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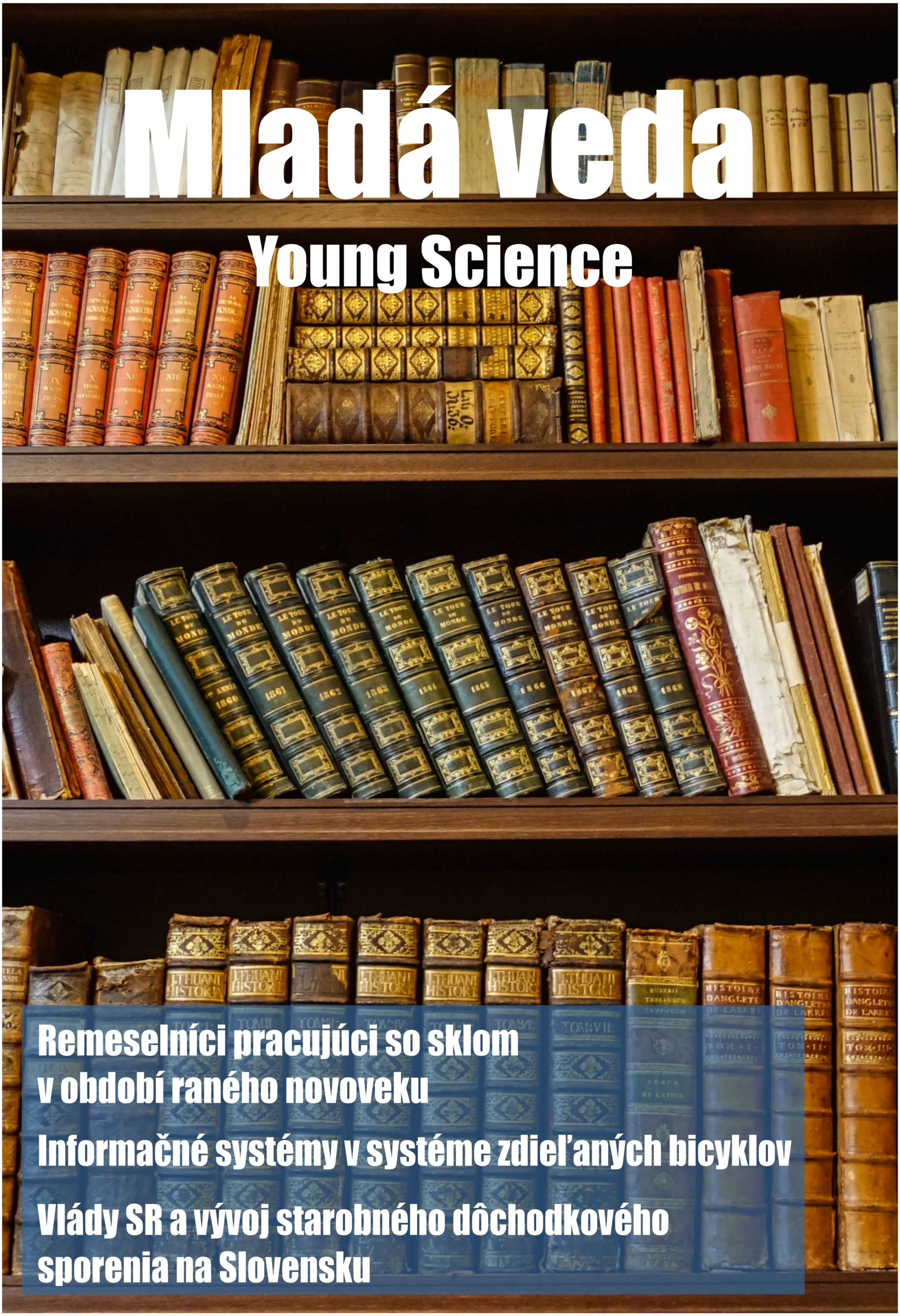

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EFFECTS OF GLAZING COLOR ON NON-VISUAL QUALITY OF DAYLIGHTING OF OFFICE ROOM

EFEKTY FARBY ZASKLENIA NA NEVIZUÁLNU KVALITU DENNÉHO OSVETLENIA KANCELÁRIE

Peter Hartman, Peter Hanuliak [1]

Obaja autori pôsobia ako odborní asistenti na Stavebnej fakulte STU v Bratislave. V rámci svojej vedeckej činnosti sa venujú aplikovanému výskumu vplyvu tieniacich zariadení na nevizuálne účinky svetla na človeka.

Both authors work as assistant professors at the Faculty of Civil Engineering STU in Bratislava. As part of their scientific work, they are engaged in applied research on the effect of shading devices on the non-visual effects of light on humans.

Abstract

Since the glazing system as part of building envelope represents the connection between outside and inside environment, it has a great effect on the room´s spectral power distribution. There were prepared two office rooms, room "A" and room "B" with the same dimensions and color of surfaces except fenestration. Room "A" has standard clear glazing and room "B" has the same window equipped with spectral filter "Orange 50 UV that cuts out the short wavelengths of the light. These wavelengths are most effective for non-visual effects of light on humans in most lighting scenarios and therefore distinct differences were obtained in levels of Equivalent Melanopic Lux (EML) and Melanopic Equivalent Daylight Illuminance (M-EDI) as metrics used to describe the non-visual effects of light.

Key words: melanopic lighting, wellbeing, daylighting

Abstrakt

Vzhľadom k tomu, že zasklenie, ako súčasť obvodového plášťa budovy, predstavuje spojenie medzi vonkajším a vnútorným prostredím, má veľký vplyv na spektrálne zloženie svetla v interiéri. Článok popisuje extrémnu situáciu, kedy sa porovnáva účinok číreho zasklenia v referenčnej miestnosti a spektrálny filter v testovacej miestnosti, ktorý účinne odfiltruje krátke vlnové dĺžky svetla. Tieto vlnové dĺžky sú najefektívnejšie pre nevizuálne účinky svetla na človeka vo väčšine svetelných scenárov, a preto boli dosiahnuté zreteľné rozdiely v úrovniach Ekvivalentného Melanopického Lux-u (*EML*) a Melanopickej Ekvivalentnej Dennej

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Osvetlenosti (*M-EDI*) ako hodnotiacich parametrov, ktoré boli použité na porovnanie miery účinku nevizuálnych účinkov svetla.
Kľúčové slová: melanopické osvetlenie, svetelná pohoda, denné svetlo

Introduction

A productive workspace should be designed in the way to provide people to do their best work and maintain their health. Office lighting is imperative to the productivity of employees, where correct lighting helps to combat fatigue and enhances wellbeing. Besides large market of electrical devices providing artificial light, which can be designed to almost all desired scenarios, still the proper design of daylighting should play the key role. We are used to evaluate daylighting through visual appearance of the spaces and also through metrics that are focused on providing adequate lighting for visual tasks and to avoid visual discomfort.

However, new standards are here to set also the requirements for non-visual effects of the light. Improper light environment (low light levels, spectral composition, bad timing, etc.) influence number of physiological and psychological functions.

Visual and non-visual system of human´s light perception differs in many parameters, where standard photometry used for visual system cannot be simply adopted to describe how the light is effective to the biological systems.

The effect of the light on human biology is cumulative and consists of these basic characteristics (1):
-the amount of the light (light levels),
-the quality of the light (spectral power distribution),
-timing,
-duration (exposition to the light),
-light history (light parameters prior to the evaluated time).

Various specific models were introduced to evaluate the light environment in connection with its non-visual effects. For example circadian stimulus (CS) (2), α-opic *EDI* (Equivalent Daylight (D65) Illuminance) (CIE) or *nvRD* (non-visual Direct-Response) were introduced during last years.

Recently discovered retinal ganglion cells, which are the most sensitive to short-wavelength (blue) part of the light spectrum represents the most powerful input sensors for regulation of human biological clocks and entraining the human circadian system (3). A new international standard, CIE S 026:2018, (4), defines spectral sensitivity functions that describe optical radiation for its ability to stimulate each of the five α-opic retinal photoreceptor classes that contribute to non-visual effects and functions of light in humans via intrinsically-photosensitive retinal ganglion cells (ipRGCs).

Lucas et al. (5) proposed a system of α-opic metrics, where illuminance is quantified according to its effective impact for each of the five known human opsins. This approach has now been formalized, as an SI-compliant system of metrology, whereby the α-opic values are equal to photopic illuminance for natural daylight (equivalent daylight illuminance; *α-EDI*).
The evaluation of biological effect of the light became also a part of the WELL Building Standard (6), which aims at the measurement, evaluation and monitoring of the buildings and

their effect on health and wellbeing of its inhabitants or users. This system incorporates a new metric, equivalent melanopic lux (*EML*), which is directly connected with the properties of spectral sensitivity of retinal ganglion cells, specifically for melanopsin. The WELL Building Standard has also started to adopt part of *α-EDI*, the Melanopic Equivalent Daylight Illuminance (*M-EDI*). The ratio between *M-EDI* and *EML* is a constant value, about 0.91. The current adaptation of *M-EDI* in WELL Building Standard is a supplement for *EML* and we used them to evaluate our measured data. For further analysis, a more complex model of *α-EDI* should be used.

Measurement devices

During experimental measurement were used two types of devices. The first was Spectrophotometer Konica Minolta CM-5, which was used for measurement of spectral reflectance and spectral transmittance of material samples, as can be seen in Fig. 1. The device measures spectral properties with increment step of 10 nm. Final courses of spectral transmittance and reflectance are showed in Fig. 2. with spectral luminous efficiency $V_{(\lambda)}$ and also curve "$WELL_{(\lambda)}$" from the WELL Building Standard with the peak in 490 nm.

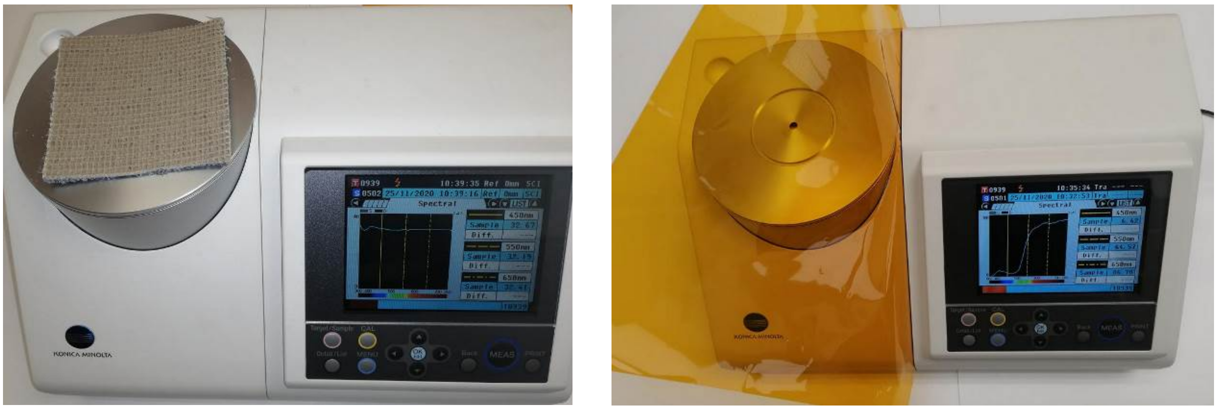

Figure 1 – Spectral properties of samples (grey carpet), on the left and spectral filter Orange 50 UV, on the right
Source: Author

Spectral properties of samples were calculated for total transmittance and total reflectance using $V_{(\lambda)}$ and $WELL_{(\lambda)}$ according formulas 1-4.

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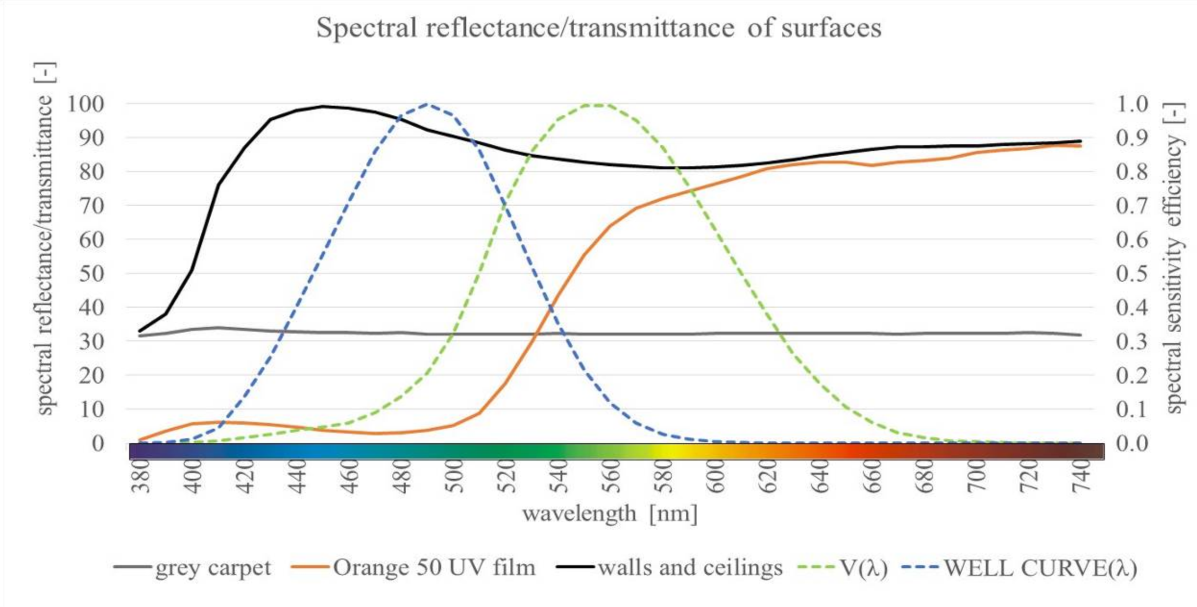

Figure 2 – Spectral transmittance and spectral reflectance of samples
Source: Author

$$\tau_V \frac{\sum_{\lambda=380nm}^{\lambda=780nm} D_\lambda \tau_{(\lambda)} V_{(\lambda)} \Delta_\lambda}{\sum_{\lambda=380nm}^{\lambda=780nm} D_\lambda V_{(\lambda)} \Delta_\lambda} \quad (1)$$

$$\tau_{(MEL)} \frac{\sum_{\lambda=380nm}^{\lambda=780nm} D_\lambda \tau_{(\lambda)} WELL_{(\lambda)} \Delta_\lambda}{\sum_{\lambda=380nm}^{\lambda=780nm} D_\lambda WELL_{(\lambda)} \Delta_\lambda} \quad (2)$$

$$\rho_V \frac{\sum_{\lambda=380nm}^{\lambda=780nm} D_\lambda \rho_{(\lambda)} V_{(\lambda)} \Delta_\lambda}{\sum_{\lambda=380nm}^{\lambda=780nm} D_\lambda V_{(\lambda)} \Delta_\lambda} \quad (3)$$

$$\rho_{(MEL)} \frac{\sum_{\lambda=380nm}^{\lambda=780nm} D_\lambda \rho_{(\lambda)} WELL_{(\lambda)} \Delta_\lambda}{\sum_{\lambda=380nm}^{\lambda=780nm} D_\lambda WELL_{(\lambda)} \Delta_\lambda} \quad (4)$$

where

$\tau_{(\lambda)}$ –spectral transmittance by CM-5 [W/m^2/nm],

$\rho_{(\lambda)}$ –spectral reflectance by CM-5 [W/m^2/nm],

$D_{(\lambda)}$ –spectral composition of D65 [W/m^2/nm],

$\Delta_{(\lambda)}$ –wavelength [nm],

$\tau_{(V)}$, $\tau_{(MEL)}$–total photopic, melanopic transmittance of samples [–],

$\rho_{(V)}$, $\rho_{(MEL)}$–total photopic, melanopic reflectance of samples [–].

grey carpet		**spectral filter Orange 50 UV**		**walls and ceiling**	
Total reflectance		**Total transmittance**		**Total reflectance**	
$V_{(\lambda)}$	$WELL_{(\lambda)}$	$V_{(\lambda)}$	$WELL_{(\lambda)}$	$V_{(\lambda)}$	$WELL_{(\lambda)}$
0.3223	0.3236	0.5078	0.1114	0.8423	0.9213

Table 1 – Calculated values of total transmittance and reflectance samples according $V_{(\lambda)}$ and $WELL_{(\lambda)}$
Source: Author

The second device, used during experimental measurement, is spectrophotometer Konica Minolta CL500A, Fig. 3. The CL500A measures spectral power distribution (*SPD*) for the whole visible range [380-780 nm] with increment step 1 nm, also photopic illuminance levels and complex of parameters used in colorimetry, such as color rendering index R_1-R_{15}, R_a index and correlated color temperature *CCT*. During the measurement, there were used three devices in combination with tripod and data logging computer. The measures were photopic illuminance levels E_V and Spectral Power Distribution *SPD*, which was applied in additional calculation for equivalent melanopic lux *EML*.

Figure 3 – Spectrophotometer Konica Minolta CL500A on tripod
Source: Author

Description of experiment

The experimental measurement was done in 3rd of November in the morning at 8:30 AM. Two unfurnished identical office rooms "A" and "B" with white walls and ceiling and grey carpet were measured for changes in daylight spectral properties. Room "B" was equipped with spectral filter Orange 50 on fenestration. Different view through fenestration and effect of spectral filter in rooms "A" and "B" can be seen in Fig. 4.

Figure 4 – View through clear glazing, on the left, and spectral filter, on the right
Source: Author

The first of spectrophotometers CL500A was fixed outside, the second and third measuring devices were fixed to tripod (Fig. 5) in the height of 1200 mm above floor in each room. During the measurement, there were selected six device´s sensor positions in different distances from window. Three positions (1x, 2x and 3x) were directed toward window and three positions (1y, 2y and 3y) were directed to wall, as can be seen in Fig. 6. The second and the third device CL500A both fixed to tripod in rooms were simultaneously repositioned from one to another position according plan in Fig. 6. During every measurement external *SPD* and E_V levels were recorded with the first device CL500-A fixed outside. From the values of *SPD* were calculated *M-EDI* and *EML* levels.

Figure 5 – Overcast sky during measurement, on the left and view on measurement –room "B" in the middle and room "A" on the right.
Source: Author

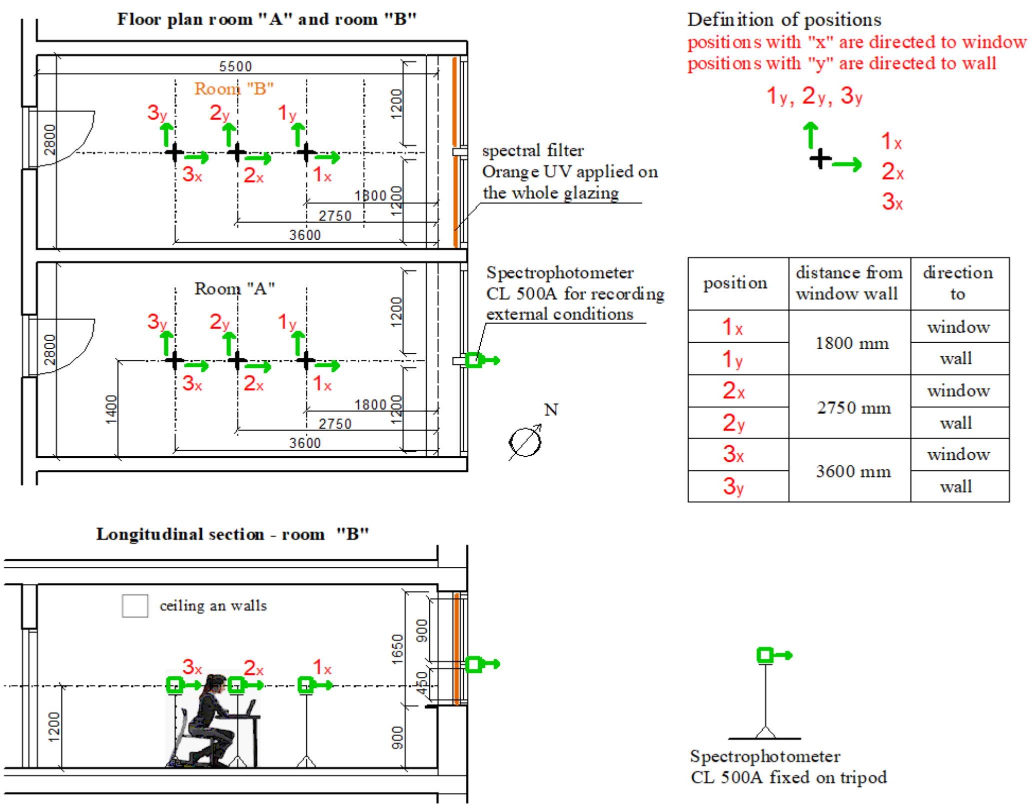

Figure 6 – Experimental scheme layout. Positions and location of devices
Source: Author

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Results of *SPD* measurement in rooms and positions

The *SPD* courses from measurement in room “A” and room “B” for all of the positions are shown in Figs. 7-9. The external *SPD* course during measurement is shown in Fig. 10. Every graph with *SPD* compares the courses measured in the same distance from window wall and both of direction, to window (with sub-label “$_x$”) and wall (with sub-label “$_y$”) in room “A” and room “B”. The courses are showed together with the spectral luminous efficiency $V_{(\lambda)}$ and $WELL_{(\lambda)}$ curve.

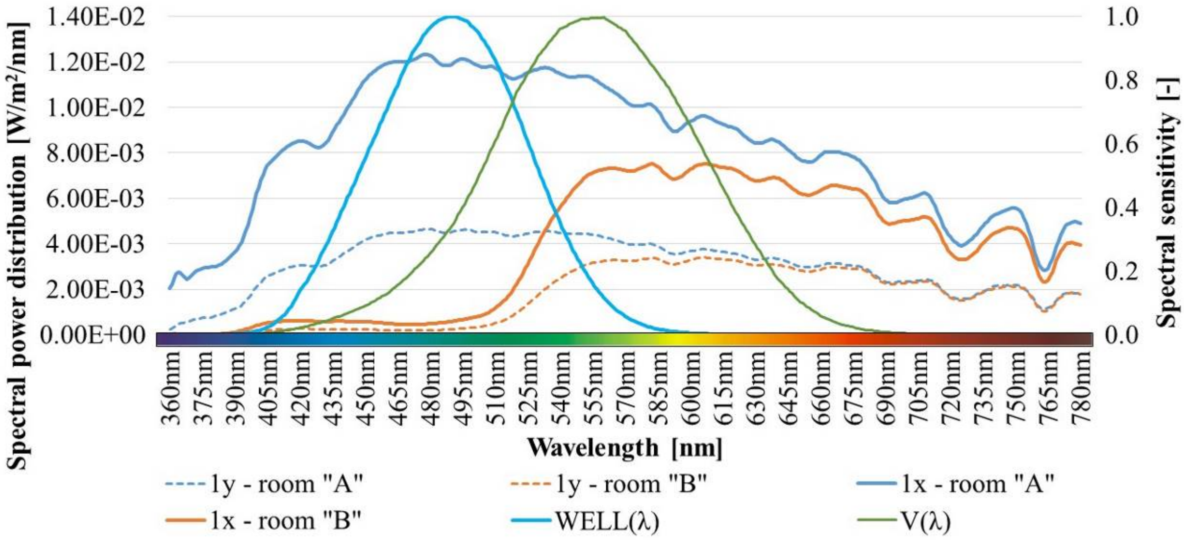

Figure 7 – Comparison of result of *SPD* in room “A” and room “B” in the positions 1_x and 1_y
Source: Author

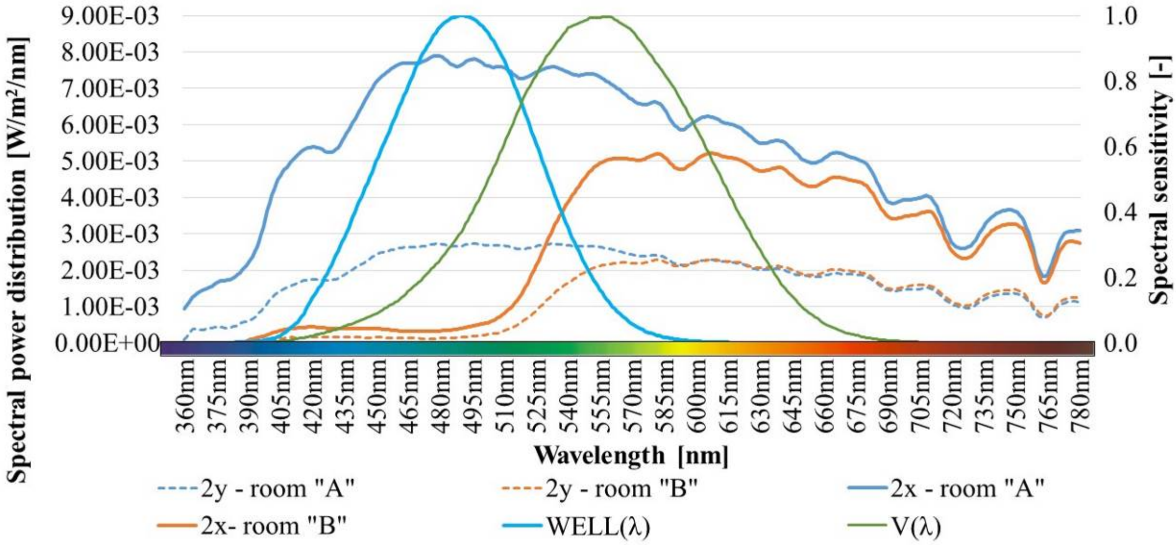

Figure 8 – Comparison of result of *SPD* in room “A” and room “B” in the positions 2_x and 2_y
Source: Author

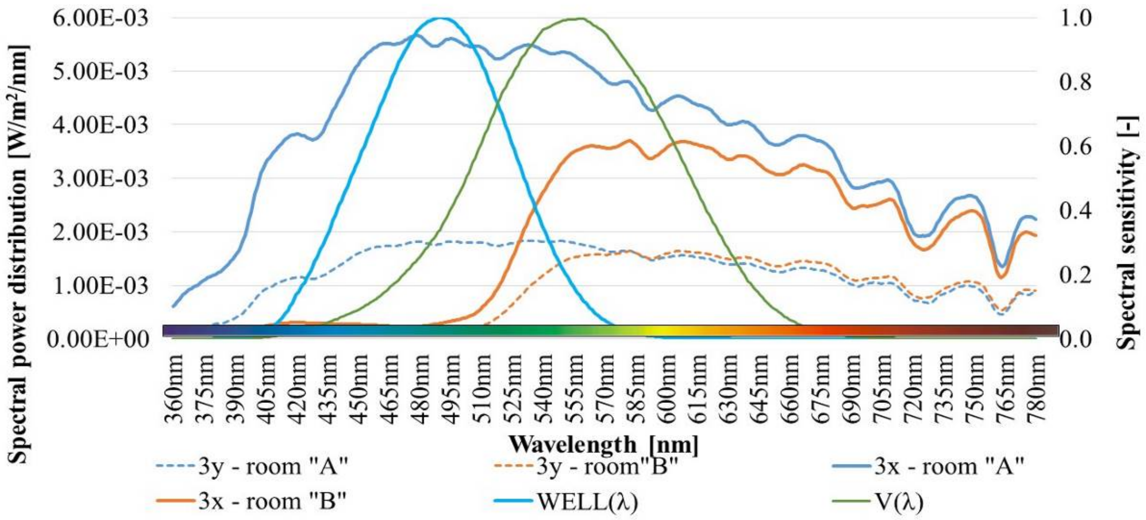

Figure 9 – Comparison of result of *SPD* in room “A” and room “B” in the positions 3_x and 3_y
Source: Author

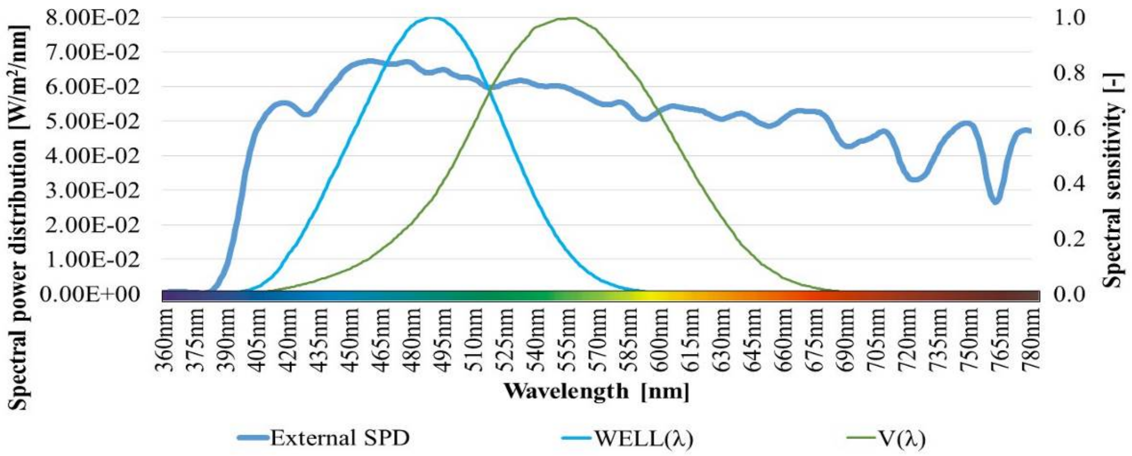

Figure 10 – External *SPD* level measured during the experiment
Source: Author

Finally, there are presented numerical results for photopic illuminance E_V, *M-EDI(D65)* and *EML* for both of room and all positions, Fig. 11 and relative ratio values in room “B” compared to room “A”, Fig. 12.

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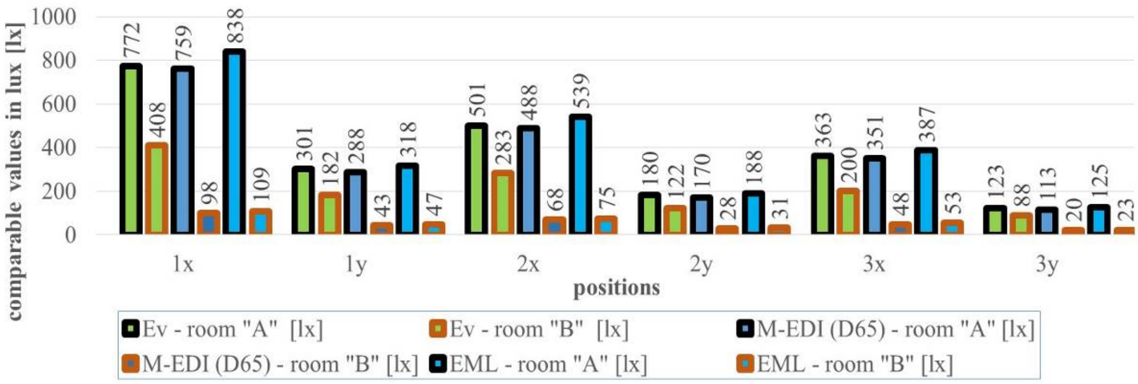

Figure 11 – Comparison of *EV, M-EDI(D65) and EML* for rooms "A" and "B" in all positions
Source: Author

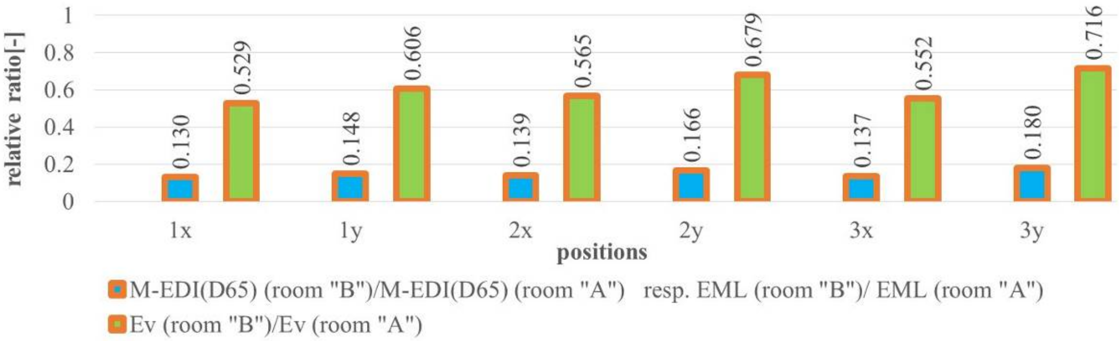

Figure 12 - Relative ratio values of photopic illuminance level E_V and *M-EDI(D65)* resp. *EML* levels measured in room "B" compared to values measured in room "A" in every position
Source: Author

An additional calculation was made to illustrate strong effect of spectral filter preventing penetration of blue dose of light inside room "B". As evaluation parameter, a partial irradiance in wavelength range 380 nm - 530 nm, most effective to non-visual stimulation and the irradiance in the whole visual spectrum range was compared with the same parameters measured outside, with the first spectrophotometer, Fig. 13.

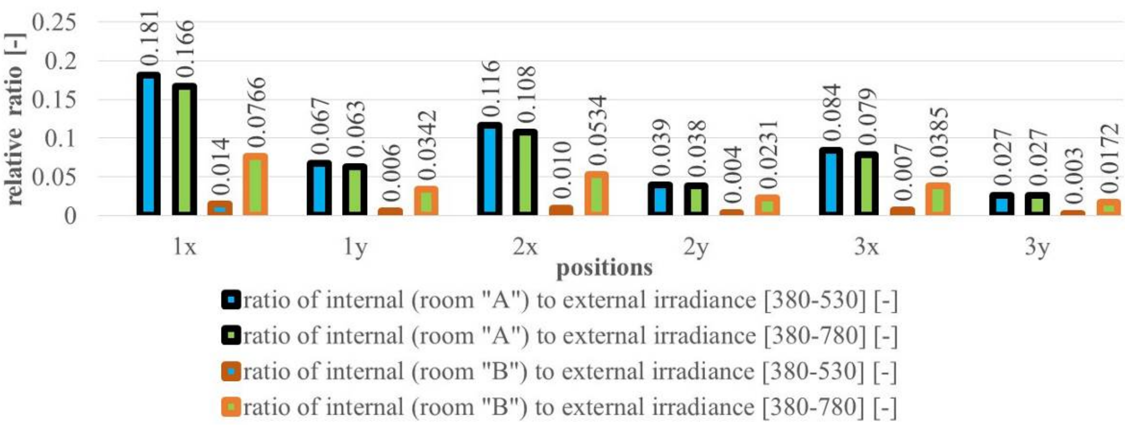

Figure 13 - Comparison of ratio of partial irradiance in wavelength ranges [380-530 nm] and irradiance [380-780 nm] measured in room "A" and room "B" in every position compared to the same parameters measured outside
Source: Author

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As was expected, the values are very low in comparison with external *SPD* conditions, but evaluation that is more important is a comparison between relative values in room “B” and room “A”, Fig. 14.

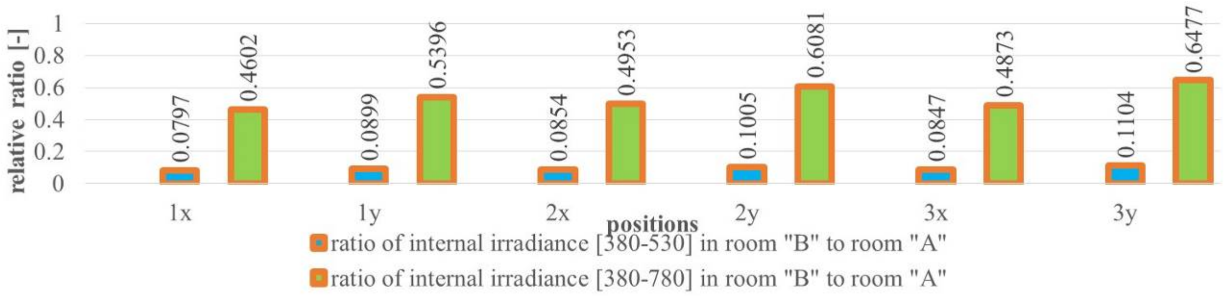

Figure 14 - Comparison of relative ratio of spectrum doses for wavelength ranges [380-530 nm] and [380-780 nm] measured in room “B” and compared to values measured in room “A” in all of the positions
Source: Author

Conclusion

Modern architecture is frequently focused on the effort to draw attention on visual appearance and can lead to design containing colorful surfaces including the fenestration. Presented experiment demonstrated still evolving technique for possible evaluation of non-visual light stimulation. This procedure was applied for testing inappropriate indoor light conditions caused by spectral filter in fenestration avoiding penetration of short wavelengths. According formulas and procedure, there were calculated non-visual parameters melanopic equivalent daylight D65 illuminance *M-EDI(D65)* and equivalent melanopic lux *EML* levels in typical positions. As was expected, spectral filter effectively filtered blue dose of daylight spectrum, which is dominating in maintenance of non-visual stimulation. This strong filtering effect is noticeable in courses of *SPD* and also the results of the comparison of relative ratios of irradiance in range 380 nm-530 nm. Subsequently, the values of *EML* are noticeable lower in room “B”, in comparison with values in room “A”. Numerically, they range from 13 % for position 1_x to 18 % for position 3_y. In the same time, the ratios of E_v in room “B” reached the levels from 53 % for the position 1_x to 72 % for the position 3_y. The person may not to realize the presence of inappropriate non-visual stimulation when sufficient visual condition are achieved. Unlike instant visual performance, the insufficient non-visual stimulation can be showed over longer time period.

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