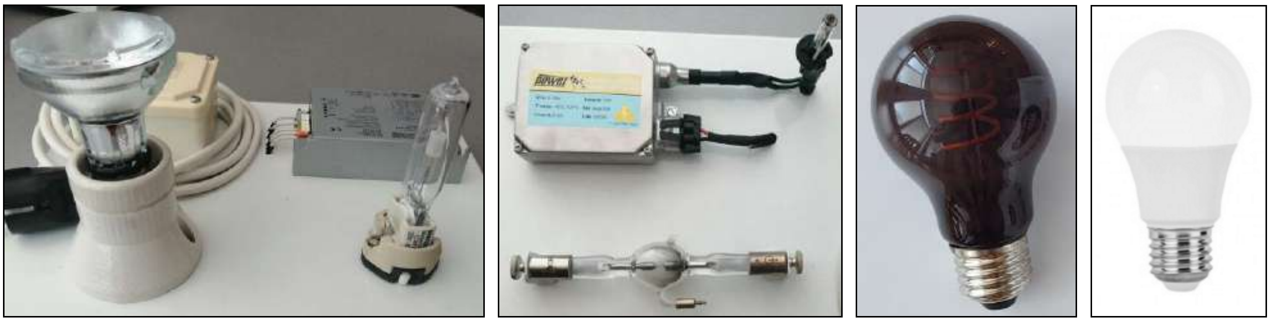


Figure 6. *Online application and service f.luxometer™ used to process the spectral power distribution data in CSV format*

a. Tungsten incandescent and halogen lamps *b. Compact fluorescent lamps*



c. Metal halide lamps *d. Xenon lamps* *e. LED lamps*

Figure 7. *Appearance of the domestic lamps studied*

Before the measurements of the colour characteristics each tested lamp is warmed up to a steady state mode according to established international lighting standards. [16,17]

3. MEASUREMENT RESULTS AND ANALYSIS

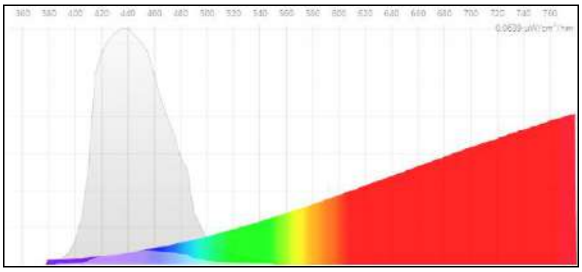
In the CCD spectroradiometer system Lisun LMS-9000B, the photometric, colourimetric parameters, and efficacy of the domestic lamps, are measured.

Table 1 shows the results of measured correlated colour temperature CCT, chromaticity coordinates CIE x and CIE y, dominant wavelength, luminous flux, radiant power, colour rendering index Ra and strong red colour sample R9, colour fidelity index Rf, and colour gamut Rg, and efficacy of tested domestic lamps.

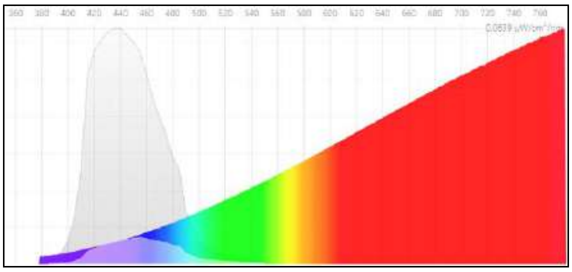
Table 1. *Measured photometric and colourimetric parameters and efficacy of tested domestic lamps*

Lamp	CCT (K)	CIE x	CIE y	Dominant wavelength (nm)	Luminous flux (lm)	Radiant power (W)	Efficacy (lm/W)	Ra	R9	Rf	Rg
Tungsten incandescent-100W	2634	0.4662	0.4131	584.4	1028.08	7.98	10.53	99.7	99	100	100
Tungsten incandescent-150W	2773	0.4544	0.4100	583.8	1787.23	13.173	11.67	99.8	99	100	100
Dichroic halogen-14.7W	2460	0.4873	0.4248	584.5	88.43	0.681	6.00	97.1	90	95	95
Dichroic halogen-15W	2500	0.4795	0.4178	584.9	97.98	0.778	6.50	99.0	96	98	98
Halogen-53W	2765	0.456	0.4120	583.6	267.00	1.937	5.03	99.6	99	99	99
CFL-11W	2642	0.4691	0.4193	583.8	424.98	1.152	39.61	81.3	-9	72	104
CFL SL-15W	5916	0.3227	0.3512	528.6	765.01	2.377	61.55	73.3	16	74	95
CFL PL-15W	2720	0.4639	0.4205	583.1	563.65	1.618	37.70	82.3	-6	74	103
CFL-21W	6336	0.3133	0.3517	504.1	507.55	1.574	33.61	77.8	24	80	97
CFL-23W	7146	0.3021	0.3256	488.5	1413.99	4.694	67.62	80.8	41	81	99
CFL-55W	3929	0.3864	0.3884	577.3	2603.44	7.516	46.26	78.5	16	76	100
MHL SDM-R-35W	2985	0.436	0.4003	583.4	2308.18	7.801	53.94	83.6	-29	81	100
MHL-35W	3094	0.4307	0.4023	582.4	3114.51	10.24	72.33	79.8	-53	77	99
Xenon lamp-60W	6798	0.3046	0.345	507.7	1978.36	7.833	33.48	56.9	-117	62	85
Xenon lamp-75W	6578	0.3091	0.3441	497.5	2655.72	10.74	35.56	63.8	-88	68	88
LED lamp-6W	6072	0.3193	0.3495	507.7	549.79	1.682	93.82	82.2	-4	83	91
LED lamp-7W	4472	0.3623	0.3673	576.1	389.64	1.179	62.74	82.1	4	83	97
LED filament lamp-4W	1585	0.5764	0.3998	593.4	60.59	0.321	14.82	90.8	60	86	89

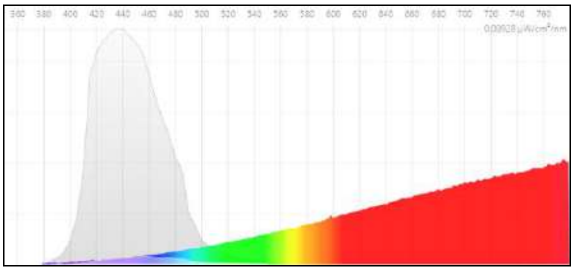
The spectral power distribution data (W/nm) of the studied lamps, measured in a spectroradiometer LMS-9000B and exported in CSV format, are processed using the f.luxometer™ application and service to calculate the results about the blue light hazard wavelength range. Spectral power distributions of the domestic lamps and blue light hazard wavelength range are compared graphically in Fig. 8.



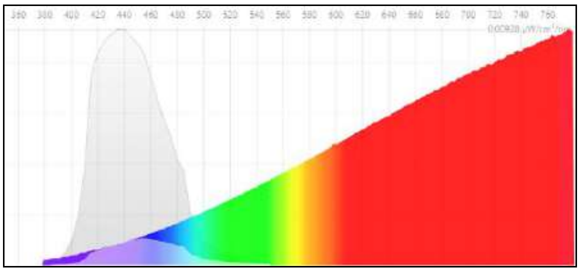
a) Tungsten incandescent lamp-100W



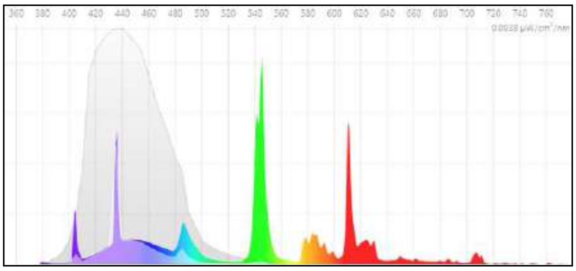
b) Tungsten incandescent lamp-150W



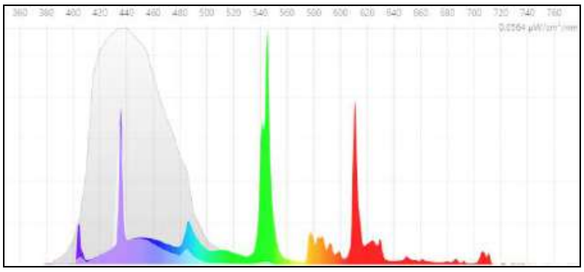
c) Dichroic halogen lamp-15W



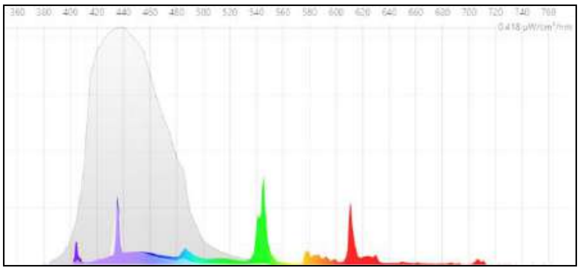
d) Halogen lamp-53W



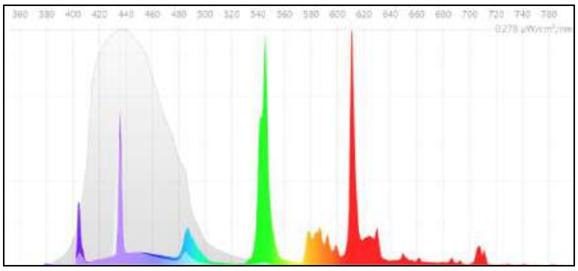
e) CFL SL-15W



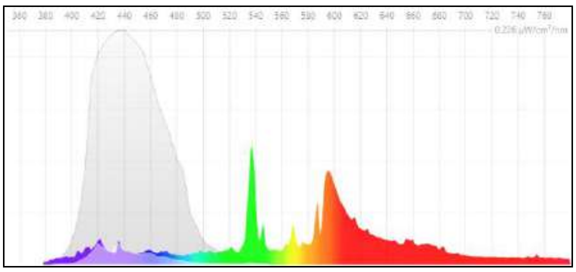
f) CFL-21W



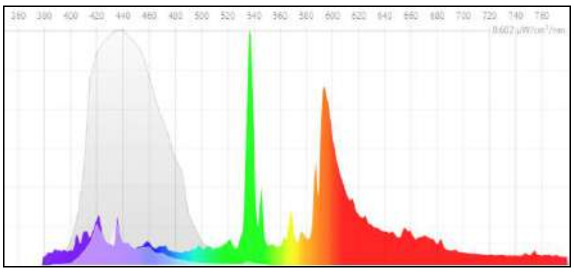
g) CFL-23W



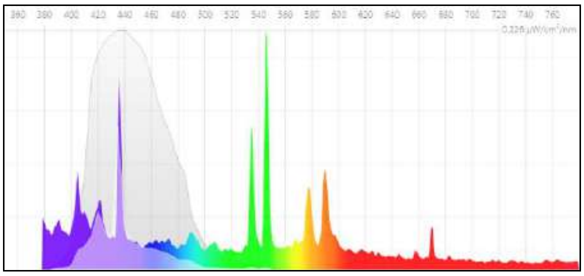
h) CFL-55W



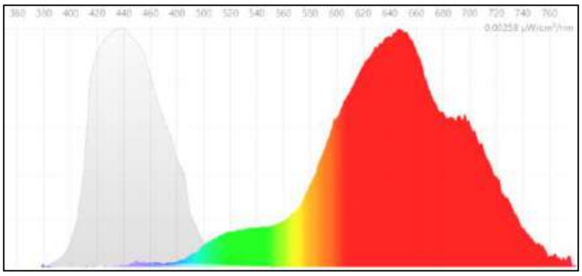
i) MHL SDM-R-35W



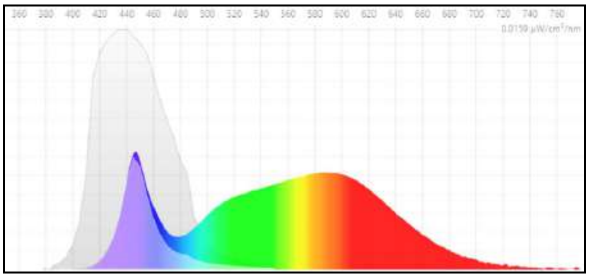
j) MHL-35W



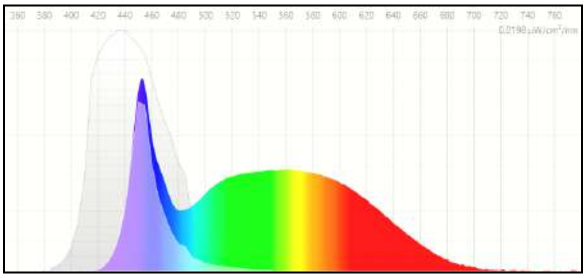
k) Xenon lamp-75W



l) LED filament lamp-4W



m) LED lamp-7W



n) LED lamp-6W

Figure 8. *Comparison between SPD of the domestic lamps studied and the BLH wavelength range*

In Table 2, results for the measured correlated colour temperature and calculated blue light (weighted power) in μW/cm^2, blue light hazard factor (weighted power/lux) $K_{B,V}$ in μW/cm^2/lux, and dominant wavelength of the tested indoor LED lamps, are systematized.

Table 2. *Measured correlated colour temperature and calculated blue light (weighted power), blue light hazard factor (weighted power/lux), and dominant wavelength of the tested domestic lamps*

Lamp	Correlated colour temperature, K	Blue light (weighted power), μW/cm^2	Blue light hazard factor (weighted power/lux), μW/cm^2/lux	Dominant wavelength, nm
LED filament lamp-4W	1582	0.003	0.0044	593.4
Dichroic halogen lamp-14.7W	2460	0.015	0.0166	584.5
Dichroic halogen lamp-15W	2500	0.020	0.0202	584.9
Tungsten incandescent-100W	2634	0.253	0.0246	584.4
CFL-11W	2642	0.105	0.0247	583.8
CFL PL-15W	2720	0.143	0.0254	583.1
Halogen-53W	2765	0.072	0.0269	583.6
Tungsten incandescent-150W	2773	0.499	0.0279	583.8
MHL SDM-R-35W	2985	0.921	0.0399	583.4
MHL-35W	3094	4.200	0.0420	582.4
CFL-55W	3929	1.340	0.0517	577.3
LED lamp-7W	4472	0.229	0.0587	576.1
CFL SL-15W	5916	0.622	0.0814	528.6
LED lamp-6W	6072	0.396	0.0720	507.7
CFL-21W	6336	0.414	0.0816	504.1
Xenon lamp-75W	6578	2.700	0.1020	497.5
Xenon lamp-60W	6798	2.050	0.1040	507.7
CFL-23W	7146	1.390	0.0984	488.5

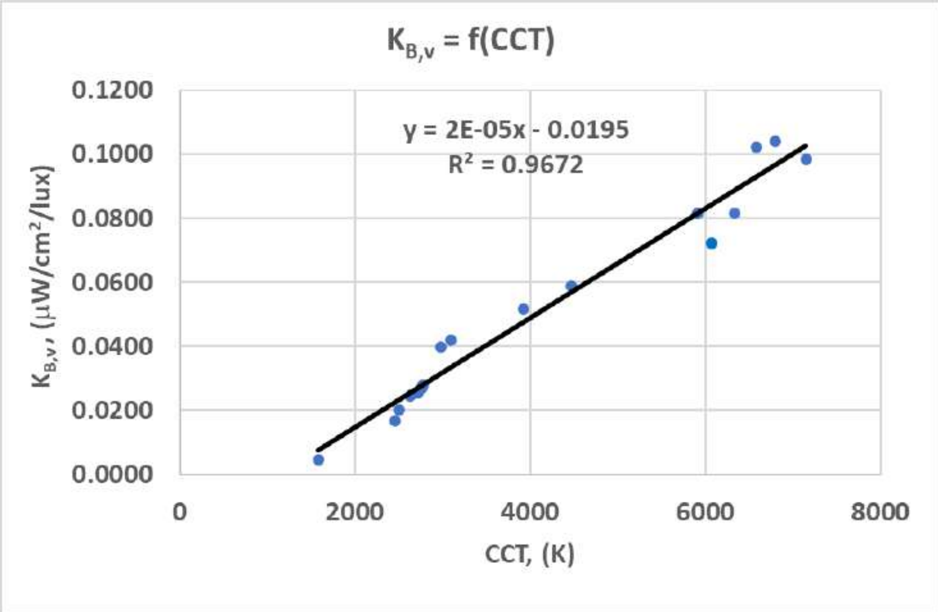


Figure 9. *Graphical and defined linear analytical dependence of blue light hazard efficacy of luminous radiation $K_{B,v}$ on the correlated colour temperature CCT of the measured domestic lamps*

The analysis of the results in Table 2 shows an approximately linear relationship between CCT and blue light hazard factor (weighted power/lux) $K_{B,V}$ in μW/cm^2/lux for the 18 domestic lamps tested. In Fig. 9, graphical and defined linear analytical dependence of blue light hazard efficacy of luminous radiation $K_{B,v}$ on the correlated colour temperature CCT of the measured domestic lamps.

4. CONCLUSIONS

The analysis of the results shows a linear increase trend in the blue light hazard factor $K_{B,V}$ with an increase in the correlated colour temperature CCT of the measured light sources not only for LED lamps, which has been a frequently researched issue in recent years, but also for the older technology domestic lamps they replace, even for tungsten incandescent and incandescent halogen lamps, which, as heat emitter technology, have a lower emission intensity in the blue of the spectrum – Table 2 and Fig. 9. It is even found that at similar levels of colour temperature, CFLs and Xenon lamps have higher $K_{B,V}$ values than LED lamps. For a more precise assessment of the real danger of falling into a risk group for blue light hazard, according to the standard IEC 62471, at the next stage, it is necessary to examine the luminance of the light source or luminaire to the eye for the specific light distribution of their optical system.

From research, it can be concluded that LED lamps, at the same light temperature and other conditions, have the same or lower light emissions in the blue light hazard wavelength range than other domestic light sources. The most important conclusion is that regardless of the technology of light sources, to provide safer household lighting with reduced blue light hazard emissions, it is advisable to use lamps with "warm" or "soft white" light, or with as much as possible -low colour temperature.

The obtained results confirm the expediency of the research and the accuracy of work of the laboratory setup created at the Technical University - Gabrovo for researching the problems with dangerous blue light, which can also be used for other research on direct or indirect photobiological effects of light.

5. ACKNOWLEDGEMENT

This work was supported by the European Regional Development Fund within the OP "Science and Education for Smart Growth 2014 - 2020", Project CoC "Smart Mechatronic, Eco- And Energy Saving Systems And Technologies", № BG-05M2OP001-1.002-0023.

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МЈЕРЕЊЕ И АНАЛИЗА СПЕКТРАЛНЕ ЕМИСИЈЕ РАЗЛИЧИТИХ ТИПОВА ДОМАЋИХ ЛАМПИ У ОПАСНОСТИ ТАЛАСНИХ ДУЖИНА ПЛАВЕ СВЈЕТЛОСТИ

Сажетак: Последњих година све више су заступљена истраживања фотобиолошког утицаја свјетлости на човјека. Значајан дио овог истраживања усмерен је на штетне ефекте, као што је опасност од плаве светлости (БЛХ) на мрежњачу људског ока, за шта постоје стандардизовани индикатори у међународним нормативним документима. Тренутно истраживање представља лабораторијска мјерења и резултате за спектралну емисију у опсегу таласних дужина опасности плаве свјетлости за неколико домаћих сијалица: конвенционалне сијалице са волфрамовим влакном, халогене и метал халогене сијалице, компактне флуоресцентне сијалице и најсавременије ЛЕД сијалице. Мјерења се врше у специјализованој лабораторији у *Технолошком парку Техничког универзитета – Габрово* помоћу фотометра са спектрорадиометром у интегрисаној сфери и обрађују се специјализованим софтвером. Приказана су графичка поређења спектралних дистрибуција сијалица у видљивом дјелу електромагнетног спектра са опасним опсегом таласних дужина плаве свјетлости. Подаци о главним фотометријским и колорним карактеристикама - свјетлосном току, свјетлосној ефикасности, координатама хроматичности, температури боје, индексу приказивања боја и индикаторима за процјену присуства опасне плаве свјетлости - плавој светлости (пондерисана снага) и фактору опасности плаве свјетлости (пондерисана снага). / лук), за различите типове сијалица, приказани су у табелама. Дати су закључци и препоруке у вези са избором врсте кућне лампе и њених карактеристика боје за ограничавање нивоа опасног плавог свјетла.

Кључне ријечи: опасност од плаве свјетлости, кућна лампа, свјетлећа диода, спектрална дистрибуција лампе, спектрорадиометарско мјерење.

Paper received: 18 September 2023 **Paper accepted: 23 May 2024**