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Spectrally Tuneable LED Lighting Simulator Laboratory Room at University of Pannonia

Abstract. *In our research laboratory – first in Europe – two laboratory rooms have been developed, which are equipped with spectrally tuneable LED lighting system. This lighting system contains 17 kinds of narrow-band colour LEDs (having peaks between 410nm and 690nm) and 3 kinds of phosphor white LEDs. Visual experiments carried out so far in lighting booths can be adapted into the real-size experimental environment, which describes real situation. In case of full-scale experiments, observer is able to do psycho-physical experiments with full immersion.*

Streszczenie. *Zaprojektowano i wykonano - pierwsze w Europie – laboratoryjne pomieszczenie ze spektralnie strojonym światłem LED. System składa się z 17 wąskopasmowych diod (między 410 nm I 690 nm) oraz trzech fosforowych białych diod. (**Laboratoryjne pomieszczenie w Uniwersytecie Panonia z widmowo strojonym oświetleniem LED**)*

Keywords: Solid state lighting, Tuneable LED, LED, Colour rendering, Colour quality
Słowa kluczowe: oświetlenie LED, charakterystyki widmowe, zmiana charakterystyki widmowej oświetlenia LED

Introduction

One of the most important phases of light source development is the optimization of its spectral power distribution (SPD). Light source SPD defines not only the luminous efficacy of the light source but also the colour appearance of our environment and has an effect on our hormone system and our alertness as well.

An old claim of light source manufacturers is to get pre-manufacturing information about colour quality parameters of light source with the help of visual experiments. Before the appearance of LEDs manufacturers had only limited possibilities for spectral optimization because of technological restrictions.

Description of tuneable LED lighting laboratory rooms

At University of Pannonia, two full scale experimental rooms (1 kitchen and dining room, 1 living room) have been realized. Ground plan of these rooms can be seen in Fig. 1. Walls of kitchen and dining room area have been painted to white, while the walls of living room area have been painted to pale yellow. Spectral reflectance of walls has been measured and will be discussed later. To be able to keep the temperature of rooms stable, both rooms have been equipped with air-condition systems. Total darkening of both rooms is possible.

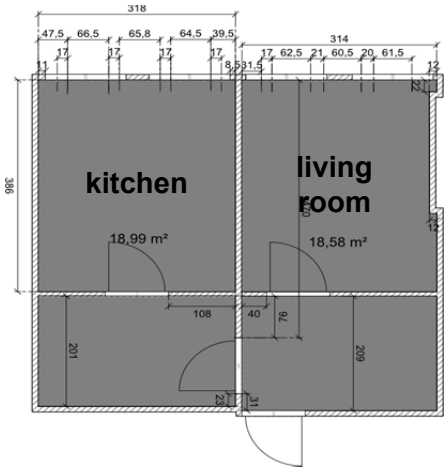

Fig. 1. Ground plan of full scale laboratory rooms with control rooms.

Both of the rooms have been equipped with reference light sources and tuneable LED light sources as test light sources. Fig. 2. shows the living room, Fig. 3. shows the kitchen and dining room area. Reference and test luminaires are specially built with the size of 60 x 60 cm (8 – reference, 8 test sources, 4-4 in each room).

Fig. 2. Full scale laboratory room simulating living room.

Fig. 3. Full scale laboratory room simulating kitchen and dining room.

Reference lamps

There are 4 reference luminaires in one laboratory room. One reference luminaire contains 9 pieces of cool beam halogen lamps at warm-white (CCT=2856K) colour temperatures. In case of neutral (CCT=4000K) colour temperature Solux halogen lamps have been used. To

achieve as homogeneous light distribution in the room as possible, a diffuser is used in each luminaire. Spectral power distribution (SPD) of halogen lamps and Solux lamps (with diffuser) can be seen in Fig. 4. Voltage can be controlled in order to keep the CCT of lamps constant.

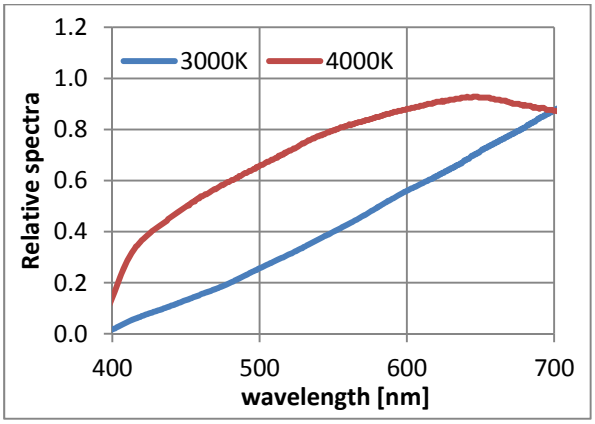

Fig. 4. Spectral power distribution of halogen reference lamps.

Test lamps

Test lamps are driven with 16 Power Supply Units, each have 24 independent channels. Forward voltage of each kind of LEDs has been measured to evaluate the maximum number of LEDs which can be connected in series to optimize the number of PSUs. Into each luminaire 24 LEDs with the same peak wavelength have been built-in (12 LEDs/ PSU channel, 2 channels with the same peak wavelength), 480 LEDs in total. 17 different colour LEDs have been used (mainly Osram Golden Dragon LEDs and some from other manufacturers) and 3 kinds of white phosphor LEDs (Osram Oslon LEDs). Fig. 5. shows the SPDs of the different LEDs built-in into the tuneable LED light source. Extreme blue with 410 nm peak is important because of the further investigation of the effect of S Cone and ipRGC (Intrinsically Photosensitive Retinal Ganglion Cells) excitation on perceived brightness and circadian rhythm. Extreme red with 670 nm and 690 nm peaks are important because of achieving and testing SPDs with extremely high colour rendering index and improving visual contrast. These two peak wavelengths will also help us to approach the SPD of Daylight illuminants.

Experimental Procedure

We conducted a pilot experiment series with a limited number of observers to check their acceptance of illumination with different correlated color temperature. We simulated three groups of spectra with different correlated color temperatures, the chromaticities of the lights in one group (A) was on the Planckian curve ($\Delta uv = 0$), the other group (B) of lights had chromaticities above the Planckian curve ($\Delta uv > 0$), while the third group had it's chromaticities below the Planckian curve ($\Delta uv < 0$). Several observers were seated together in the laboratory simulating a living room. The observers saw the different lights for about 20 seconds each iterated several times and had to put the lights in the order of their general preference. As a second task they had to choose the most preferable light regarding different properties like britghtness, warmness, relaxing, alertness, and the most mood enhancing (+++).

The SPD of the different lights was calculated using an Excel workbook where the Solver conditions were set in a way that selected colorimetric properties (CIE Color Rendering Index – CRI [1], Feeling of Contrast Index – FCI [2], ganglion cells (ipRGC)[3] excitation) could have been kept between given limits. Fig. 6. shows the resulting spectra and Fig. 7. shows the chromaticity co-ordinates around the Planckian curve. Table 1 summarizes the colorimetric properties of the spetra used in the experiment.

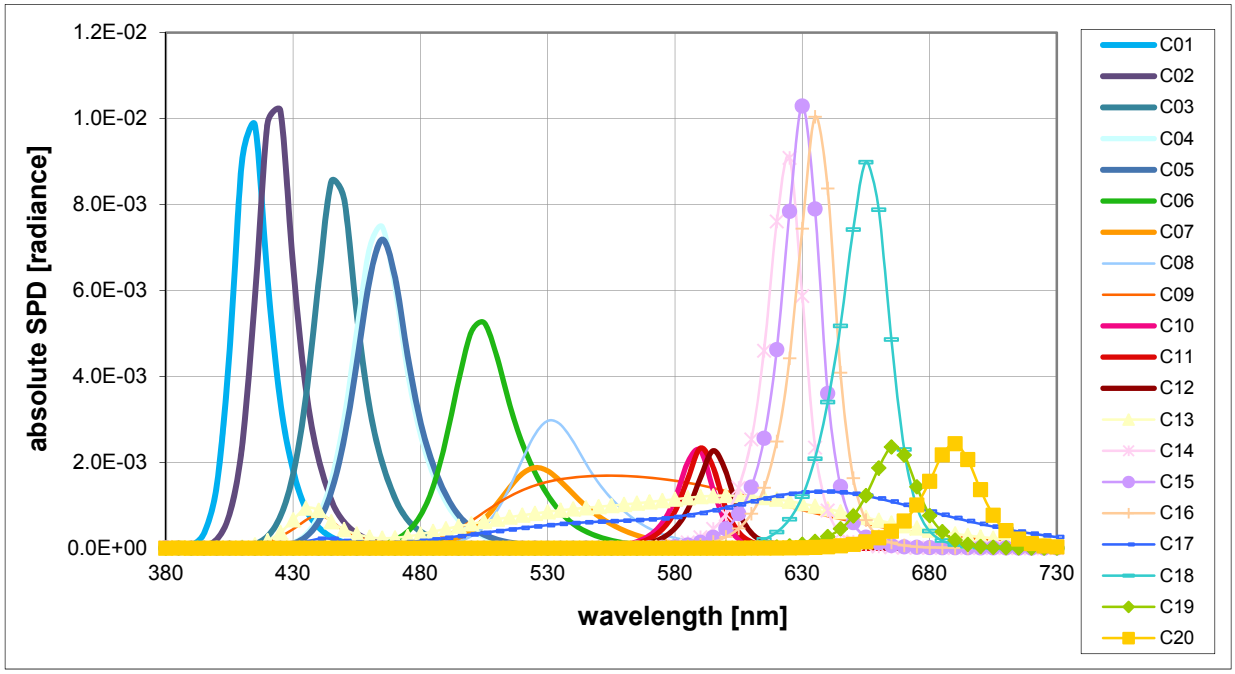

Fig. 5. SPD of LEDs built-in into the tuneable LED light source.

Table 1. Summary of the colorimetric properties of the spectra used in the different light groups of the experiment

	Light group A (Δ*uv* = 0)					Light group B (Δ*uv* > 0)				Light group C (Δ*uv* < 0)			
	AL1	**AL2**	**AL3**	**AL4**	**AL5**	**BL1**	**BL2**	**BL3**	**BL4**	**CL1**	**CL2**	**CL3**	**CL4**
X	134	132	130	127	126	128	124	122	110	133	130	126	126
Y	**120**	**120**	**120**	**120**	**120**	**116**	**116**	**117**	**111**	**117**	**118**	**117**	**120**
Z	38	43	47	53	56	27	35	40	45	42	49	52	67
x	0.459	0.448	0.436	0.424	0.417	0.471	0.451	0.436	0.415	0.455	0.436	0.429	0.402
y	0.411	0.407	0.404	0.400	0.398	0.428	0.422	0.420	0.417	0.401	0.398	0.396	0.384
TCC	**2705.0**	**2855.9**	**3004.9**	**3204.9**	**3304.9**	**2676.3**	**2909.1**	**3138.6**	**3500.8**	**2686.1**	**2964.3**	**3075.0**	**3513.6**
Δ*uv*	0.000	0.000	0.000	0.001	0.001	0.005	0.005	0.006	0.009	-0.003	-0.002	-0.002	-0.002

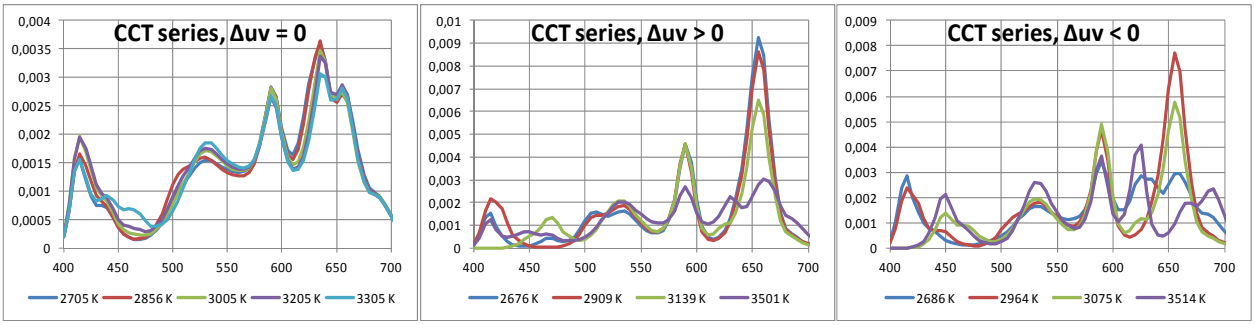

Fig. 6. SPD of CCT series representing different Δ*uv* values.

Table 2. Summarized ranking table of the light groups A, B and C for all observers

	Light group A (Δ*uv* = 0)					Light group B (Δ*uv* > 0)				Light group C (Δ*uv* < 0)			
	AL1	**AL2**	**AL3**	**AL4**	**AL5**	**BL1**	**BL2**	**BL3**	**BL4**	**CL1**	**CL2**	**CL3**	**CL4**
1st	0	5	8	2	0	0	13	1	1	2	11	2	0
2nd	4	6	2	3	0	6	0	1	8	7	2	1	5
3rd	2	4	3	5	1	8	1	4	2	5	1	4	5
4th	6	0	2	5	2	1	1	9	4	1	1	8	5
5th	3	0	0	0	12								

Table 3. Summarized rankings of the lights by different aspects for the three light groups for all observers

	Light group A (Δ*uv* = 0)					Light group B (Δ*uv* > 0)				Light group C (Δ*uv* < 0)			
	AL1	**AL2**	**AL3**	**AL4**	**AL5**	**BL1**	**BL2**	**BL3**	**BL4**	**CL1**	**CL2**	**CL3**	**CL4**
brightness	1	4	3	7	0	0	13	1	1	2	7	0	6
warmness	4	5	2	0	4	6	0	1	8	12	2	1	0
relaxing	6	7	2	0	0	8	1	4	2	11	2	2	0
alertness	1	0	6	7	1	1	1	9	4	1	6	0	8
+++	1	6	8	0	0	6	8	1	0	6	8	1	0

Results and Discussion

First the observers had to rank order the presented lights in each group based on a general preference. The result of this ranking is summarized in the a), b) and c) parts of Table 2. The table's cells are coloured according to their values columnwise (green - lowest value, red - highest value), so one can see which light was selected most frequently as the 1st, 2nd and so on. In group A the light identified by AL3 was most often selected as best, AL2 was ranked as the second best light in this environment. The AL5 light was selected almost always as the least liked one. In group B the BL2 light was most often selected as the most liked one, and BL3 was ranked in most cases as the fourth light. In group C the light CL2 was preferred the most and CL3 had the lowest preference. In Table 2 in each row the light with highest score gets the place in the order represented by the given row. (Table 2 AL3 has top score in row one as described above.).

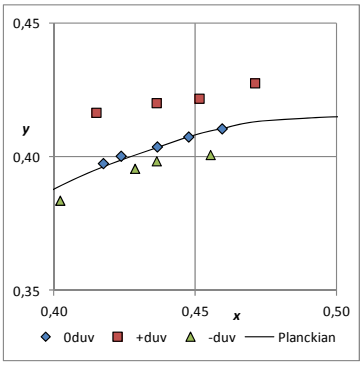

Fig. 7. CIE 1931 chromaticity co-ordinates of the lights used in the experiment.

The second task of the observers was to select the most preferable light based on the given aspect. The results (see Table 3) of this part of the experiment showed that there are aspects where some trends can be observed. In Table 3 the cells are colored rowwise. Lights with similar correlated color temperatures (CCT) are preferred for different aspects, like in aspect of *relaxing* light always one of the first light of a group was selected most often, which was always the light with the lowest CCT of the group. The other aspect where a peak in the selections is observable is the *alertness* where in all three groups one of the lights with higher CCT was selected. In the aspects *brightness* and *warmness* there is no correlation between the CCT of the light and the preference of the observers. This two aspects need further investigation. The last aspect in the table is the most *mood enhancing* property (+++) of a light. In this aspect in all three groups lights from the lower CCT region where selected as the most preferable lights.

Future Plans

As the main phase of full-scale acceptance studies, we will conduct experiments to find out end-users' acceptance and preferences for different LED spectra. In visual investigations, total of 40 observers from different age groups (20-40 years, 65 + years) and with different genders (20 male and 20 female) will participate. Observers will perform given tasks (kitchen work, reading books & papers, computer/Internet learning) for several hours in each lighting condition. During the investigations, observers will fill-in questionnaires at regular intervals, will do some objective tests for testing their well-being, fatigue, as well as physiological tests. Trade offs between light quality and efficacy will be also evaluated.

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