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Its content is organised in six parts: Editorial, Papers, Theses and Dissertations, Conferences and Symposiums, Information, Anniversary.

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Dorin BEU

One of the fascinating things about lighting is the sense of the community that you have in any conference or seminar concerning this topic. Most of the people I met in a lighting conference share the same passion about this subject and it is impossible to not find a common ground. Sometimes I feel that we are like a secret society, but without any special pin, salute or other exterior sign. After all, we are the *illuminati*, in the basic sense of this word. The feeling of community was very clear on a regional conference BalkanLight 2012, which was held in Belgrad in September this year. When someone hears about Balkans, man can thing never-ending disputes (I once had a company who did not want to sponsor a Balkanlight Conference, as the marketing director considering being a dangerous topic). In fact, the common ground I was talking at the beginning, made this event a special one. There were 82 peoples from 12 countries, and the atmosphere was great (many thanks to Miomir Kostic and Lidija Djokic).

Last months I was working for a FP7 proposal with 10 other partners both from academic and private sector. At the beginning, communication looked to be very difficult (some partners were old friends some not, some with physics, other with electrical, electronic or architectural background) but after two weeks the sense of community was there. Despite the huge numbers of pages that you have to read before, language and cultural barriers, busy weeks, sickness, we managed to submit on time. Of course, without Internet and EU Portal, this was mission impossible. The speed of changes is so high that we tend to forget that more than ten years ago it was science fiction.

When you see the evolution of TV from black and white to smart TV you have to think to a similar evolution for lighting. I think we will have in next year's smart luminaires and smart windows, both Web connected. The light distribution of this smart luminaires will adapt according to different detectors. Already you can replace the remote control with your smartphone, but I think that instead of presence detector or badge we will soon use the same device. On your smartphone you can select your preferences: illuminance level, color temperature and so on. But what if you forgot at home your mobile phone or if you refuse to have it all time?

Speaking of Community and Web; there are many lighting communities on net. I enrolled on some of them, and beside

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receiving tenth of e-mails daily and not being able to read all comments, at the end of the day I consider them very interesting, because you see what's new and learn from the others. For instance, there are many discussion regarding the new LED lamp replacement for the 100W classic incandescent lamp

There are important changes regarding Romanian National Lighting Committee and our journal. In the first case, professor Cornel BIANCHI (congratulations for his 80th anniversary) had become Honorary President and a Board of Directors with four members (Dorin BEU, Mihai HUSCH, Marilena MAIEREAN and Dan VATAJELU) will be in charge with the Lighting Committee. Every year one of the four will take the position of president.

Last, but not least, professor Florin POP has retired from the position of Executive Editor of Ingineria Iluminatului journal. Everyone who read this journal from the beginning was familiar with Florin activity and knew that he is the man behind the idea and the one who kept alive this journal from 1999. The position of Executive Editor will be held from this number by Professor Catalin GALATANU, from the Technical University Gheorghe Asachi of Iasi. Catalin accepted this challenge, as it need two to replace Florin.

Let's hope that we will manage to convince you that we keep the spirit of Ingineria Iluminatului.

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BENCHMARK REPORT ON THE PHOTOMETRIC AND ELECTRICAL PERFORMANCE OF LED REPLACEMENTS OF GU10 HALOGEN SPOT LAMPS

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Abstract: *Starting more than ten years ago, LED technology continuously penetrates the lighting industry with new products. The ongoing ban of several types of lamps works as a motivation to more and more manufacturers to design LED replacements for most types of common used lamps. This paper presents the results of photometric and electric tests of various LED lamps that are promoted as replacements of halogen reflector lamps with GU10 base. These lamps are widely used most in commercial lighting. The tests and corresponding calculations were carried out in the Lighting Laboratory of National Technical University of Athens according to the European Standards. Some classic halogen lamps were also included in the tests as reference lamps for the comparisons. The first part of the paper describes the procedures and the methodology of the applied tests. The tests were divided into two categories, photometric and electric tests. The photometric measurements were luminous intensity, color temperature and color rendering index of each lamp. The performed electric tests were power quality measurements and determination of the dimming curves. All tested lamps were suitable for dimming. The second part of this paper illustrates the results of the photometric and the electric measurements and the corresponding calculations. The results were also compared with the technical specifications of the manufacturers. The tests show that the lamps produce the nominal luminous flux and the maximum luminous intensity. Issues are raised in colour rendering as well as in the power factor and the harmonic distortion of the current.*

Keywords: LED replacements, GU10, halogen, benchmark, photometric tests

1. Introduction

The technology of LEDs has increased rapidly in the past ten years. At the beginning, the luminous efficacy of LED was nearly 30 lm/W, while now days most of commercial available types reach easily 100 lm/W (bare led) [1]. Furthermore, the European Eco Design regulations will ban low efficacy lighting sources, including halogen lamps, from the market in the next years [2]. One characteristic type of the lamps that will also be banned in next years is the halogen PAR16 reflector lamp with

GU10 base. The above mentioned type of lamp was used for years not only in professional lighting but also in households. For these reasons the penetration of a huge number of LED lighting products in the market, such as modules, lamps and luminaries is rapid. However, the compact size, the warm colour and the excellent colour rendering are the strong advantages of halogen lamps. Many lamp manufacturers around the world introduced few years ago some LED lamps in order to replace the halogen one after their future ban. The effort of the manufacturers is still to develop a LED lamp with the same characteristics of the traditional halogen, such as dimming, color rendering index except from its low luminous efficacy. So, can the switch of halogen lamps to LED to be carried out without any misapprehension? The present paper tries to focus on this issue using experimental procedures.

2. Tested lamps

The tested lamps were selected between various models of branded GU10 LED lamps. These lamps claimed to be the replacements of the traditional 50 W Halogen GU10 reflector lamp. The products below were found in the market in February, 2012. The selection of the tested lamps was based on their photometric characteristics. The selected lamps are shown on Figure 1 and their electrical and photometric characteristics are shown on Table 1. Two lamps of each type (total 12 lamps) were used in the experiments.

Table 1 Characteristics of the tested LED lamps according to the manufacturers

		Toshiba	**Megaman**	**Philips**	**Sylvania**	**General Electric**	**OSRAM**	**Halogen**
Power	(W)	8.5	8.0	7.0	8.0	6.5	10	50
Luminous flux	(lm)	275	380	310	300	380	350	350
Luminous efficacy	(lm/W)	32	48	44	38	58	35	7
Beam angle	(°)	35	35	40	35	35	36	35
Max luminous intensity	(cd)	530	900	650	600	750	950	900
Colour temperature	(K)	3000	2800	3000	3000	2700	3000	2700
Colour rendering R_a		>80	>80	>80	>80	>80	>80	100

Philips Megaman G. Electric Toshiba Sylvania Osram Halogen

Figure 1 Photographs of the tested LED lamps and a typical Halogen reflector lamp.

3. Electrical measurements

The first step was to measure the electrical characteristics of the lamps. A FLUKE Norma 4000 power analyzer was used for this purpose. Each lamp was fitted to a bare GU10 socket that was connected to the power analyzer. A voltage stabilizer (230 V AC) was used as power supply. The lamps were not fitted to any housing or any type of luminaire in order to avoid thermal stress of LEDs.

Before the measurements, each lamp was operated for at least one hour. The measured electrical quantities where: supply voltage, lamp current, apparent power, active and reactive power, power factor and the total harmonic distortion (THD) of the current. Table 2 shows the results of the measurements. The last column contains the electrical characteristics of a typical 50 W halogen for a direct comparison.

Table 2 Measurement of the electrical characteristics of the tested LED lamps.

		Toshiba	**Megaman**	**Philips**	**Sylvania**	**General Electric**	**Osram**	**Halogen** *(typical)*
$\mathbf{V_{rms}}$	(V)	230	230	230	230	230	230	230
$\mathbf{I_{rms}}$	(mA)	55	49	46	42	34	44	220
P	(W)	8.7	7.7	7.0	8.2	6.6	9.6	50
S	(VA)	12.6	11.4	10.6	9.6	7.7	10.0	50
Q (capacitive)	(VAr)	9.1	8.4	8.0	5.0	4.0	3.0	0
PF		0.69	0.68	0.66	0.85	0.85	0.95	1.00
$\mathbf{THD_{current}}$	(%)	69	69	80	53	53	30	0

4. Photometric measurements

4.1 Measurement of the luminous flux

The measurement of the luminous flux was carried out using a goniophotomer (Figure 2). The first step was to measure the distribution of the luminous intensity of each lamp. Each measurement was performed in CIE C-planes with 15º steps of C-planes and 2.5º of gamma angles [3]. The lamps were left to operate until their luminous intensity stabilized. In some cases, this took more than one hour. The luminous flux was then calculated with integration of the above measurements. The result of the luminous flux measurement (averaged values from two measurements) are presented in Table 3.

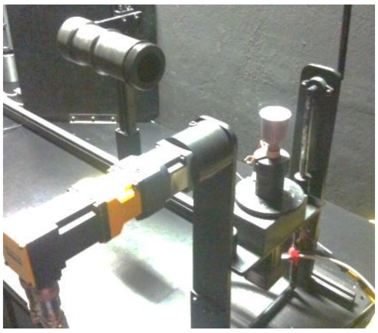


Figure 2 The goniophotometer for the measurement of the luminous intensity distribution of the lamps.

Table 3 Measured* and calculated photometric quantities of the tested LED lamps.

		Toshiba	Megaman	Philips	Sylvania	General Electric	Osram	Halogen *(typical)*
Luminous flux	(lm)	308	309	312	303	368	353	350
Luminous efficacy	(lm/W)	35	40	45	37	56	37	7
Maximum luminous intensity	(cd)	679	791	677	787	745	786	600

**Average values from measurement of two samples of each lamp type.*

4.2 Measurement of the spectral distribution

The spectral distribution was measured using a high precision spectrometer (ORIEL Instruments, MS260i 74086) with 1 nm step and the results are shown in Figure 3. The curves are normalized to the maximum spectral power of each measurement. Each sub-figure contains the spectra of two samples from each lamp type.

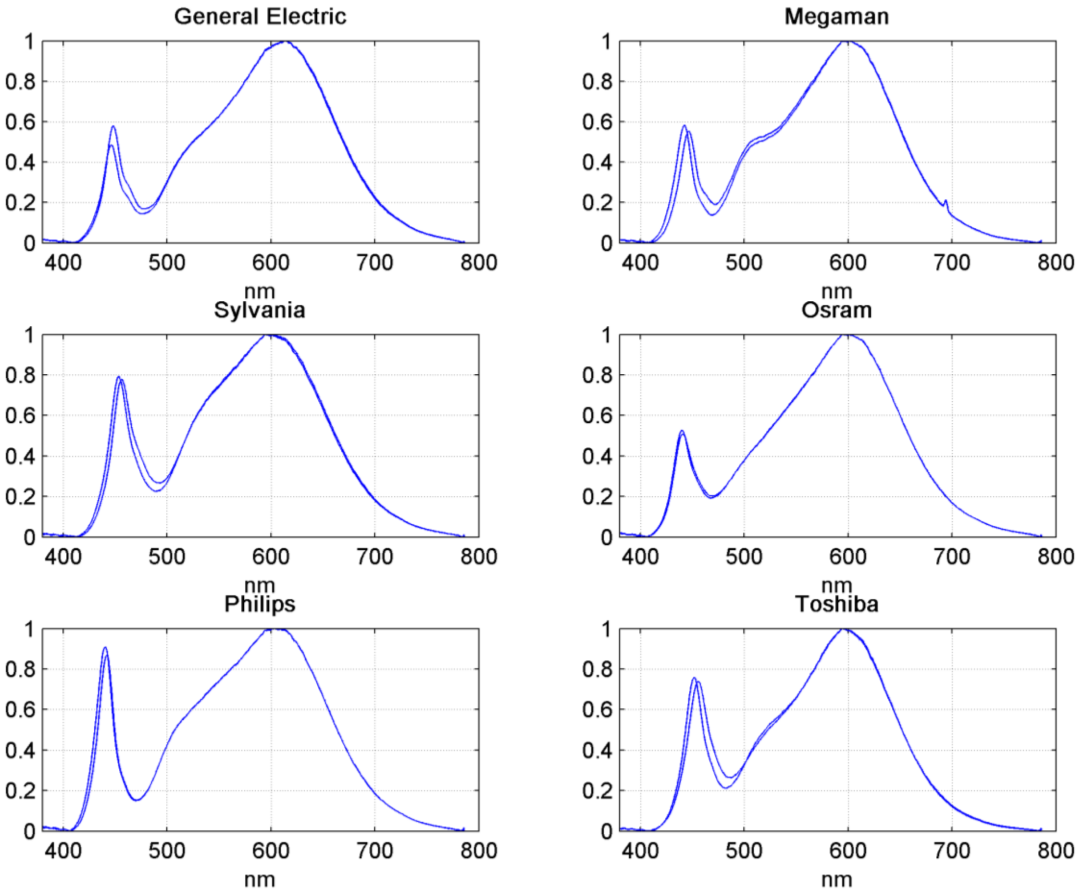


Figure 3 Measurement of the spectrum of 2 samples from each lamp type.

4.3 Colour temperature and colour rendering index

One of the most important factors of the selection of a lamp is the colour rendering index. In other words, in some cases, is needed to have an accurate reproduction of the colours inside a room using the artificial light. The halogen lamp, as an incandescent lamp, has excellent colour rendering index (R_a=100). The issue with the LEDs as well as with other light sources is their capability to produce accurate colours. This depends on lamp's spectral distribution. The measurement of the spectral distributions was performed in order to check the capability of each lamp for colour reproduction and to calculate the R_a index.

The R_a was calculated based on the rendering score of each lamp to each of 15 standardized CIE colour targets. In other words, it was tested how accurate the light source reproduces the colour of each standard target. The spectral reflectance distributions of these colour targets are given by CIE [4]. A representation of these 15 targets is shown in Figure 4.

The calculation of the rendering capability was performed using a dedicated script developed in MATLAB according to CIE method [5]. The inputs were the spectral distributions of the lamps and the colour targets while the output was the rendering score on each target as well as the total colour rendering index. The R_a index is calculated from the first 8 targets. The results of the calculations are shown in Table 4.

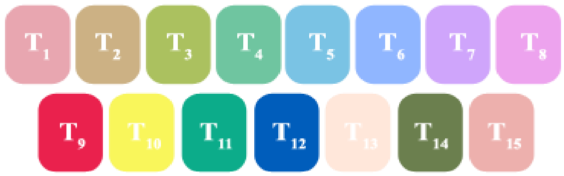


Figure 4 Representation of the colour of the 15 standard R_a test targets

Table 4 Colour rendering of the tested LED lamps

Target	Toshiba	Megaman	Philips	Sylvania	General Electric	Osram
T_1	80	80	84	82	85	80
T_2	91	89	89	91	91	88
T_3	95	98	92	95	96	96
T_4	78	83	85	79	86	81
T_5	80	81	84	81	85	80
T_6	87	88	86	86	89	85
T_7	81	85	86	85	87	85
T_8	58	60	70	66	70	61
T_9	3	5	27	19	31	7
T_{10}	78	77	74	75	80	73
T_{11}	76	83	87	75	86	80
T_{12}	68	75	74	62	75	73
T_{13}	83	82	85	84	87	81
T_{14}	98	99	95	97	97	98
T_{15}	74	72	79	78	80	72
R_a	**81**	**83**	**85**	**83**	**86**	**82**

Average values from measurement of two samples of each lamp type. Best score is 100. R_a is calculated from Targets 1 to 8 [5].

The colour temperature of the selected lamps was measured using a Minolta CS-200 chroma meter. In each lamp, we measured the colour temperature in several circular areas (1 degree spot measurements) of its luminous surface and calculate an average value. The results are shown in Table 5.

Table 5 Measured* and calculated colour characteristics of the tested LED lamps.

		Toshiba	**Megaman**	**Philips**	**Sylvania**	**General Electric**	**Osram**	**Halogen** *(typical)*
Color temperature	(K)	2952	2954	3066	3143	2783	2958	2700
Color rendering index R_a		81	83	85	83	86	82	100

**Average values from measurement of two samples of each lamp type.*

4.4 Dimming

In most cases, especially in commercial use, lighting installations with halogen reflector lamps are equipped with dimming control. Thus, the tested lamps were selected in order to have the option of dimming. In case of mass replacement of halogen lamps with LED ones, it's more likely that the dimming control will remain the same. For this reason, the selected lamps were tested in a dimming circle from 230 V to 0 V using a common dimming circuit that does not affect the sinusoidal wave of voltage (autotransformer). The supply voltage was reduced in 5 Volt steps. The duration in each voltage level was about 10 minutes and the luminous flux and the active power were recorded (just before next voltage step) using a power analyzer. In this case, the luminous flux variation was calculated using the variation of the illuminance reading of an integrating sphere in which each lamp was placed. The sphere was kept open except of some seconds when the measurements were taken. The results of the dimming test for each lamp are shown in Figure 5. The abnormal behaviour of Osram samples means that these lamps require a dedicated Osram dimmer.

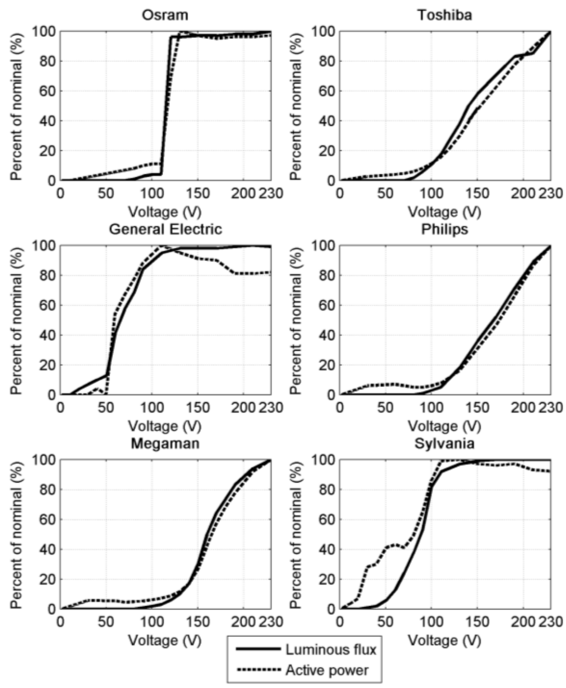
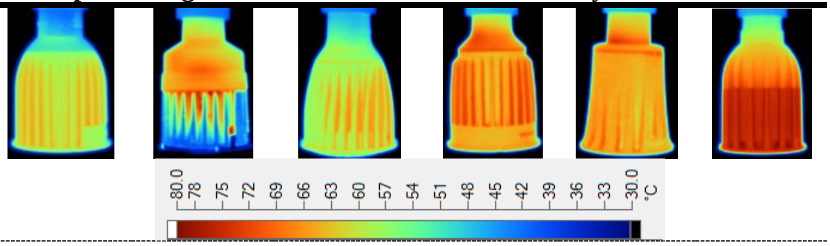


Figure 5 Dimming test results of the tested LED lamps.

Table 6 Thermal images and key temperatures of the tested LED lamps (common emissivity factor).



	Philips	Megaman	G. Electric	Toshiba	Sylvania	Osram
Average	58°C	58 °C	59 °C	66 °C	65 °C	70 °C
Minimum	40 °C	30 °C	45 °C	51 °C	58 °C	50 °C
Maximum	65 °C	77 °C	67 °C	73 °C	74 °C	80 °C

5. Thermal measurements

One important factor in both design and operation of a luminaire, is the management of the thermal load of the lamps. LEDs are producing a significant amount of heat, so a well designed cooling system is mandatory. As shown in figure 1, all LED lamps have a kind of heatsink design in the perimeter of their body in order to dissipate the heat off the LEDs. In order to see how these heatsinks manage the heat, the thermal distribution of each lamp was measured using a thermal camera FLUKE Ti10.

The lamps were left to operate mounted on a bare GU10 base until their temperature stabilized. The temperature of the laboratory during the test was 25 °C±3 °C.

The measured values of the average temperature on the surface of the lamps (in common colour scale), as well as the minimum and the maximum temperatures are shown in Table 6.

6. Conclusions

In terms of photometric quantities, luminous flux and maximum luminous intensities all lamps achieved similar or greater values than a common halogen 50 W lamp. The differences were strongly depended on the wattage class of each lamp. There is no common wattage classification between different brands. All tested lamps produced light of colour temperature very close to the claimed value by the manufacturer. Small differences were found between the two samples of each type but this was expected. One of the noticeable point of the measurements is the span of the luminous efficacy of the tested lamps. This value varies from 35 lm/W to 56 lm/W, which is due to different types of LEDs that manufactures are using, possible different current that LEDs are driven as well as different management of heat (see Table 6).

One weak point of the tested lamps was their colour rendering capabilities. As seen in Table 5, all lamps have R_a>80 (as expected) but the fact is their rendering scores on the colour targets. Figure 6 shows the variation of colour rendering scores of all lamps on each one of the 15 colour targets.

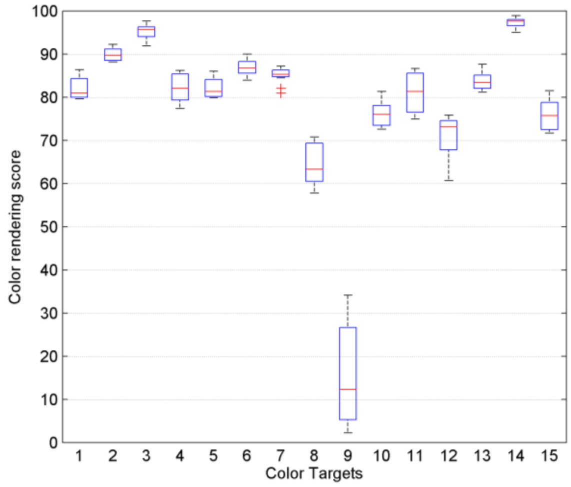


Figure 6 Distribution of rendering scores of tested LED lamps on each of the 15 colour targets.

In this diagram, each box represents the statistic results of the colour rendering score of all lamps in each colour target. On each box, the central mark is the median, the edges of the box are the 25th and 75th percentiles, the whiskers extend to the most extreme data points, and the outliers are plotted individually with red crosses. From this figure is obvious that most of the lamps are performing well (around 80) and with close scores on most of colour targets and excelled in few ones. In targets 8, 11 and 12 the variation of the rendering score is relevant big. The weakest point of these LEDs was the target T_9 which, according to Figure 4, is rich in red colour. In this colour, the scores varied from 3 to 31. This issue is not noticeable from the overall colour rendering index which in all lamps is above 80. The meaning of this score is that these lamps reproduce most types of red colours very poorly. This can be a significant disadvantage in cases where a good or better colour rendering is needed, like art galleries, clothes and vegetable stores and other. In those cases, specific LED replacement lamps with higher R_a (around 90) can be used with higher cost and still with not as excellent rendering capabilities as halogen lamp.

The last but not least issue of the tested lamps is their size. As shown in Figure 7, all LED lamps are at least 50% longer than the typical halogen lamp. Also, in terms of weight, the LED lamps are noticeable heavier. This could be an issue in cases where the halogen lamp fits tight inside the luminaires or in luminaires with aiming options that cannot manage the increased lamp weight.

Figure 7 Difference in size between LED lamps and a typical halogen lamp.

Regarding the electrical measurements (Table 2), the active power in all lamps was measured as expected. Two were the main points. First, the average/low power factor in some types. This will have no effect in installation where the apparent power in not under consideration but will limit the reduction of the electric cost in cases of consumers whom billing scheme includes apparent power. Second, the current's total harmonic distortion. This could be lead to power quality issues in installations where LED lamps are a large part of the installation.

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EVALUATION OF DISCOMFORT GLARE FROM LED LIGHTING SYSTEMS

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Abstract: *Along with concerns for energy efficiency, the increase in the efficacy of LEDs has accelerated the utilization of LED lighting systems in general lighting applications. In designing general lighting solutions with LED lighting systems, a very important aspect is visual comfort. Discomfort glare is a crucial component of visual comfort. The most widely used glare rating system is the Unified Glare Rating (UGR) system developed by the CIE The last addition to the current formulas evaluating discomfort glare have been made in 2002 and therefore do not include the novel developments in the field of lighting with the introduction of LEDs as interior lighting sources. The lighting market on the other hand is aiming at replacing incandescent lamps with LED retrofits. In this study, two important parts of the glare rating formulas, position index and apparent area are elaborated for LED light sources with non-uniform luminance distributions. For this aim, luminance measurements of an LED retrofit have been made and the results have been used for calculations and interpretations of the glare created by the light source. During the process, several important questions have been raised and the importance of further research on the subject of discomfort glare from LED lighting systems has been emphasized.*

Keywords: LEDs, discomfort glare, UGR, position index, apparent area.

1. Introduction

Lighting constitutes 19% of the World's and 14% of the European Union's total energy consumption [1]. With the 2020 energy initiative and the phase-out of incandescent lamps in Europe, energy efficient lighting technologies gained more importance. The EU has recently published the Green Paper "Lighting the Future – Accelerating the Deployment of Innovative Lighting Technologies", proposing to launch new policy initiatives in Europe on the deployment of Solid State Lighting Products [2]. Along with concerns for energy efficiency, the increase in the efficacy of LEDs has also accelerated the utilization of LED lighting systems in general lighting applications. In designing general lighting solutions with LED lighting systems, a very important aspect is visual comfort. It is crucial for the energy efficient lighting system to meet the necessary visual comfort conditions; without users being content with their lighting environment, the energy savings potential is of no use.

Discomfort glare is a very important component of visual comfort. CIE 117:1995 defines discomfort glare as “glare which causes discomfort without necessarily impairing the vision of objects”. The literature on glare includes different formulas and glare rating systems developed over the years with the introduction of different light sources into lighting applications. The most widely used glare rating system is the Unified Glare Rating (UGR) system developed by the CIE which combines features of the glare rating formulas of Einhorn and Hopkinson and also incorporates the Guth position index [3]. The UGR system was further developed in 2002 with CIE 147:2002, with new formulas and recommendations for the calculation of UGR for small, large and complex sources [4]. Unfortunately, this was the latest development on the UGR formula and therefore the current formulas do not include the novel developments in the field of lighting with the introduction of LEDs as interior lighting sources.

As been stated in the work of CIE TC 3-50 Lighting Quality Measures for Interior Lighting with LED Lighting Systems, for luminaires in which the LED distribution is clearly visible as in LED arrays or systems with optics, the small sized light sources with high brightness appear to be causing more glare than traditional light sources, making the utilization of the current UGR formulas inconvenient [5]. In this study, two important parts of the glare rating formulas, the position index and the apparent area are elaborated for LED light sources with non-uniform luminance distributions and the importance of further research on the subject for LED lighting systems is emphasized.

2. Unified glare rating

The CIE Unified Glare Rating (UGR) formula is given by:

$$UGR = 8log\left[\frac{0{,}25}{L_b}\sum\frac{L^2\omega}{p^2}\right] \quad (1)$$

and the UGR formula for small sources are given by:

$$UGR = 8log\left[\frac{0{,}25}{L_b}\sum 200\,\frac{I^2}{r^2p^2}\right] \quad (2)$$

where L_b is the background luminance in cd/m^2, L is the luminance of the luminous parts of each luminaire in the direction of the observer’s eye in cd/m^2, ω is the solid angle of the luminous parts of each luminaire at the observer’s eye in sr and p is the Guth position index for each luminaire, I is the luminous intensity toward the eye in cd, and r the distance between the observer’s eye and the light source in m.

The UGR formula for small sources, which is the category that includes the majority of LED lamps has been developed on the grounds that the original UGR formula produced results that would be deemed as ‘intolerable’ by the users even though the glare they caused was “somewhat tolerable”. Originating from this argument, the CIE report 147:2002 Glare from small, large and complex sources sets the size of a small source with a projected area A_p<0,005 m^2 (corresponding to a disk of 80 mm in diameter) equal to 0,005 m^2 and calculates the luminance of the source as:

$$L = \frac{I}{A_p} = 200 \cdot I \quad (3)$$

Looking at the size and the luminous intensity distributions of LED lighting systems, it appears that this addition to the UGR formula for small sources could be applicable. However, the UGR formula for small sources comes from the research of Paul et al., a study in which the glare source was a 200 W incandescent lamp [6]. Whether this research would apply for the LED lighting systems is a question mark.

3. Position index

Position index is defined as the change in discomfort glare experienced relative to the angular displacement of the source from the observer's line of sight [7]. An early study from 1925 by Luckiesh and Holladay showed that the glare sensation was changing in relation to the position of the light source in the visual field [8]. Luckiesh and Guth went further with this study in 1949 and created what they called the BCD criterion – the sensation at the borderline between comfort and discomfort. In their study, an extended visual field of uniform brightness and sources of circular geometry, uniform luminance distribution and constant spectrum were used. The subjects were initially asked to set the luminance of a test source directly in the middle of their field of view to a value that they found at the border of comfort and discomfort. From these luminance values, an average luminance value was calculated and this value was deemed as the BCD luminance. Using this luminance value, the BCD luminances of the sources as they were displaced at various angular distances from the line of vision were determined. The relationship between the obtained values was named as the position index [9]. In 2007, the study of Luckiesh and Guth was repeated by Kim et al. with similar conditions plus an addition of the lower visual field. The study showed a similar value for the BCD sensation but the position index values obtained from the study were smaller compared to Guth's position index [10].

In both of the aforementioned studies, the BCD luminance and the position index were determined using sources with uniform luminance distributions, a set circular geometry and a constant spectrum. When it comes to using LEDs as interior lighting elements, this is not the case. The biggest part of the LED market is aiming at replacing incandescent lamps with LED retrofits by bringing together a number of power LEDs to match the luminous flux of existing light sources and fitting these into the most suitable design that would allow for the suitable luminous distribution and correct thermal management. Other concerns include resemblance to current sources and a perfect fit for the existing electrical connections. In order to satisfy all these needs, power LEDs with very small sizes and very high luminances are arranged in different configurations, with or without optical systems, most of the time creating non uniform luminance distributions. Examples of luminance photos from two LED retrofits can be seen in Figure 1.

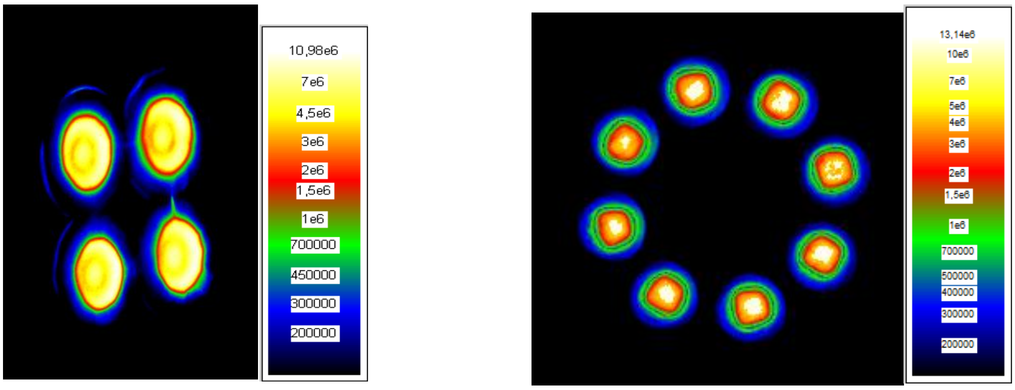


Figure 1 Examples of luminance distributions from LED retrofits systems

A study by Takahashi et al., examining the position index for a matrix light source where the luminance distribution is non-uniform, provided the results that for central vision, the matrix light source caused more discomfort glare than the uniform light source while the discomfort ratings for peripheral vision were similar from the non-uniform to the uniform source [11]. The study by Waters et al. examining non-uniform sources of luminance on the other hand showed again more glare in the central vision but less glare in the peripheral vision from the uniform source to the non-uniform source. The results of these two studies are contradictory for the peripheral vision, which constitutes an important part of the glare calculations considering interior lighting distances [12]. These issues rise the question of whether it is correct to use the position index of 1949 in the glare calculations made with the technology of today. It is important to emphasize at this point that further research on the position index should be made in order to ensure the correct utilization of UGR formulas for the prediction of glare from LED lighting systems.

4. Apparent area and the estimation of luminance

As been previously discussed, in calculating the UGR value from a light source, the background luminance, the source luminance, the solid angle and the position index are taken into consideration. The luminaire luminance, *L*, is generally derived from dividing the luminous intensity of the luminaire in the direction of the observer, *I*, to the projected area of the luminaire, A_p, as been given in formula (3).

The calculation of the luminance value in such a fashion induces the utilization of an average luminance value in the calculation of the glare rating index. For light sources with LEDs, due to the high luminances of the LED light source itself, taking the average luminance value into consideration constitutes a problem. While a retrofit which looks like an opal incandescent lamp, hiding the LEDs inside diffusing cover may have a uniform luminance distribution, the same is not true for systems in which the LEDs and the optics are visible. Going back to the luminance distributions given in Figure 1, it is possible to see the extent to which the non-uniformity can reach for systems with power

LEDs. For the first luminance photo, the maximum luminance value reaches $11.0 \cdot 10^6$ cd/m^2, creating four extremely bright spots in the users' field of view. Similarly, the maximum luminance value for the second LED system reaches $13.2 \cdot 10^6$ cd/m^2, this time creating eight bright spots in the field of view. One question that comes into mind is whether it is a correct approach to take the corresponding intensity value from the luminous intensity distribution and divide it into the apparent area or whether these bright spots should be evaluated as single light sources in the calculation of glare rather than taking the whole system as a single light source.

In calculating the glare from LED lighting systems, the shape and configuration of the light source creates a challenge as well. Due to thermal and optical concerns, the designs of these sources are diversified. This diversity in design makes it difficult to estimate an apparent area in the calculation of luminance from luminous intensity measurements. In order to communicate this difficulty of estimation of luminance for different viewing angles, luminance photos have been made for an LED retrofit, as the biggest part of the LED market is aiming at replacing incandescent lamps with LED retrofits. A photo of the chosen retrofit has been given in Figure2.

Figure 2 The retrofit

As can be seen from the photo, the light source includes four power LEDs, which have been embedded in the heat sink and covered by an optical system of diameter 12.5 mm. The diffusing glass has a diameter of 38.3 mm in total and the diameter of the retrofit is 60 mm. To enable efficient air movement, the heat sink has been equipped with air channels at the sides. The retrofit has been photographed using the Techno Team LMK 98-3 luminance camera from the front, at 45 degrees and from the side. The luminance photos and their legend in cd/m^2 have been given in Figure 3.

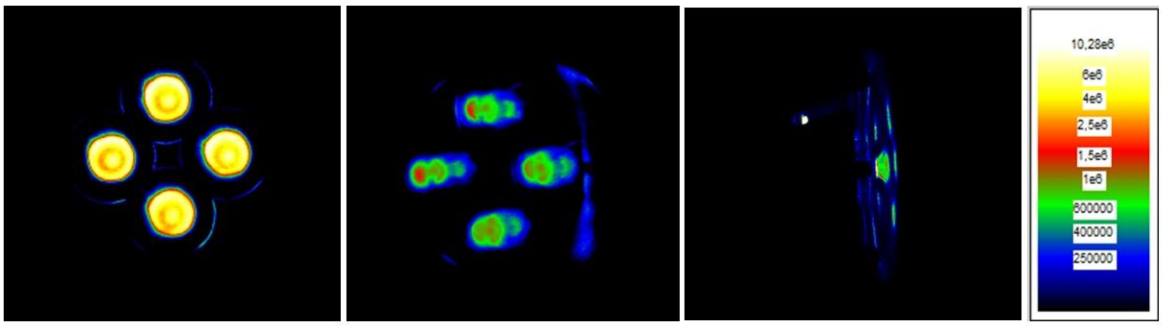


Figure 3 Luminance distributions of the Retrofit from the front, 45 degrees and from the side [cd/m^2]

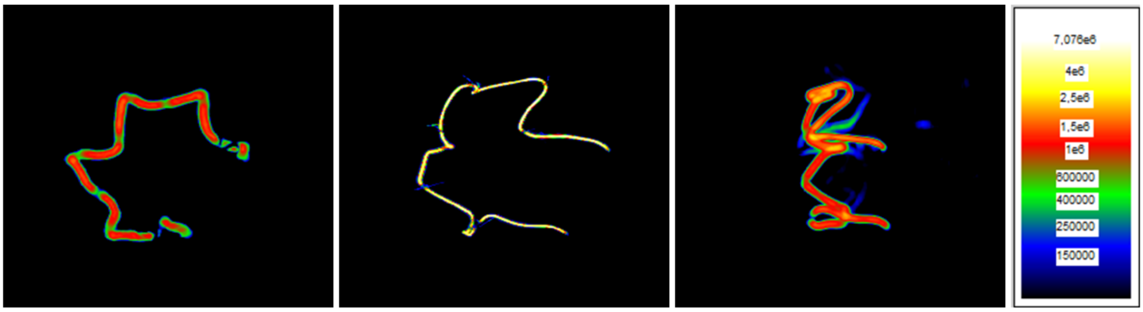


Figure 4 Luminance distributions of a 200 W incandescent lamp viewed from the front, from 45 degrees and from the side [cd/m^2]

The legend for the photo of the side view is reduced to 10^{-2} of the legend for the photos from the front and from 45 degrees.

While the luminance photo from the front reveals all the LEDs in their full brightness, the situation is different for other angles of view. Due to the shape of the heat sink, the luminance photo for 45 degrees includes reflections from the inner sides of the sink itself. The photo for the side view of the retrofit shows light coming out of one of the air channels of the heat sink on the upper side. The special form and configuration of the source creates an important challenge for the estimation of apparent area. The maximum and average luminance values in cd/m^2 obtained with the luminance camera have been given in Table 1. The average values have been computed only using the full area that includes the four LEDs and this area has been referred to as the surrounding area. The measurement results show that the maximum luminance value starts at $10.28 \cdot 10^6$ cd/m^2, a very high value attributable to the direct facing of the power LEDs; drops down to $1.97 \cdot 10^6$ cd/m^2 for 45 degrees and $0.23 \cdot 10^6$ cd/m^2 for the side view. If the average values for these luminance distributions are calculated, the values drop down to $0.99 \cdot 10^6$ cd/m^2, $0.10 \cdot 10^6$ cd/m^2 and $0.008 \cdot 10^6$ cd/m^2 respectively. There are two question marks at this point.

- Are the average values the correct values to use in the calculation of the glare index?
- Which area should be used in the computation of luminance from the luminous intensity distribution?

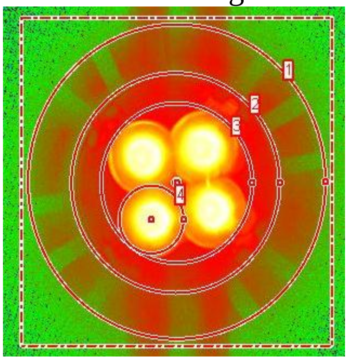
Another important question is which UGR formula is to be used for the calculation. As the size of the retrofit falls into the category of “small”, is the apparent area accepted as 0.005 m^2 and the glare

Table 1. Maximum and average luminance values for the retrofit and the incandescent lamp according to orientation of view

Light Source		Front	At 45 degrees	Side
Retrofit	L_{max} / 10^6 cd/m²	10.28	1.97	0.23
	L_{avg} / 10^6 cd/m²	0.99	0.10	0.008
Incandescent lamp	L_{max} / 10^6 cd/m²	1.69	7.08	2.70
	L_{avg} / 10^6 cd/m²	0.14	0.21	0.29

rating calculated using the small UGR formula? It must be kept in mind that the small Glare Formula was produced through an experiment using a 200 W incandescent lamp. With a clear incandescent lamp, the tungsten wire is exposed to the eye in all viewing angles, while this is not the case with most of the novel LED retrofits surrounded by optics and heat sinks. Figure 4 shows the luminance distributions of a 200 W incandescent lamp photographed from the front (the bottom of the lamp), from 45 degrees and from the side. It is possible to see from the photos that in all viewing angles, the maximum luminance value is in the range of 10^6 due to its special form with the tungsten wire in the middle of the glass cover. Looking back at Figure 3, it can be seen that the LED retrofit has a totally different luminance distribution than the incandescent lamp, once again raising the question of whether the formula created by the research of Paul et. al. is convenient for LED light sources as well. To see the UGR rating produced by the light source at hand and to analyze the different results that can be obtained by changing the apparent area taken into consideration, an exemplary calculation similar to the conditions given in CIE 147:2002 for small light sources has been repeated. The report gives a numerical example, calculating the glare created by a 15 W bare incandescent lamp, placed two *m* above and four *m* away from the subject's eye, with a background luminance of 30 cd/m^2. The intensity is taken as 160 cd with the filament luminance $4{\cdot}10^6$ cd/m^2, making the projected area $4{\cdot}10^{-5}$ m². In such an example, the original formula results in a UGR rating of 39, while the small formula predicts a UGR of 22, where the difference between the two values are drastically.

To provide a better understanding of the questions that have been raised in the paper, this calculation has been repeated using the values from the chosen LED retrofit instead of the 15 W incandescent lamp. For the calculation with the original UGR formula, three different apparent areas have been selected. These areas have been defined as the emitting area of one LED with its optics, the surrounding area of all four LEDs with optics, and the whole retrofit. The defined areas can be seen in Figure 5.



1 – Whole Retrofit; 3 – Surrounding Area; 4 – Emitting Area

Figure 5 Areas used in the calculation

The position in the example calculation corresponds to the luminous intensity value at 26.5 of 110 cd. The results have been given in Table 2. It can be seen that the numerical values of UGR are showing important differences when the apparent areas are changing. In order to emphasize the importance of these results, the UGR values have been further expressed as subjective evaluations, with the assumption that the retrofit is being analyzed for the interior lighting of an office room. *EN 12464-1:2011 Light and lighting - Lighting of work places - Part 1: Indoor work places* defines the maximum UGR value for writing, typing, reading and data processing in an office as 19 [13].

Looking at the values obtained by using the whole retrofit, which includes the LEDs as well as the heat sink and the optics, the subjective evaluation would be comfortable, as the UGR value is below the maximum value in the standard. If the surrounding area of the LEDs is taken into consideration, the UGR value rises up to 23, exceeding the maximum value for offices, making it uncomfortable for the office user. Finally, when only the emitting area is used for the calculation and the four LEDs are considered as four separate light sources, the UGR value rises up to 25, creating a very uncomfortable situation for the office user. When the UGR formula for small sources is used on the other hand, the UGR values become 17, 17 and 21, corresponding to the subjective evaluations of comfortable, comfortable and uncomfortable for the respective areas.

Table 2. Calculation of luminance from apparent area and luminous intensity

Part	Whole Retrofit	Surrounding Area	Emitting Area
d **[mm]**	60	27.9	4x 12.5
Area **[m²]**	28.2×10^{-4}	6.11×10^{-4}	4.91×10^{-4}
I_0 **[cd]**	833	833	833
$L_{0\ calculated}$ **[cd/m²]**	0.30×10^{6}	1.36×10^{6}	1.70×10^{6}
$L_{0\ measured}$ **[cd/m²]**	0.29×10^{6}	1.13×10^{6}	1.46×10^{6}
$I_{26°}$ **[cd]**	110	110	110
$L_{26°}$ **[cd/m²]**	0.04×10^{6}	0.18×10^{6}	0.23×10^{6}
UGR*	17	23	25
ie. Office Lighting**	Comfortable	Uncomfortable	Very Uncomfortable
UGR_{small}	17	17	21
ie. Office Lighting**	Comfortable	Comfortable	Uncomfortable

**UGR* values calculated assuming the apparent area changes according to the cosine law

**According to EN 12464-1:2011 Light and lighting - Lighting of work places - Part 1: Indoor work places

With the results of this calculation, it is possible to say that the uncertainty in defining the apparent area creates an important uncertainty in the UGR results as well. Is the light source in hand adequate for a glare free environment? Unfortunately the answer is not certain. Keeping this difficulty in mind, the reader is invited to go back to Figure 1 and reflect on the estimation of the apparent area for the LED retrofit with eight LEDs, positioned in a circular configuration, with a big area of very low luminance in the middle. How is the apparent area and therefore the average luminance computed in this case?

5. Further discussion and conclusion

To conclude, it is a question mark whether the available glare rating formulas are suitable for the novel light sources using LED technologies. The position index calculated in 1949 with sources of uniform luminance distributions, a set circular geometry and a constant spectrum appears to be inconvenient for today's technology with

LED lighting systems having a wide variety of luminance distributions. Later studies on the position index have provided contradictory results and there is no study conducted using actual LEDs. In addition to the position index, the shape of the novel light sources, along with their configuration makes the calculation of luminance from the luminous intensity distribution and apparent area very difficult. It is not easy to define the apparent area for the majority of LED light sources, especially with those which have complex heat sink designs and embedded optics. The fact that the current LED products in the market are evaluated according to the available UGR formulas is a major problem for the end user. While an LED product with non-uniform luminance distribution may prove to be “glare-free” according to the current formulations, the user who eagerly purchases the product despite its high price, thinking that it’s energy efficient and environmentally friendly, may take it home and end up resenting the product because at the end it may not be “glare-free” at all. It is important to mention that the lighting simulation programs are also dependent upon the current formulations and may be producing faulty results for the calculations including LED lighting systems. This turns the trustworthiness of the calculations into a big question mark. With the information in hand, it is not certain that the current glare rating formulas can be used with LED lighting systems and further research into this field is extremely necessary.

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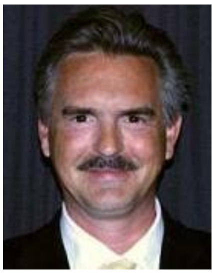

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LIGHT POLLUTION AND ENERGY SAVINGS

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Abstract: *High quality street lighting should be characterized not only by good visibility and a satisfactory visual comfort, but also by energy efficient lighting installations that do not produce unacceptable light pollution. The aim of this paper was to analyze the relationship between the reduction of light pollution and energy savings in public lighting. The main assumption that gives the possibilities of energy savings is that there are spaces, as well as objects, which do not need to be illuminated during late night hours. The immediate consequince is that lighting of streets needs to have at least two regimes. The first one should satisfy requests imposed by normal traffic, while other regime need to fulfil requests for reduced traffic density. The second regime is characterized by a reduced light level, causing less light pollution. It was shown that all forms of light pollution could be considerably reduced by the application of various measures, described in detail in this paper. Special attention was dedicated to the use of devices for continuous light control, which are most suitable for the application in the existing lighting installations. Results of the conducted lighting demonstration project showed that, without jeopardizing traffic safety, energy savings of around 30% could be achieved in public lighting, which would cause not only a considerable reduction in light pollution, but also a reduction of thousands of tons of emitted greenhouse gasses, contributing to the measures against global warming.*

Keywords: street lighting, measures against light pollution, devices for continuous light control, global warming

1. Introduction

The aim of high quality lighting design is achievement of good visibility and a satisfactory visual comfort, while creating appealing light effects and minimizing electricity consumption, negative environmental effects and light pollution.

The most common form of light pollution is intensive sky glow above cities, which not only interferes with astronomical observations, but also prevents complete satisfaction in observing astronomical objects which are seen much better against the dark sky.

The second basic form of light pollution is light trespass, caused by the light directed towards surfaces and spaces which are not intended to be lit (for example, light

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coming from public lighting that illuminates our apartments and backyards).

The third basic form of light pollution is glare, which decreases visual abilities or creates feeling of discomfort.

The aim of this paper is the analysis of influences of the reduction of light pollution in public lighting on energy savings and the reduction of global warming coming from CO_2 and methane emissions.

2. Recommendations for the reduction of light pollution

2.1 Basic parameters

The basic parameters which influence light pollution are:

- illuminance (luminance) level;
- duration of public lighting;
- characteristics of lamps and luminaires;
- public lighting control.

Determining an appropriate illuminance (luminance) level is especially important in lighting design because it relates to the amount of light which, after reflecting from the streets and sidewalks, is directed to the sky. Also, there are spaces, as well as objects, which do not need to be illuminated during late night hours. In order to minimize light trespass, there are several issues that need to be considered, such as type of luminaires (with appropriate light distribution), as well as their position and direction. Lighting of streets and roads needs to have at least two regimes. The first one (usually after 6AM and before midnight) should satisfy requests imposed by normal traffic, while other regimes (usually lasting between midnight and 6AM) need to fulfil requests for reduced traffic density. They are characterized by a reduced light level, causing less light pollution. Those regimes can be realized by using devices for discrete or continuous light control. Since devices for continuous light control can comply with almost every present street lighting installation (regarding the lamp type, present light level and voltage drops), they represent a much better solution than devices for discrete light control.

2.2 Light zoning

Effects of light pollution differ depending on the location. According to [1], and depending on the brightness of the surroundings, four light zones are defined, as described in Table 1. By determining the appropriate light zone and considering the corresponding requests, light pollution can be decreased, certainly leading to energy savings. The fulfilment of those requests should provide lower sky glow (the specific request is referring to the maximum allowed luminaire Upward Light Ratio), reduction of light trespass (this request is defining the maximum allowed values of vertical illuminance) and acceptable level of glare (the specific request is defining the maximum allowed values of luminaire luminous intensity in relevant directions).

Table 1 Light zones

Zone	Description
E1	Dark areas (national parks or protected territories)
E2	Low brightness areas (industrial zones or rural settlements)
E3	Moderate brightness areas (industrial or residential suburb areas)
E4	High brightness areas (city centres or commercial areas)

3. Reduction of light pollution in urban lighting and its influence on energy savings

3.1 The reduction of light pollution in architectural lighting

Light pollution in architectural lighting is most frequently caused by the illumination of buildings and bridges. Luminaires are usually set on a certain distance from the object and directed upward, often causing all basic types of light pollution. Inadequate luminaire light distribution can contribute to light pollution. A lot of time needs to be dedicated to the choice of luminaires in the process of design. Testing on the spot is also necessary in order to achieve the desired effects. Due to their small dimensions and directional light beams, LED lights can significantly reduce the negative effects.

One of the causes of light pollution is also the use of dynamic lighting with quick changes in light intensity and colour. Since this kind of lighting has negative effects on observers, it should not last long and should be characterized by slow changes of light, especially in residential areas.

3.2 The reduction of light pollution by changing the light characteristics of luminaires used in street and ambient lighting

Quality street and ambient luminaires emit upward (directly towards the sky) less than 3% of their total luminous flux. Although there have been attempts in the EU to forbid the use of luminaires that emit light upward, they failed due to very strong opposite arguments. Our photometric calculations, made in the cooperation of the Schreder Group from Belgium, showed that around 25% more luminaires with HID light sources and flat horizontal protectors (light is emitted only downward) are needed than in case of standard (bowl) luminaires with HID lamps, because the former have a narrower light beam in the longitudinal plane. This increases the amount of light directed toward the road and sidewalk surfaces by the same percentage. As reflectances of these surfaces range between 0.1 and 0.3, the light directed towards the sky (due to reflection) is increased by 2.5–7.5%, which finally results in more light directed towards the sky than in case of standard luminaires. Increased electricity consumption by as much as 25% represents yet another negative effect.

It should be emphasized that the latest types of LED luminaires are characterized by the flat horizontal protector and wide light beam in the longitudinal plane (because they are equipped with lenses that widen the light beam). However, although street and ambient lighting solutions with LEDs generally provide energy savings of around 20%, they are still much more expensive than the conventional lighting solutions [2], so a detailed financial analysis is still necessary for each specific case in order to justify the application of LEDs.

3.3 The reduction of light pollution by the use of devices for continuous light control

Nowadays many devices for continuous light control intended for public lighting are available on the market. Such devices can work with all types of conventional light sources used in public lighting (fluorescent, high-pressure sodium, high-pressure mercury and metal-halide). They are equipped with a control unit through which their operation can be programmed by defining the luminaire voltages for different time periods (regimes) during the operation hours of public lighting. The device is usually programmed in a way that it provides voltage close to the rated one in the evening hours (highest car and pedestrian traffic densities) and lower voltages in late night hours. Most often two regimes with reduced voltages (luminous fluxes) are programmed, with the usual reduction of light of about 25% and 50% [3] (since both car and pedestrian traffic densities are significantly lowered in late night hours, these reductions of luminous flux generally do not jeopardize traffic safety).

A diagram that shows how both luminaire luminous flux and power depend on voltage represents the basic characteristic of the devices for continuous light control. Such a diagram is presented in Figure 1 [4], where both curves are shown for a case of a high-pressure sodium luminaire.

As seen in Figure 1, the luminous flux reduction of 25% is achieved at a voltage of 205 V (the power reduction is 20%), while the luminous flux reduction of 50% is achieved at a voltage of 178 V (the power reduction is 42%). It should be mentioned that our tests showed that public lighting installations with high-pressure mercury or metal-halide lamps are characterized by slightly lower power reductions and, therefore, provide less energy savings.

During spring of 2011, a pilot project was conducted in Belgrade, in a street with 32 luminaires with 150 W HPS lamps, with the aim of determining the numerical indicators for possible energy savings by applying several regimes in public lighting. Programming of the device for continuous light control was done in the following way:

- from the time of turning on the lighting installation until 10PM the illuminance level was 10% lower than the one existing before the device had been installed (this is justified because the light level tolerance equals 10% and the streets are usually overlit),
- from 10PM to midnight the illuminance level was reduced by another 25% (32% in total), and
- from midnight to the time of switching off the lighting installation the illuminance level was set to 45% (0.9·50%) of the one existing prior to the device installment.

The pilot project, which lasted for 30 days, showed energy savings of 31.6%. Taking into account the fact that throughout the year there is a change of timing for public lighting switching on and off, this project also showed that the annual energy savings would be 30%.

4. Influence of the application of devices for continuous light control on the reduction of CO_2 and methane emissions

Since about 110,000 luminaires are installed in the Belgrade public lighting, with the total power of around 20 MW, the possible annual energy savings amount to 30% 20 MW·4000 h=24,000 MWh (the Belgrade public lighting operates for about 4000 h a year).

About 70% of the consumed electricity (~17 million kWh) is produced in thermal power plants, which emit CO_2 and other greenhouse gases (sulphur dioxide, nitrogen oxides and methane).

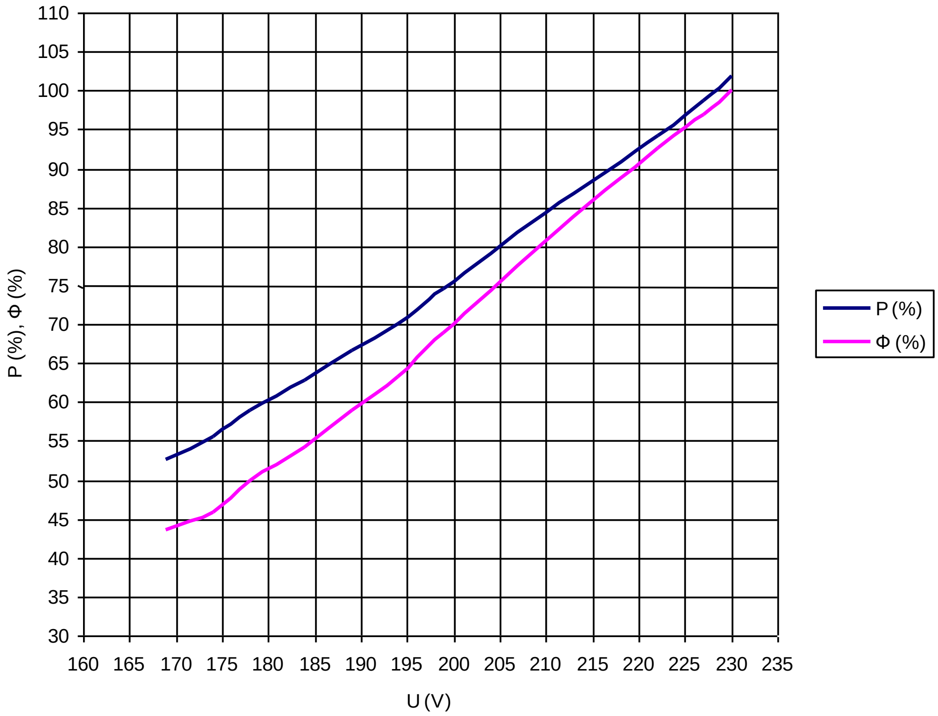

Figure 1 Luminaire power (*P*) and luminous flux (*Φ*) in relation to the voltage (*U*) - case of a high-pressure sodium lamp

Since every saved kWh means 0.42 kg of CO_2 less in the atmosphere (European average), it can be concluded that the application of light control devices will not only reduce light pollution, but also provide significant energy savings and reduction of CO_2 emissions (around 7000 tons in Belgrade annually).

Since one tree annually absorbs about 20 kg of CO_2, this further implies that about 350,000 trees in Belgrade would be free for absorption of CO_2 generated by other pollutants (cars, heating plants, industry...).

Also, by installing devices for continuous light control in Belgrade, each year emissions of sulphur dioxide would be reduced for about 60 tons and emissions of methane, which has a high global-warming potential, for as much as 9000 tons.

5. Conclusions

All forms of light pollution can and should be reduced to acceptable levels by the application of various measures described in this paper, related to the appropriate choice of the illuminance (luminance) level, duration of public lighting, choice of adequate lamps and luminaires, as well as the use of devices for light control. Special attention was dedicated to the use of devices for continuous light control. Results of the conducted lighting demonstration project show that, without jeopardizing traffic safety, energy savings of as much as 30% could be achieved in public lighting, which means a reduction of thousands of tons of emitted CO_2 and methane, contributing to the measures against global warming.

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LIGHTING PROMOTING SAFETY AND CREATING A SENSE OF PLEASANTNESS IN SUBURBAN ENVIRONMENTS

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Abstract: *Better lighting is considered to affect positively fear of crime and preference after dark. This field study explores the possible lighting attribute predictors of perceived safety and pleasantness. The aim is to reveal the most significant connections between the variables in near-home suburban environments. In doing so, the study will clarify whether increasing the level of brightness is the best means of enhancing perceived safety in suburban areas. The results will also clarify whether the same attributes will enhance both safety and pleasantness or whether there are conflicting factors. Twenty-nine participants rated three pathway locations and twenty-six participants rated two pavement locations based on the perception of five lighting attributes (colour quality, evenness, extensiveness, brightness and glare) and pleasantness and safety appraisals. Linear regression analysis was used for the data analysis. The results indicate that in familiar suburban environments, the perceived colour quality, 'the colour of the light makes the environment pleasant', is the most significant attribute in forming connections with both perceived safety and a pleasant lighting environment. At very low luminance levels, perceived pathway brightness may form stronger connections with perceived safety and pleasantness than perceived colour rendering. However, when the brightness increases, it may lose significance and the perceived colour quality of the light may become a stronger indicator of pleasantness and safety. Furthermore, the results give some indications that people prefer warmer tones to colder tones at low illuminance levels.*

Keywords: fear; preference; pleasantness; brightness; perceived colour quality.

1. Introduction

The use of lighting to promote safety has a long history. At first, 'navigation' lights imposed structure and order on the city[1]. Later, with the help of gas lanterns, public lighting started to convert darkness into dusk[2], and now, at the time of the electric light, it is hard to find complete darkness in urban areas. Despite the modern sea of light, the fear of crime is still present in urban environments. This fear is often manifested through avoidance to go out after dark or the tendency to avoid certain places considered to entail a high risk of social danger or isolated places with low social control. In particular, women and older people who feel more vulnerable may avoid going out after dark[3, 4].

Numerous lighting interventions have taken place to make people feel less fearful, whereas scarcely any attention has been paid to pleasant lighting environments. However, especially in near-home environments, the environmental needs may also emphasize comfort and pleasure whereas in unfamiliar environments people may be more sensitive to the negative environmental cues[5] and set higher demands for the visual performance. So far, the nightscapes have been seen primarily as sources of fear. There is a need for a wider approach that promotes an attractive and comfortable night-time environment.

It is suggested that better lighting is connected with higher feeling of safety [6-9]. It is also often considered that the improvements in perceived safety are achieved through better visual performance. However, also the hedonic tone/pleasant appearance may affect safety perceptions[8].

Since a number of lighting attributes have been changed during the lighting interventions, it is difficult to identify the significance of a single attribute. It is assumed that perception of higher brighness will improve feelings of safety. The assumption is also supported by empirical evidence[8-10]. However, the research also suggests that this relationship is not linear, but weakens after a certain level of illuminance has been reached[10]. What that level is may depend on the estimated risk of social danger, so that higher illuminance levels are appreciated in urban areas. However, in urban areas the surrounding illuminance levels may also be higher, which may also have an effect on lighting expectations. There are also reports indicating that higher levels of brightness may increase fear if they make signs of disorder more visible[7], or that high differences in the brightness of the lighting between the pathway and the area surrounding it may create the feeling that an assailant is lurking in the darkness[11].

Spectral power distribution may also affect perceived safety. There is research evidence suggesting that spectral power distribution affects perceived brightness[12-14] thus affecting safety perceptions[10,15]. However, as spectral power distribution is connected with preference[16] and as the perceptions of pleasantness are connected with safety[8], spectral power distribution may also affect perceived safety mediated by pleasantness.

Research suggests that places that provide an offender refuge and victim a limited prospect and escape will be seen as unsafe[17] Therefore, it may well be hypothesized that the extensiveness of the illuminated area and glare will also affect feelings of safety. Hanyu[18] has found that safe/active appraisals are related to bright and uniform lighting, which indicates that evenness may also be one factor affecting perceived safety.

There is also new research evidence indicating that focus of light may affect perceived safety[19]. Focusing light on greenery may result in higher ratings of perceived safety, whereas focusing light on parking lots and roads may result in lower ratings of perceived safety. The results imply that focus of light serves as a guide to the eye, offering different visual affordances and affecting environmental experiences as well.

While there is plenty of research regarding lighting and safety, only a few studies focus on the issue of preferred and comfortable night-time lighting. Boyce et al.[10] concluded that good lighting is perceived to be bright, even, comfortable, extensive in area and well-matched to the site. Preference may also be affected by the focus of light, so that preference is greater when light is focused on greenery than when light is focused on parking lots and roads[19].

Spectral distribution may also affect preference. There is research evidence suggesting that the CIE Colour Rendering Index is connected to preference, so that better colour rendering is appreciated[20]. In indoor environments, there seems to also be differences in the preferred CIE Correlated Colour Temperatures depending on such subjective factors as gender and such environmental factors as illuminance. In low illuminance conditions, preferences tend to shift towards the warmer end of the colour temperatures scale, whereas at high illuminances higher colour temperatures (colder tones) are appreciated[21]. Since many outdoor lighting studies have compared sodium lighting with metal halide lighting, it is difficult to differentiate the role of the colour temperature from the role of the colour rendering capabilities. However, we can assume that at low illuminance levels, lower colour temperatures are also preferred in outdoor lighting.

In conclusion, previous research suggests that in unfamiliar environments, perceived safety may be connected with the perception of the following lighting attributes: brightness, spectral power distribution, the focus of the light, extensiveness, evenness, and glare. Pleasant lighting may be related to brightness, spectral power distribution, the focus of the light, extensiveness, evenness, comfort, and the perception that the lighting matches well with the site. Furthermore, because glare causes feelings of discomfort, we may assume that it is negatively related to pleasantness.

2. Study Objectives

Research has suggested that several lighting attributes may affect perceived safety and pleasantness in unfamiliar environments. Practical lighting interventions tend to use higher levels of brightness as a general tool to enhance safety, whereas only minimal attention has been paid to other lighting factors. The present field study explores the relationship between the perception of five lighting attributes (perceived colour quality referring to spectral power distribution, evenness, extensiveness, brightness and glare) and perceived safety and pleasantness appraisals in familiar suburban neighbourhoods. The aim is to reveal the most significant connections between the variables in near-home environments. In doing so, the study will clarify whether increasing the level of brightness is the best means of enhancing perceived safety in suburban areas. The results will also clarify whether the same attributes will promote both safety and pleasantness or whether there are conflicting factors. Furthermore, the study will provide insights into how varying lighting and environmental conditions affect the connections between the variables.

Figure 1 Test locations: upper row shows areas A-C and lower row shows areas D and E.

3. Method

3.1 Areas

The test areas were located within two suburban areas near Helsinki; Herttoniemi and Roihuvuori (see Figure 1). Table 1 presents the key environmental features of the test areas. The photometric measurements are presented in Table 2. Luminance measurements give a good reference for the subjective evaluations. The luminance measurements were conducted with an LMK Mobile Advanced 1009 imaging luminance photometer with Canon EOS 350D and were based on the SFS-EN 13201-3 road lighting standard. In Roihuvuori illuminance measurements were also carried out, but in Herttoniemi environmental obstructions prevented the measurements. TI values give some reference for the subjective perceived glare values. However, TI values describe disability glare in road lighting conditions, whereas perceived glare describes the subjective feeling of discomfort. The CCT and CIE Colour Rendering Index (CRI) measurements, giving reference for the perceived colour quality, were conducted with a Konica Minolta CL-500A illuminance spectrophotometer.

Both horizontal and vertical values were measured beneath the luminaire (1.5 m above the ground surface). Horizontal values are closer to the spectral quality of the measured light source, whereas vertical values are closer to human perception and more affected by the other light sources and reflecting surfaces.

3.2 Participants

In Roihuvuori, 29 subjects (14 female, 15 male) participated in the study, with a mean age of 39 years. In Herttoniemi, 26 subjects (16 female, 10 male) participated in the study, with a mean age of 40 years. The subjects for the study were recruited through local residents' associations, by putting advertisements on the university notice boards, and by stopping passers-by in the test areas. Most of the participants knew well the areas they evaluated (in Herttoniemi 88%, in Roihuvuori 79%).

Table 1 Key environmental features in the test areas.

	Area A, pathway	Area B, pathway	Area C, pathway	Area D, pavement	Area E, pavement
water feature	no	no	no	no	no
prominen trees	yes	yes	yes	some	some
pathway curvature	no	yes	yes	no	no
vehicles	no	no	no	yes	yes
walkability and prospect limitations	hill, metal fence	bushes	no	hedges, cars	hedges, cars hill
surrounding buildings	block of flats at the end of walkway	service centre	block of flats	block of flats	terraced houses detached houses
walkway surface	asphalt	asphalt	gravel	asphalt	asphalt
connected with	forest, playground (unilluminated)	playground	games court	asphalted front gardens	front gardens
social environment during the experiment		playing kids people walking	playing kids people walking	people walking	people walking

Table 2 The lighting features of different areas. Light source, lamp/luminaire power (*W*), luminous flux (*lm*), horizontal (CCT_h) and vertical (CCT_v) values of Correlated Colour Temperatures (*K*), horizontal (Ra_h) and vertical (Ra_v) values of CIE Colour Rendering Indices, mean luminance (L_{ave}) (cd/m^2) on the walkway and in the surroundings, general luminance uniformity on the walkway (U_o), longitudinal luminance uniformity on the walkway (U_l), and Threshold Increment (*TI*) (%) value of the areas.

	Area A, pathway	Area B, pathway	Area C, pathway	Area D, pavement	Area E, pavement
Light source	mercury vapour	LED	LED	mercury vapour	LED
Power (W)	125	45	42	250	59
Luminous flux (lm)		2011	3060		59
CCT_h (K)	3546	3899	4560	2805	4239
CCT_v (K)	3260	3664	4432	3058	4028
Ra_h	49	65	69	46	76
Ra_v	49	59	68	47	79
$L_{ave\ walk\ way}$ (cd/m2)	0.47	0.46	0.59	0.28	1.07
$L_{ave\ surrounds\ left}$ (cd/m2)	0.14	0.20	0.17	0.14	0.32
$L_{ave\ surrounds\ right}$ (cd/m2)	0.12	0.18	0.40	0.30	0.13
U_o	0.54	0.70	0.56	0.59	0.49
U_l	0.50	0.75	0.39	0.34	0.27
TI (%)	7	4	2	3	2

3.3 Measures

We assessed the perceived colour quality via the following statement: 'The colour of the light makes the environment pleasant – unpleasant.' Further statements related to the lighting factors were as follows: brightness – 'The lighting on the pathway is too strong – totally inadequate'; evenness – 'The lighting on the pathway is too uneven – very even'; and, extensiveness – 'The lighting in the area surrounding the pathway is too abundant – totally inadequate.' The pleasantness of the lighting environment with the following statement: 'The lighting in the area is very pleasant – very unpleasant.' Finally, perceived safety was assessed via the following statement: 'The feeling of safety produced by the lighting is very good – very weak.' We evaluated the statements using 7-point Likert scales. Also, though we measured perceived restorativeness, the results are not reported here. Besides responding to the statements, the subjects were also free to comment on the lighting environment in their own words if they wished to do so.

The perceived glare was measured by having the subject walk one pole length and look straight ahead as they normally would do. The perceived glare, measured on a 0-3 scale (0= no glare, 3=very strong glare), was written down in a graph by an assistant who walked slightly behind the subject. A sorter scale was used in order to make the evaluation task easier.

We used single-item scales rather than multi-item scales for the measurements as a way of limiting the evaluation time. During the cold and dark season it would have been difficult to get willing subjects to participate in a lengthy outdoor study.

3.4 Procedures

We conducted the experiments at the beginning of November 2011, starting around 6-7 p.m., so that it was completely dark. There was no snow on the ground and the tests and measurements were carried out in dry weather. There was still some foliage on the trees and on the ground.

First, the participants were informed about the test site locations and the contents of the test forms, which they filled in themselves. The background data of the subjects were recorded close to the test area in order for their eyes to have time to adapt to the lighting situation. The subjects could walk freely around the test areas, but the desired evaluation direction was indicated on the test maps, and verbal reminders of this were also given during the test. The evaluation direction was chosen so that the visual background was as similar as possible between the test areas.

In Roihuvuori, the mean test duration was approximately 40 minutes and half of the subjects (14 out of 29) conducted the test in reverse order (Area C first). In Herttoniemi, the mean test duration was approximately 25 minutes and all of the subjects conducted the test in the same order (D first). This was done to prevent the subjects from perceiving the areas against an undesired background prior to the study, which may have affected the results. After participating in the test, the subjects were compensated with two film tickets.

3.5 Data processing

When examining multicollinearity, we noted that Pearson's product-moment correlations did not exceed 0.9. The highest significant value was 0.61. The Shapiro-Wilk test indicated that some of the factors were not normally distributed. Normality corrections were performed, but they did not result in normal distributions. Therefore, the significant relationships revealed by the linear regression analyses were checked using the Spearman correlation as well. Independent analyses were performed because it was considered important to get area-specific results.

Although the areas within the neighbourhoods were rather similar, different neighbourhood and lighting components may yield different connections between the factors.

Regression analysis examines a group of independent variables at the same time and seeks the independent explanatory effects (controlling for other variables in the model) instead of mere zero-order correlations; it was therefore considered suitable for an exploratory study.

Possible connections between the lighting attributes and safety/pleasantness were first explored with linear regression analysis (enter method)/standard multiple regression; the analysis revealed significant relations between the lighting attributes and the dependent variables. Only these attributes were included in the subsequent regression analysis (enter). Finally, the suggested connections were tested using the Spearman correlation as well.

As with in some of the statements, the scale ranged from negative to positive and again back to negative (e.g. 'lighting on the pathway is too strong – totally inadequate'): Nonlinear regression was also checked, but no significant nonlinear connections were detected.

Table 3 Mean values (*M*) (on 0-6 scale) and standard deviations (*SD*) for all rating items in the five test areas (A-E).

	Roihuvuori						Herttoniemi			
	A		B		C		D		E	
	M	SD	M	SD	M	SD	M	SD	M	SD
Perceived safety produced by the light	4.00	1.36	5.31	0.97	4.66	1.23	3.32	1.49	4.85	1.22
Pleasant lighting	3.67	1.44	4.57	1.14	3.76	1.15	3.27	1.56	3.46	2.14
Colour quality	3.81	1.27	4.65	1.16	3.89	1.20	3.96	1.27	3.50	2.06
Evenness of lighting on the walk way	3.15	1.41	4.72	1.36	3.59	1.45	2.58	1.27	4.15	1.73
Lighting is extensive	2.33	1.30	3.31	0.76	3.07	1.36	2.35	1.09	3.35	1.09
Perceived brightness on the walk way	3,23	0.99	3.28	0.65	3.90	1.11	2.38	0.75	3.77	0.99
Glare*	0.81	0.66	0.64	0.43	0.96	0.56	0.36	0.67	1.07	0.81

*Evaluation on 0-3 scale

4. Results

Descriptive statistics are presented in Table 3. Brightness perceptions corresponded well with the luminance measurements whereas there were considerable differences between the *TI* values and perceived glare measurements. However, as stated before, *TI* values describe disability glare in road lighting conditions, whereas perceived glare describes the subjective feeling of discomfort.

Data on the significant ($p \leq 0.05$) connections and coefficients are presented in Table 4 (perceived safety) and Table 5 (pleasant lighting). The tables present the significant coefficients indicated by the linear regression analysis (enter method). After conducting regression analysis, we used the Spearman correlation test. Data on the significant correlations (Spearman correlation, $p \leq 0.05$) between the variables are provided in Table 6 (perceived safety) and Table 7 (pleasant lighting).

The results indicate that in suburban nightscapes, perceived safety is most strongly connected with the perceived colour quality of light. It also had single connections with even, extensive and bright lighting. Also, a pleasant lighting environment is most strongly connected with the perceived colour quality of light. It had a single positive connection with brightness in area *D* and a negative connection with glare in area *E*. In area *C*, it had a close to significant connection with even lighting.

Table 4 Linear regression (enter) between perceived safety and the five lighting attributes, significant ($p\leq0.05$) connections and standardized coefficients

	Roihuvuori			Herttoniemi	
	Areas			Areas	
Attributes	**A**	**B**	**C**	**D**	**E**
Perceived colour quality	0.46	0.74			0.78
Evenness			0.56		
Extensiveness	0.47				
Brightness				0.72	0.33
Glare					

Table 5 Linear regression (enter) between pleasant lighting and the five lighting attributes, significant ($p\leq0.05$) connections and standardized coefficients

	Roihuvuori			Herttoniemi	
	Areas			Areas	
Attributes	**A**	**B**	**C**	**D**	**E**
Perceived colour quality	0.85	0.49		0.48	0.79
Evenness			0.51	-0.39	
Extensiveness					
Brightness		-0.53	-0.47	0.50	
Glare				-0.34	-0.24

Table 6 Spearman correlation ($p \leq 0.05$) between perceived safety and the five lighting attributes

	Roihuvuori			Herttoniemi	
	Areas			Areas	
Attributes	**A**	**B**	**C**	**D**	**E**
Perceived colour quality	0.58	0.49			0.72
Evenness			0.49		
Extensiveness	0.60				
Brightness				0.72	
Glare					

Table 7 Spearman correlation ($p \leq 0.05$) between pleasant lighting and the five lighting attributes

	Roihuvuori			Herttoniemi	
	Areas			Areas	
Attributes	**A**	**B**	**C**	**D**	**E**
Perceived colour quality	0.85	0.51		0.56	0.93
Evenness			(0.34)		
Extensiveness					
Brightness				0.49	
Glare					-0.65

In the free responses, participants referred to pleasant lighting using words like beautiful, relaxing, good, even, soft, atmospheric, and tender. They referred to unpleasant lighting as hard, bleak, cold, unnatural, even, uneven, dark and too bright. In terms of the lighting attributes, the participants mentioned dark surroundings and uneven pathway lighting most often in relation to the perceived safety of an area *A* (dark areas were mentioned 11 times and safety concerns 6 times). In other areas, they expressed hardly any ideas concerning perceived safety. In areas *C* and E 11 participants commented the lighting as too bright whereas in area *D* 3 participants considered the lighting as too dim.

5. Discussion

This study explored the relationship between five lighting attributes (perceived colour quality, evenness, extensiveness, brightness, and glare) and perceived safety and pleasantness in five suburban locations. The results indicate that the spectral distribution, ‘the colour of the light makes the environment pleasant’, is the most significant attribute in promoting both perceived safety and a pleasant lighting environment.

The relation between pathway brightness and perceived safety was significant in only one area (*D*), where the average luminance on the pavement was 0.28 cd/m^2. We also evaluated this area in a direction in which the background luminances were much higher (average pavement luminance 1.07 cd/m^2). Thus, the results of this study suggest that in familiar environments, perceived pathway brightness is a significant factor only at very low luminance levels. The result corroborates the findings by Boyce et al.[16], who suggest a non-linear connection between brightness and perceived safety. However, the results indicate that already at fairly low luminance levels, spectral distribution may be a more important factor than perceived brightness in predicting safety and pleasantness in near-home environments.

The results may be affected by familiarity. Lighting needs and expectations may differ in near-home environments from those in unfamiliar environments. In areas that are only used occasionally, visual performance may be more important because people will want to observe the environment thoroughly, whereas a pleasant atmosphere may be more appreciated in near-home areas. There were also no special safety concerns in the study areas.

The relation between extensive lighting and perceived safety was significant in area A, which was a more remote area with very little surrounding lighting and a rather high spatial enclosure. Also, in the free responses for area A participants mentioned dark spots between the street luminaires, the spatial enclosure and dark surroundings.

In area *C* perceived safety was connected with evenness. This may be due to the fairly uneven luminance distribution (U_l=0.39). However, in Herttoniemi the U_l values were even lower in both areas (0.34 and 0.27) but evenness was not a significant factor. This may be due to that the U_l values were fairly similar between the areas whereas there were higher differences in the colour quality (*Ra* and *CCT* values).

The results of this study indicate that at very low luminance levels, pathway brightness may be the strongest factor in predicting perceived safety in near-home environments. When the luminance level becomes higher, it may lose its significance and perceived colour quality may be the strongest indicator of perceived safety. Depending on the lighting expectations in relation to the environment, the evenness and extensiveness of the lighting environment may also be significant factors. In this study, glare was not related to perceived safety. However, more research in different environments is needed to validate the results.

The relationship between a pleasant lighting environment and lighting attributes followed the same pattern as between perceived safety and lighting attributes. The results indicate that a pleasant lighting environment substantially accounts for perceptions that the colour of the light makes the environment pleasant. It was the dominant factor in four estimated areas out of five. In addition, the Spearman correlation coefficients were very high; they varied between 0.51 and 0.93. At low luminance levels (area *D*), the pleasantness of the lighting environment may also be connected to perceived brightness on the pathway.

Glare had negative connection with a pleasant lighting environment in area *E*. Since glare did not form connections with perceived safety, the results indicates that the glare needs to be fairly strong in order to have a strong effect on perceived safety, whereas less glare is needed to create an unpleasant feeling.

Since this was a field study exploring the effects of lighting attributes, there was no control for the attributes describing spectral distribution. Thus, there was a variation in both colour temperatures and colour rendering properties. The variation in colour temperatures was between 3058 K and 4432 K (vertical values). The CIE Colour Rendering Indices varied between 47 and 79. In Roihuvuori there was a significant difference in the pleasantness of the colour-rendering properties between areas *B* (3664 K and *Ra* 59) and *C* (4432 K and *Ra* 68) ($p<0.05$), so that the colour quality of area B was considered to be more pleasant even though the Ra value is slightly lower. The result suggests that people prefer warmer tones in outdoor lighting. While the differences in the colour temperatures were not very high, they were easy for the subjects perceive because the areas were next to each other. Furthermore, the preference for warmer tones was supported in the free responses as well. The participants described warm colours as soft and tender, whereas they described the colder tones as hard, bleak and unnatural. The responses suggest that the colour of the light may have a considerable effect on the atmosphere of the lighting environment. However, more research on the preferred spectral qualities is needed.

In practical terms, the results of this study indicate that using high luminances in suburban outdoor environments may not benefit safety; rather, it constitutes a waste of energy with a potential risk of disrupting the physiology of biological organisms[22] . In the free responses a high level of brightness seemed to account for unpleasant feelings, because participants often described it as being hard and bleak. Thus, a pleasant spectral distribution in near-home environments may promote perceived safety more effectively than high luminance, which may have potential disadvantages. Pleasant and safe appraisals are important as they may encourage the use of outdoor spaces by walking and cycling, with possible positive effects on physical and mental health and the built structure of the urban areas[23, 24]. Furthermore, a pleasant environment may benefit community pride and confidence[25].

What comes to the limitations of the study it should be noted that familiarity is a potential source of bias. However, the importance of perceived colour quality persisted in both suburban areas. It should also be noted that semantic bias is possible as the colour quality was measured with a statement including the word pleasant. However, there is research evidence indicating that the correlation between preference and fear may be weak or insignificant[19]. Furthermore, as the subjects were familiar with the environments the results may not be generalised to unfamiliar environments. Also, the use of single item scales and limited number of subjects should be taken into account when interpreting the study results. However, both neighbourhoods produced analogous results converging earlier findings[8].

6. Conclusions

The results indicate that in mundane, near-home settings, both perceived safety and pleasantness form the strongest connections with the perceived colour quality. The other lighting attributes (evenness, extensiveness, brightness, and glare) formed only single connections. At very low luminance levels, perceived pathway brightness may form stronger connections with perceived safety and pleasantness than perceived colour rendering. However, when the brightness increases, it may lose significance and the perceived colour quality of the light may become a stronger indicator of pleasantness and safety. Furthermore, the results of this study as well as previous research indicate that people perceive of fairly low *CCT* lighting as being pleasant at low illuminance levels.

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COLOUR RENDERING – A PERSONAL VIEW

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Abstract. *The term colour rendering of light sources was originally used to describe how accurately the test light source reproduces the colours of test samples compared to the illumination with a reference illuminant. Now we call this colour fidelity, and two further terms related to colour rendering are used, colour preference and colour discrimination.*

Author discusses the three sub-sections of colour rendering based on his research he conducted in this field during the past 30 plus years.

Research that concluded in a new colour fidelity metric is discussed in detail, problems with the term colour preference, once called colour flattery, are discussed, and a compromise solution for slightly preference enhanced fidelity is suggested that takes also the energy efficiency of the source into consideration.

Colour discrimination is important for some industries. It has been shown that distinction between small colour differences is not necessarily well described by gamut area, but a new metric has been proposed that maps small colour differences in the vicinity of some target colours.

The final proposal is based on the CRI2012 model that was worked out by a consortium, where the author of this paper was one participant. This model uses the most up-to-date colorimetry (CAM02-USC space, CIE 10° observer), non-linear averaging and scaling, and very special sets of test samples. It is hoped that this model can in the future be harmonised with colour preference metrics, and optimised for LED light source efficacy.

Keywords: colour rendering, colour fidelity, colour discrimination, flattery index.

1. Introduction

Colours fascinated mankind since the prehistoric times. Colours were already used in the Altamira cave paintings, Homer compared the colour of his/her heroes to the colour of nature. Also the Bible uses colour terms to describe super-natural items. But up to the end of the 19th Century we had no possibility to influence the spectrum of our artificial sources, to show the objects in natural or more pleasing colours.

With the incandescent lamp we still had to accept light source colour as provided by the incandescent tungsten. Only with the introduction of gas discharge lamps became mankind capable to produce sources that showed colours of our surrounding different as usual. With the introduction of the gas discharge lamps that rendered the colours of the environment differently as the incandescent lamp or daylight, it became necessary to introduce a metric to describe the colour rendering properties of the different types of light sources[1]. The first CIE colour rendering index was based on the dissimilarity of the spectrum of the test and a reference light source[2]. But the purpose of a colour rendering index is to find a correlate of the visual impression the observer has when viewing the illuminated scene. Thus researchers looked for alternative methods. One of these was based on the colour difference of test samples illuminated with a test and a reference source[3, 4]. CIE decided to introduce a recommendation to evaluate colour rendering of light sources by the test sample method[5,6]. CIE published an updated, revised edition of this publication in 1974[7], and republished it later with minor editorial changes[8].

Soon it was observed that one can tailor the spectrum of a lamp in such a form that objects look nicer under the modified spectrum as under daylight or incandescent light. Judd coined the term flattery index to describe this as early as in 1967[9]. Later the term was modified to colour preference, to soften the negative over tune of "flattery". A source with a high colour flattery index might falsify the observer and show e.g a not too fresh meet to be quite appetizing.

There are applications where the inspection under a light source is intended to discriminate between small colour differences, i.e. high colour discrimination ability is required. To make the selection of light sources for such purposes easier, the concept of colour discrimination ability, and the colour discrimination index were constructed[10, 11].

Neither the colour preference, nor the colour discrimination index got yet general acceptance, although much research went into both directions recently.

2. The three aspects of light source colour rendering

As shortly mentioned in the Introduction light source colour rendering can be subdivided to give answers on the following three questions:

- how well a source reproduces colours compared to a reference illuminant, this we call now colour fidelity;
- whether the source provides a more pleasing atmosphere of the scene, or of some objects, compared to their colour appearance under a reference illuminant, this we call colour preference;
- how easy it is to distinguish between small colour differences under the given light source, this we call colour discrimination.

An early overview of all three questions was delivered in a paper presented at the Plovdiv colour conference in 1980[12]. For all three aspects indices have been developed, thus they can be measured by the colour fidelity, colour preference and colour discrimination indices. To be exact the still valid definition of colour rendering[13] "effect of an illuminant on the colour appearance of objects by conscious or subconscious comparison with their colour appearance under a reference illuminant" describes the above colour fidelity. Fidelity, preference and discrimination have not been defined in the CIE International Lighting Vocabulary yet.

3. Colour fidelity

The first colour fidelity/rendering index[6] was based on only chromaticity differences, but as a three dimensional colour difference metric became available, it was extended to three dimensional description[7]. Despite the fact that the colour rendering index (CRI) is in practically unchanged form current, during the past almost forty years many attempts were made to update the method, or propose alternative techniques (for a review see[14, 15]).

Some authors questioned whether the use of reference illuminants of equal correlated colour temperature (CCT) as that of the test source is a good technique, or one could use a single reference illuminant[16]. We have discussed the question of using a single reference illuminant as early as in 1981[17], and we have shown that if the influence of different light sources on the colour appearance on objects is tested in a simulated scene, the rank order of light sources changes drastically compared to that of the prediction of the current CRI test method[18, 19].

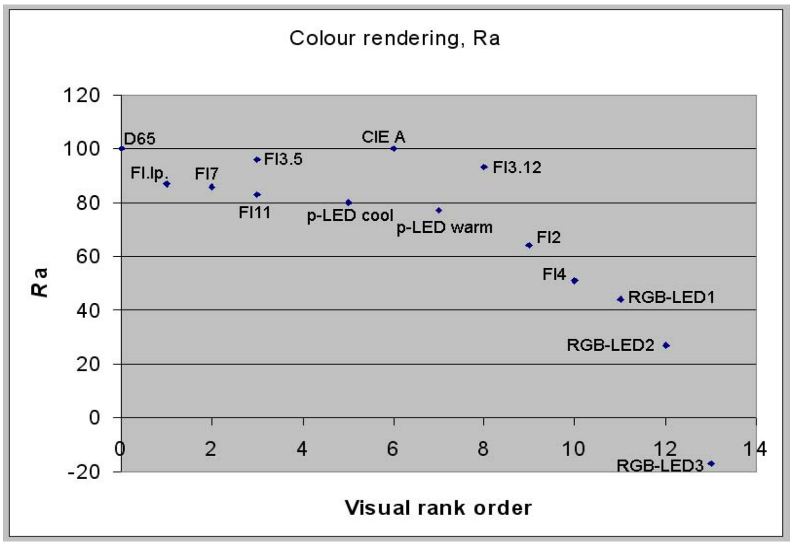

Figure 1 CIE Ra versus visual rank order of different light sources based on a computer simulation.

Figure 1 shows the results of the computer simulation experiment: Pictures, where the spectral reflectance was known pixel by pixel, were rendered using different light source spectra and chromatically transformed to D65 using CIECAM02 colour appearance model, and were compared to the rendered picture using illumination with D65 illuminant. The CIE CRI Ra values are shown for the visual evaluation rank order. For D65 the best position (rank order 0) is obvious. But e.g. the CIE test method provides Ra=100 for the CIE Standard illuminant A illuminated scene, but in the simulation experiment a number other sources got better scores (e.g. CIE illuminant 7 and 11), with much lower Ra value. Only the two RGB-LEDs scored visually and according to the CIE test method in similar sequence.

One of the problems is that the CIE CRI test method is based on relative colorimetry, i.e. the absolute value of the illumination is not considered, although the visual impression depends on light level as well. Only advanced colour appearance models permit to take light levels into consideration, a possibility to use such metrics was discussed in [20].

Never the less I am now convinced that for different situations the reference illuminant should have a correlated colour temperature near to that of the test lamp: nobody would be of the opinion that a scene seen in the light of the setting Sun is les normal, has lower fidelity, as the same scene in midday sunshine, despite the fact that at sunset the light illuminating the scene has a much lower CCT as at midday.

All over the world several laboratories dealt with the problem, how the CIE CRI test method could be updated. With the introduction of the tri-band fluorescent lamps, and later with the LEDs it became obvious that visual impressions and calculated colour rendering indices do not correlate. We have participated in this international work and performed a number of visual investigations[21, 22, 23, 24, 25, 26], concluding that the CIE method needs updating and pointing on possible updates, mainly to use colour difference evaluations based on the CIECAM02 colour appearance model[27].

Thus, for developing a new colour fidelity metric, our intention was to update the present CRI test method, using most advanced colorimetric techniques. To do this the single major steps of calculation were re-examined.

For chromatic adaptation CIE selected first the Nayatani formula before settling down on the Bradford transformation. An early recommendation to change to a more up-to-date chromatic adaptation transform was presented at the Farb-Info in 1980[28].

The selection of the test samples is a further question, with which we have dealt already in the early 80th, especially with the better representation of skin tones[29, 30]. The final finding on the question of selecting samples for colour rendering investigations were summarized in a paper for CIE Division 1 in 2010[31]. In this investigation we have found that metameric samples to the CIE Test Samples can lead to very different CRI values, and concluded that more than the present 8+6 samples are needed, and that it is important to use metameric samples of low and high colour inconsistency to cover properly the multitude of real samples. Further steps in this direction[32, 33, 34], using virtual samples as well, are still under discussion. The CRI2012 metric[35] provides two outputs: based on some very special artificial reflectance spectra a general colour rendering index was designed, and using two times 90 real test samples of low and high colour inconsistency indices the user gets information where in the colour solid one has to count with poor colour fidelity.

4. Colour preference

Based on the first evaluations by Judd[36] and Jerome[37], CIE started research, investigating what the spectrum of a light source has to be to render the appearance of test objects more favourable as the reference illuminant (Planck source or phase of daylight). Our contributions went first in the direction to find relationship between colour rendering and the impression of visual comfort[38], checking for the preferred skin tone[39]. We found that skin tone of Caucasian subjects, tested by European observers, is darker and more reddish as the CIE test sample. Based on these investigations also a combined colour rendering-colour preference index was suggested[40]. Difficulty with colour preference is that it is not easy to specify what preference for an average interior scene means. Our experiments have shown that for questions like preferred, more vivid, more lively, more natural, not the same light source gets the highest scores[41].

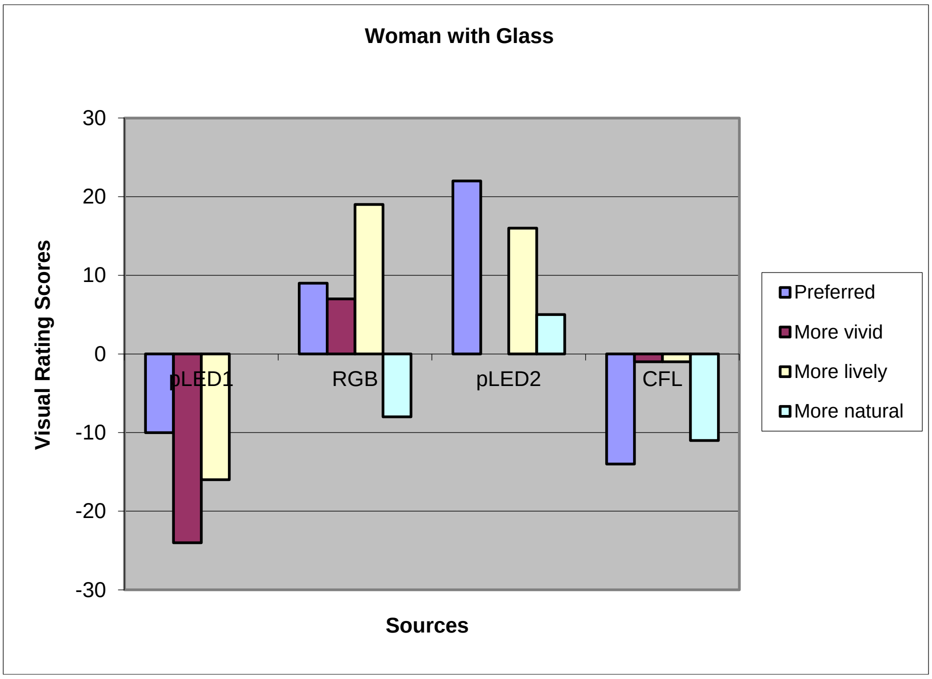

Figure 2 Visual rating scores of four light sources (two p-LEDs, an RGB-LED and a CFL) for the questions preferred, more vivid, more lively, more natural.

As seen in Figure 2 e.g. for the RGB-LED liveliness is evaluated positively, but naturalness negatively; none of the descriptors run in parallel, thus one cannot define a general colour preference scale, for different purposes different sub-metrics seem to apply.

There is also a further problem with preference – that goes back to flattery: If e.g. a lady intends to prepare a lively make up under her home light of good fidelity and goes then into a room with highly flattery sources, she will be certainly be shocked about her make-up. It is safer to use high fidelity sources and design the environment to look natural and preferred under those sources. This will also help against the misuse of such lamps in shops (see “butcher’s lamp” that shows non-fresh meat as acceptable).

A better direction for preference is to use light spectra that keep the harmony of the environment compared to the harmony under natural light[42, 43]. If a test light source distorts the colours systematically compared to the reference source, thus e.g. changes the hue angle of the colours in the scene in the same direction and approximately by the same amount, this will not be observed as offending, but if for one colour the change is in one direction, and for another in another direction, so that the relative distances between the colours change, this will distort the harmony, and will not be accepted by the observer.

5. Colour discrimination

For a number of industries the easy distinguishing between colours is important (cotton shading, using coloured wires). First ideas went in a direction that a higher gamut will enhance colour discrimination ability[44]. We could show that due to non-uniformities of colour spaces this is not always the best solution, and recommended an alternative method, where the small colour differences in the vicinity of some reference colours was used[45, 46]. The new index correlated much better to visual observations[47] as gamut area or CRI.

6. Summary and further work

The original single quantity: colour rendering covers now a day three different quantities: colour fidelity, colour preference and colour discrimination. All three quantities need metrics and units to be able to decide how well different light sources satisfy one criterion or the other. We have shown that for colour fidelity we might use up-to-date colorimetry to develop a colour fidelity index, and we hope that with CRI2012 we are on the right track[35].

The construction of a colour preference index seems to be more complicated, and further research is needed in this field.

To describe colour discrimination, most papers try to use gamut area. We could show that as here small colour differences have to be evaluated, better metrics could be envisioned.

But there is a further question when the spectrum of a light source – and especially the spectrum of an LED – has to be optimised: the light source has to be efficient. Good colour rendering and high efficacy have to be attained at the same time. And here the question of a harmonised colour fidelity-colour preference index might be re-visited. A further step could be to combine the colour fidelity model with our model described in reference[40], and not punish small deviation from the reference colour if these are in a direction that would increase colour preference. Optimizing all these with light source efficacy would lead to the future optimum home lighting light source.

Acknowledgments

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CIE Centenary Conference

TOWARDS A NEW CENTURY OF LIGHT

Paris, April 15 and 16, 2013

Dear Colleagues, CIE's hundredth Birthday is approaching fast! Find below the Invitation Letter of the CIE President and the President of CIE France. Submission Guidelines are included in the system itself. The respective link will be published at www.cie.co.at.

Invitation letter

CIE is celebrating its one hundredth anniversary! A century during which our knowledge of lighting fundamentals has taken enormous leaps forward, bringing new applications of light supported by both technological advances and economic success. A century that began with the revolution of the electric light and efforts to bring both the electric light bulb and the power it required into common use ends with the need to reduce energy distribution and use, and brings a technology that promises to achieve this for lighting.

CIE's mission "to promote worldwide cooperation and exchange of information on matters associated with light and lighting" is as relevant today as it was one hundred years ago.

As we move into a new century, knowledge, technology and the economy bring new challenges, among them:

- Light is important for vision, and is also crucial for health and mood
- Light is in need of measurement, appropriate to application and effect
- Light is a commodity, but it is also art and design, interactive and personalised
- Light is a commodity, but it can also be disruptive, a pollutant, an irritant, a waste.

Our understanding of new technologies and the impacts of light must be used to enhance the positive and reduce the negative effects of light. Light, like life, should show versatility, intelligence and sustainability, realising that "the more the better" is not always necessary or best.

In celebration of a centenary of knowledge, and in recognition of our new challenges, we present a conference centred around three themes:

- Rhythm of life, rhythm of light
- Intelligent lighting
- City at night

We would like to celebrate our centenary in the company of our valued CIE members, with their vast technological expertise, and with those who use and appreciate light as art and healing or inspiration, providing a special forum for discussion and interaction.

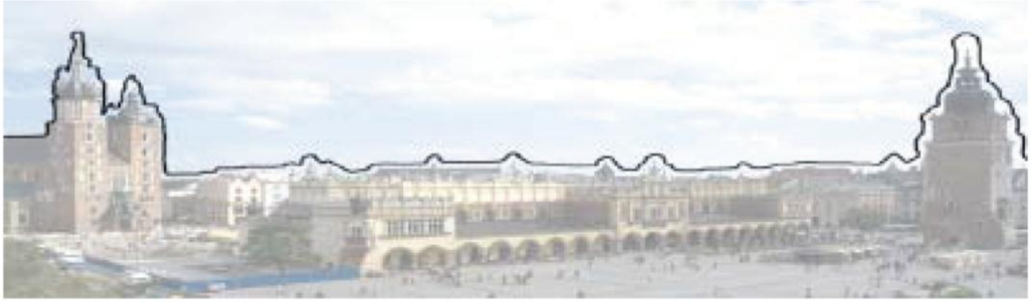
It is our honour to invite you to discuss these subjects during a two-day conference, as participants or as contributors. We have chosen the venue in Paris for its very obvious long history in lighting. This is also where the CIE was officially created and hosted.

We are looking forward to meeting you in Paris.

Ann WEBB
President of the CIE

Cyril CHAIN
President of CIE-France

www.cie.co.at



LUX EUROPA Kraków 2013

LUX EUROPA 2013
12th European Lighting Conference

KRAKOW
September 17th – 19th, 2013

Application meets Technology in Lighting

Invitation letter

Dear Colleagues,

On behalf of the Polish Committee on Illumination and the Organizing Committee of the LUX EUROPA 2013 Conference, I have the pleasure to invite you to the 12th European Lighting Conference in Krakow. We hope that the conference will provide an opportunity to present the latest scientific and technical developments as well as to broaden existing contacts and to make new acquaintances. It will also enable participants to visit some attractive places in Krakow and in Southern Poland.

Krakow is the former capital of Poland. The 13th century merchants' town has the largest market square in Europe and numerous historical houses, palaces, churches including the Gothic cathedral where the kings of Poland were buried and ancient synagogues, as well as the Polish oldest Jagiellonian University. Its new compound will be the venue of the conference. The city historic centre together with the nearby Wieliczka salt mine were two of the first 12 objects included in the UNESCO World Heritage List. The Tatra Mountains situated ca. 100 km south of the city, together with the popular ski resort

Ingineria Iluminatului 2012; **14, 2**: 57-58

Zakopane, provide an excellent opportunity for relax at any time of the year.

LUX EUROPA is a society of 20 European illuminating associations, with a task to spread lighting ideas, lighting knowledge and lighting expertise by holding European lighting conferences every four years.

The 12th European Lighting Conference will be held in Krakow on 17th – 19th September, 2013.

The Conference will be organized by the Polish Committee on Illumination SEP.

On behalf of LUX EUROPA Council and of the Conference Organizing Committee, I have the pleasure to invite you cordially to take part at the event.

Conference Subjects:

- Lighting Technology
  - LED and OLED
  - Lighting Controls
- Daylighting
- Interior Lighting
- Exterior Lighting
- Lighting for Transport
- Light and Architecture
- Human Aspects of Lighting
  - Vision and Physiology
  - Light and Health
  - Psychological Aspects of Lighting
- Photobiology and Photochemistry
- Measurements and Standardisation
- Economics of Lighting
- Light and Environment
  - Sustainability
  - Energy Efficiency

Presentation Types

- Presentation (15 min)
- Poster with a short presentation (5 min)
- Poster

Conference Languages

- English
- German
- French

with simultaneous translation.

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http://www.ee.pw.edu.pl/CIEPoland/LUXEUROPA/en/index.htm

ENERGY MANAGEMENT IN PUBLIC LIGHTING INSTALLATIONS

Răzvan-Bogdan VASILIU, Technical University of Cluj-Napoca

The Thesis Advisor: Ph.D. Mircea CHINDRIŞ, professor, Technical University of Cluj-Napoca. The Ph.D. thesis was presented in a public debate at the Technical University of Cluj-Napoca, Romania, on 2 October 2012. The author obtained the scientific degree of Ph.D. in Electrical Engineering.

The aim of the thesis was to study the possibilities to manage the energy consumption in public lighting installations. This concern is fully justified for the following reasons: public lighting is a major energy consumer presenting a significant potential for energy savings, public lighting installations operate in harmonic and unbalanced regime that cause increased power losses in the phase and neutral conductors, the low quality of electrical energy determines lower performances for lighting equipments and the fact traditional public lighting systems can not provide an adaptive and efficient lighting service.

The thesis is divided into five chapters, references and appendixes.

Chapter 1 Equipments used in public lighting analyzes the performances of lighting equipments used in public lighting by describing all the electrical, photometrical and general quantities that define the main types of light sources used, provides a comparison of luminous efficacy of the lamps, an analysis of power losses due to ballasts and present the software application for analyzing the lighting equipments offer. Although there are a variety of types of light sources that can be used in public lighting applications the thesis only analyzed compact fluorescent lamps, high pressure sodium lamps, quartz and ceramic metal halide lamps and LEDs because they satisfy important requirements such as high values for luminous efficiency, light output, lifetime, color rendering, etc. An important quantity that describes the efficiency of light sources is represented by luminous efficacy. A study was conducted in order to present a comparison of luminous efficacy as a function of light output and light temperature between the same type of lamps. The chapter also covers important details related to control gears and wiring diagrams used in public lighting. In order to optimize the lamp-ballast selection an analysis was conducted that compared power losses due to ballasts as a function of lamp power and ballast type. The study was based on data provided by the manufacturers. It was assessed that in a traditional lighting system that uses discharge lamps, electronic ballasts provide up to 50% lower losses compared to electromagnetic ballast. For LEDs the study revealed that losses due to drivers represent on average 15% of all the power.

The final part of the first chapter presents the software for analyzing the lighting equipments available on the market. The program aims to assist the lighting designer in the stage of preselecting lighting equipments. The Visual Basic programming environment was used to develop the software which relies on a database containing data on over 1000 lamps, ballasts and luminaires. The program consists of several windows that perform key functions as: presenting the main electrical, photometrical and general characteristics of the lighting equipments, allowing the comparison between the same type of equipments, providing the user with the possibility to obtain a complete lighting solutions so it could be implemented in a new lighting network, allowing the possibility to update the database so it can display new products available on the market. Based on these features the user can compare the existing equipments and determine the best solutions available.

Chapter 2 Power quality in public lighting installations synthesizes the aspects regarding electromagnetic disturbances (unbalances and harmonic distortions) that determine the growth of power losses in lighting networks and provides the results obtained due to the analysis of three study cases. It also presents the methodology for calculating the power losses in power lines and the results obtained due to the power losses calculation in lighting networks working in asymmetrical sinusoidal, symmetrical sinusoidal, asymmetrical sinusoidal and asymmetrical non-sinusoidal operating regimes.

The connection of the same number of identical lamps on every phase of the supply system very often does not assure the balance of the distribution network. The advantage of using the U distribution, which assures the same voltage losses, is highlighted. The methods used to calculate the supplementary neutral current do to the use of discharge lamps that represent single-phase non-linear loads are also presented.

The measurements of the electrical characteristics of three lamp-ballast assemblies (equipped with high pressure and metal halide lamps and electronic or electromagnetic ballast) are presented. The measurements were conducted for different supply voltages in order to observe the variation of the main electric quantities (active and reactive power, power factor, input current) and harmonic pollution indicators (THD, current harmonics level).

In order to determine the neutral current based on the measurement results, three study cases were defined that implied a lighting network (consisting of 30 luminaires equipped with the above mentioned assemblies) operating in balanced or unbalanced regimes. The results show a decrease in value for the neutral current as the supply voltage is reduced for the assemblies equipped with electromagnetic ballast and just the opposite in the case of the one equipped with an electronic ballast.

Based on the methodology of determining power losses in power lines a study was conducted. The study implied the calculation of power losses in active and neutral conductors for a lighting network, equipped with the assemblies described before, operating in theoretical and real working regimes. The study revealed that in the real working regime (unbalanced) the neutral current has an important value that leads to significant additional losses compared to the balanced regime.

Chapter 3 Switching and control of public lighting installations describes the main switching and control methods used in public lighting installations. The analyzed methods are: manual switching, automatic switching (using photocells, timers or motion detectors) and telemanagement control systems.

Classical public lighting systems use either manual or automatic switching methods. The manual switching method is outdated compared to automatic methods which present some advantages like: on/off switching based on a specified scheduled (timers), based on ambient light levels (photocells) or based on motion detection.

The importance of implementing modern control systems is also described. Different literature research studies classify these modern control systems in adaptive or intelligent systems. The main dimming methods used nowadays for discharge lamps and LEDs are synthesized. By dimming the light output of lamps important energy savings can be obtained. The thesis also describes the importance of telemanagement systems and the most common architecture with its main subsystems. The final part of this chapter assesses some existing systems implemented in Europe and highlights the energy savings obtained or forecasted.

Chapter 4 Energy management in public lighting installations analyses the energy management problems in outdoor lighting installations by presenting the main objectives, policies and strategies for energy efficiency and how they were implemented as part of a telemangement system.

Telemanagement control systems reduce energy consumption by remotely controling and monitoring public lighting installations. In order to determine the energy savings that can be obtained by controlling two public lighting installations (consisting of 30 luminaires each) and how these savings can be improved, a telemanagement system suggestively entitled TELISYS (TElemanagement LIghting SYStem) was developed. First, the system's arhitecture with its main subsystems and the communication protocol used are presented. The software component is also described as it represents a key aspect in understanding how the system is controlled.

The interface and computing blocks that are part of the software are presented. The interface is intended to simplify the complexity of monitoring lighting installations. It comprises of a set of windows performing important functions such as: planning, maintenance, etc. The computing blocks enable harmonic pollution analysis, calculation of power and voltage losses for each network and for each segment of these networks. In addition, the program allows the visualization of current waveforms in the network analyzer window and displays the values of the main electrical and photometrical quantities of each luminaire.

The simulation of the telemanagement system is also detailed. First the control devices and lighting equipments installed in the two lighting networks are presented. Based on experimental measurements and the use of cubic spline interpolation function the behavior of two lamp-ballast assemblies operating in normal and dimming conditions was successfully implemented in the system.

The chapter also treats important aspects regarding the monitoring and control of the two lighting networks by describing the working schedules (based on sunset/sunrise times, traffic density) used in order to operate the lighting networks. Based on the results obtained by using the schedules mentioned above, the final part of the chapter presents the results of an economic analysis that highlights the energy savings obtained due to the use of the telemanagement system compared to the results obtained in its absence.

Chapter 5 Conclusions and personal contributions presents the final conclusions and contributions of the author's work in this thesis and possible directions to follow on the approached subjects.

The main contributions of the author are:

- Comparative analysis of luminous efficacy between the same type of light sources considering the manufacturer, light output value and light temperature;
- Optimization of lamp-ballast selections by comparing power losses for main types of ballasts;
- The development of a software application that includes a database containing more then a 1000 lighting equipments, that can be used in order to identify and analyze the best equipments available on the market;
- Comparative analysis of harmonic pollution induced by three lamp-ballast assemblies used in street lighting;
- Determination of power losses due to the use of three lamp-ballast assemblies in lighting networks working in theoretical or real operating regimes;
- The development of a software component for a telemanagement system in Matlab/ GUIDE in order to achieve energy savings by managing the energy consumption in two lighting networks. The software has the following key attributes: an interface with several key windows for controlling and monitoring lighting networks, graphical map showing the position and operating status of each luminaire, computing blocks for determining line and neutral currents in different operating regimes, active power losses and voltage losses for each segment of the phase or neutral conductor as well as total losses and power quality indicators.

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Răzvan-Bogdan VASILIU received the Dipl.Ing. Degree in Electrical Engineering from the Technical University of Cluj-Napoca, Romania in 2009. His fields of interest are lighting and energy management in public lighting installations. He attended research visit sessions in Romania (Braşov) and abroad (Budapest-Hungary).

INTRODUCTION TO CENTER FOR SUSTAINABLE HEALTHY BUILDINGS

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Dr. Jeong Tai KIM is a Professor of the Department of Architectural Engineering at Kyung Hee University located in Republic of Korea. He got his doctoral degree from Yonsei University, Korea in the area of architectural lighting. His professional life is densely filled with research, practice, publication, and teaching for the growth of environment-friendly architecture. He has been directing the “Light and Architectural Environment Laboratory (LAEL)” nominated as the National Research Laboratory (NRL) by Korea Government since July 2001 and the first NRL in field of lighting and architecture.

The Center for Sustainable Healthy Buildings (CSHeB)

The Center for Sustainable Healthy Buildings (CSHeB) has been nominated as an ERC in September of 2008. It dedicates to the advancement of new ideas, substantiation of related researches, international cooperation, the training of professionals, and the growth of pragmatic knowledge in the field of healthy building design, control, construction, operation and management.

As the director of the CSHeB, he has tried to establish an outstanding R&D center with global competitiveness by providing on-site research facilities, formulating synergistic interconnection with inter-disciplinary researchers, and promoting collaboration and cooperation with various industries, government departments, and international universities. He also plays a key role in promoting sustainable healthy building technologies academically by hosting international symposiums, seminars, and workshops. During the last 5 years as director of CSHeB, he presented lots of research outcomes on various aspects of the health design works in terms of sustainable environment.

Research Grant

Total research grant is approximately US$ 15 million for 10 years (September of 2008 to February of 2018) including Government, University and industries’ fund.

COE & ERC

The Engineering Research Center (ERC) of the Center of Excellence (COE), funded by Ministry of Education, Science and Technology, and National Research Foundation of Korea has been established for purpose of systematizing a pool of excellent university researchers across the country and fostering a team of world-class leading scientists by providing intensive support for them.

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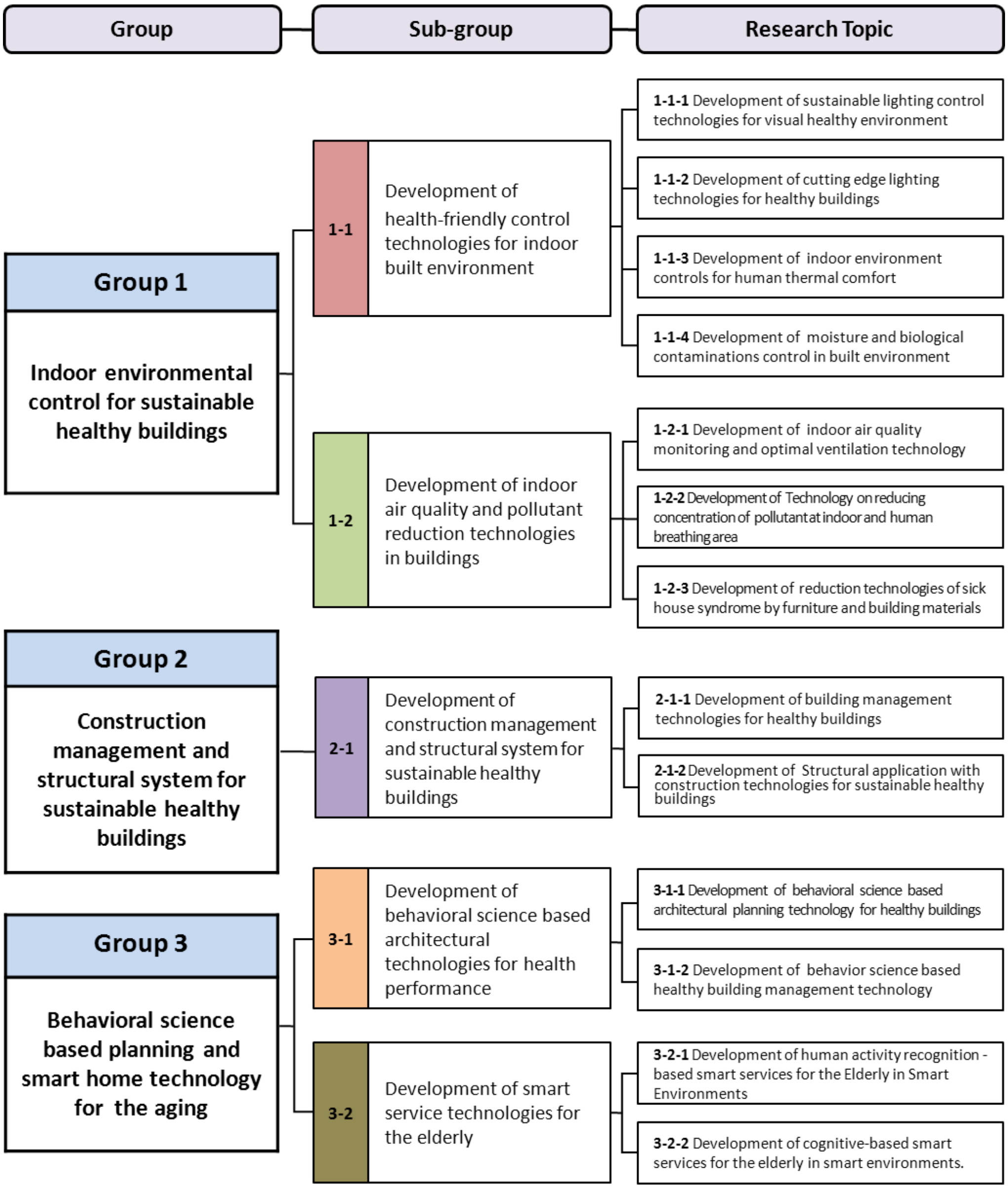
Matrix of Research Topics

The CSHeB is conducting the whole of the research projects in three phases for 10 years as follows: 1st Phase (Sep. 2008 – Feb. 2012)/2nd Phase (Mar. 2012 – Feb. 2015)/ 3rd Phase (Mar. 2015 – Feb. 2018). The CSHeB consists of 3 research groups, 5 sub-groups and 13 research topics with 7 universities, 15 professors, 10 post-doctor fellows and 60 graduate students. The following is the research matrix of the 2nd Phase.



Lighting related research topics

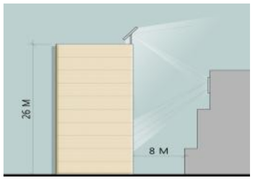
Prof. Jeong Tai KIM, the Director of Center for Sustainable Healthy Buildings is responsible for the whole research program. And he also has been leading Group 1-1 in conducting the whole of the research projects on health-friendly control technologies for indoor built environment. Due to the limited pages, this section describes two lighting related topics 1-1-1 and 1-1-2.

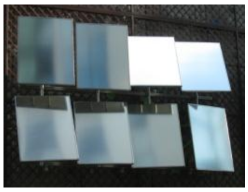
Topic 1-1-1 Development of sustainable lighting control technologies for visual healthy environment:

This research project recently developed a refurbished version of conventional daylighting system for the purpose of maximizing its role for occupants' visual health and sustainability of the indoor environment, dealing with basic performance elements such as floor plan, geometry, orientation, controls and glazing materials. This research project proposes an experimental configuration of external shading device which can be applied to apartment houses, promising the most efficient performance with various adjustments of control techniques. The research project also investigates spectral characteristics and intensities of UV rays which penetrate into built environments, revealing their harmfulness for occupants' visual health. With newly-developed advanced health-oriented visual system, the research project aims toward the expectation of an average 15 percent surge in its daylighting and view performance / an average 20 percent surge in visual comfort / an average 20 percent attenuation in CO_2 emission / an average 10 percent surge in optical function of daylight.

Topic 1-1-2 Development of cutting edge lighting technologies for healthy buildings:

This study aims to contribute to creating healthy buildings which improve both the health of occupants and the carbon performance of buildings using cutting-edge natural and artificial lighting technologies. In order to achieve this aim, this study has developed advanced daylighting devices such as an active mirror type device, and also created their performance prediction models on the basis of field measurements, so that the advanced devices can be easily integrated into the design of architectural lighting systems. Another outcome of this study is the development of wavelength controllable lighting systems, which provide the spectral power distributions that match closely with the sensitivity of human circadian rhythms. This study will also provide the prototype of sustainable healthy lightings systems and their operation manuals for various buildings types.





International Symposium

The CSHeB hosts annual international symposium on Sustainable Healthy Buildings (SHB) twice a year. The 1st International Symposium on Sustainable Healthy Buildings was held on 6 February 2009 at Grand InterContinental Hotel, Seoul, Korea. And the 2nd (9 October 2009), 3rd (27 May 2010), 4th (19 November 2010), 5th (10 February 2011), 6th (27 February 2012), 7th (18 May 2012) and 8th SHB (19 September 2012) were successfully held in the same venue. More than 200 people participated in the every symposium. And world-leading scholars were invited as the keynote speakers.

Invited Speakers at the 1st International symposium. From left to right; Professor Alan Dilani at International Academy for Design and Health in Sweden, Professor Qingyan Chen at Purdue University (Editor in Chief of Building and Environment), Professor Jeong Tai Kim of the CSHeB Director, Professor Koen Steemers at University of Cambridge, Professor Jan Sundell at University of Texas at Tyler (Editor in Chief of Indoor Air).

International Cooperation

The CSHeB has cooperated with many well-known oversea research institutes as follows; University of Cambridge, Georgia Institute of Technology, University of Michigan, Texas A&M University, University of Florida, Karolinska Institute in Stockholm The International Academy for Design and Health, University of Art and Design Helsinki, Leibniz University Hannover, University of Shanghai for Science and Technology, University of New South Wales, China National Engineering Research Center for Human Settlements (CNERCHS), Chinese University of Hong Kong.

From left, MOU with Cambridge University, ISBE, CNERCHS and Florida University.

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Invitation for Post-doc. and Postgraduate students

The CSHeB cordially offers post-doctoral positions and research fellowship to foreign doctoral degree holders and to foreign postgraduate students. For more detailed information, please contact directly to **jtkim@khu.ac.kr**

LIGHTING IN THE NEW WORLD

Cristian ŞUVĂGĂU
BC Hydro, Vancouver

LEDs- Leading the Digital Revolution

Any conversation about LEDs, between practitioners or simple users, is becoming these days a replacement for other lighting topics. The quantum dynamics that create light in the LED semiconductor represent as much of a technology step change as the move from candles to incandescent lamps in the 19th century. With fast, bold steps the digital/ solid state technology is taking over the conventional lighting and LEDs are leading this revolution.

In less than 10 years (this is my third editorial on this particular technology since 2004), LEDs have not only jumped from low-light applications (under-cabinet and traffic lights) to high flux ones (tunnels and high-masts) but challenging with growing, continuous success the “Wholly Grail” of applications: ambient lighting. Although still not as energy and effective as their T8/T5 fluorescent counterparts, LED luminaires are found more and more in office and institutional general lighting applications. And on the HID battle-front, few manufacturers have now high-bay LED luminaires that can match illuminance levels coming from conventional 400 W MH or HPS and also save a min 30% in energy costs.

Where Is the SSL Revolution Headed?

Efficient lighting in our homes, offices and city streets is a key part of a “clean” revolution – a swift and massive scaling up of clean technologies to create a safe climate, boost economic growth, and secure a prosperous future for all.

While the potential of a revolutionary technology is many times under or over-estimated (function of each ones analytical understanding of the present and visionary concept of the future) its development is always a battle with the past. If LED lighting is so economical, why does the market not deliver it automatically? The explanation can be found in a number of barriers that limit deployment of cost-effective lighting technologies. End-users and market actors are often unaware of the savings potentials and lighting-quality advantages and without information are inclined to use the technologies that they have always used.

Moreover, the success of a technical revolution is when the market is offered a different paradigm. For example, the recent introduction of electroluminescent TV displays (plasma, LCD) has allowed not only a better watching experience but (using the solid-state status) has integrated on-line content (internet, Facebook, Youtube)

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transforming thus the simple TV in a powerful media/entertainment center.

When it comes to LED lighting the paradigm change is not so easy: Edison's invention does not let go so easy. Over 80% of worldwide lamp sales are for incandescent bulbs. With billions of ceiling sockets, residential general service lighting (i.e 60 W-100 W A19 lamp) has the largest economically attractive electricity savings potential for LED upgrade. Still, one major hurdle for LEDs: create omnidirectional light distribution with directional point sources! So many manufacturers have tried, and some have brilliantly succeeded also by creating new enabling innovations for light distribution (Philips' remote-phosphor) or heat–management (metal fins - GE and Osram - or passive-convection with cooling liquid - Switch). These mentioned manufactures (and few others) can now effectively challenge lumen outputs of 75 W and 100 W bulbs as well.

For the reflector lamps the task is somehow less difficult (LEDs being native directional sources) but the challenge is still in exact beam control (the multi-beam selector switch from Light Science) and the elimination of the heavy aluminum heat sinks (more have started using enhanced polycarbonate bases). However, a (minor) paradigm change for LED directional lights is to standardize the components of LED luminaires to reduce costs. GE (INFUSION) and Bridgelux/Molex (HELION) have already produced flexible, upgradable and replaceable LED modules (used like "light cartridges") for track or recessed spot lights offering 500 – 1500 lm in narrow, medium and flood beam angles.

One of the leading force for LED standardization is ZHAGA, a consortium of worldwide LED industry players (light engine and luminaire manufacturers) focused on setting global standards regarding interface standardization for LED light engines (mechanical, electrical, thermal, controls and photometrical). Founded in 2010 the consortium has grown to over 280 companies – a clear indication of the need for interchangeability.

The real change is however when manufacturers move away from the old luminaire-lamp paradigm and allow SSL's unique characteristics and strengths to guide the design, just as the industry's focus is beginning to shift toward integral luminaires rather than replacement lamps. In order for LEDs to fulfill their potential and truly revolutionize the lighting market rather than just penetrate it, the industry has to look beyond short-sighted solutions (re-lamp existing sockets) and completely rethink many of its aspects that we've taken for granted (such as direction of light, ceiling/suspended luminaires or static color temperature). Smart-designed, integral LED luminaires not only benefit from the LED direct light distribution to focus on visual tasks that once required sophisticated optics (from fluorescents or HIDs) but often use the whole luminaire mass for optimal heat management.

Current SSL Lighting Trends:

- **Recessed downlights** – represent a more mature technology using mainly high-flux LEDs in fixtures of 3-6 inch diameter. The great majority these lights meet or exceed incumbent (CFL) output levels. LED downlights' efficacy varies greatly from 12 lm/W to 80 lm/W, but the average of the category as a whole (45-55 lm/W) exceeds the average CFL benchmark (30-40 lm/W). LED downlights have high average CRI values (82) and have a small spread of CRI values pointing to the more demanding color requirements of residential applications.

- **Edge-lit LED flat panels** – area light sources poised to replace fluorescent general lighting have originated from LED backlight technology in LCD displays. Emission from LEDs at panel edge is coupled into the waveguide, propagates and is scattered by surface features (v-groove, microlens) with efficiencies (panel output/LED output) varying widely from 55 to 95%. The emission spectrum is by-and-large the same as the LEDs used. It is possible to use both cool and warm white LEDs and have a CCT tunable source (e.g. LG Innotek), or to use RGB LEDs and perform color mixing within the waveguide. Since tens or even hundreds LEDs may be used, tight binning of individual LEDs is not as critical to panel-to-panel color matching. Alone or in combination with additional optical films it is possible to realize high angle cut-off for glare control and bat-wing distribution for indirect, volumetric lighting. Harnessing the rapid development of LEDs in both performance and cost, edge-lit LED panels will certainly be a major area source technology. There are currently few manufacturers that can deliver more than 5000 lm for a typical 2x4 troffer benchmark or 3000 lm for a 2x2 at comparable 50-70 lm/W overall luminaire efficiency.

- **High-flux modular luminaires** – mainly used to replace high-lumen fixtures in medium to high ceiling or outdoor applications. The multi-watt LEDs are designed for 350-700 mA currents and can be under or overdriven for longer life or respectively higher output. The photometrical enhanced lenses are built in the individual LED assembly according to the chosen distribution. While some manufacturers lay LEDs in patterns that will complement the photometrical delivery (circular, ellipsoid, asymmetric), other simply use rectangular modules (bars) with individual lensed LEDs. The apparent advantage is that incremental luminous output can be obtained using the same chassis by adding or subtracting the modules without significantly affecting the photometrics. This not only reduces the costs by standardizing the components, facilitates effective maintenance (easy replacement) but also allows for an easier upgrade (to more efficient, higher-flux newer LED generations). Some luminaires are built with open spaces between the bars to allow for enhanced and efficient (chimney-effect or rain-wash) cooling.

- **OLEDs** - As futuristic as they may seem, OLEDs are also edging toward the brink of market-readiness. The opportunity to surface printable luminescent materials can dramatically revolutionize the way we know lighting. Acuity Brands Lighting has presented OLED luminaires prototypes that, of 3000-4000 lm, >70 lm/W) and color-tunable (2700 K-4000 K). Imagine your wall or ceiling being now the luminous source!

- **Dynamic sources** – color-changing or tunable sources using RGB LED chips mainly for decorative or mood-setting light concepts. While the color-changing LEDs have been used for few years mostly for façade lighting or architainment (architectural entertaining lighting) with the scope of projecting non-white effects, the tunable sources are used to display various white color temperatures to suit the occasion. Research has shown that different colors of light affect more than just our conscious vision system. The newly discovered intrinsically photosensitive retinal ganglion cells (ipRGC) in our eyes respond to blue light by suppressing production of sleep-inducing melatonin, so the naturally blue-rich light of daytime keeps us alert, while reddish evening light lets us ease into sleep. With LEDs it would be possible to adapt light color for different activities such as alertness, which in turn can affect circadian rhythm positively.

The controllability of LED light color, intensity and direction allows novel lighting system designs that can deliver a wide range of social benefits. In schools, for example, an LED lighting system with three color/intensity settings (red-rich "relax", blue-infused "energy", yellowish-mild "concentrate") has been shown to dramatically improve student performance. NASA is developing similar lights for the International Space Station because astronauts have trouble sleeping more than 6 hours a night. The lights will switch from blue-rich to keep the astronauts alert during their working day to red-rich light when they are relaxing before bed. Just recently, Philips and Apple launched the Hue bulb, which can be tuned using smartphones or tablet computers to provide any desired light color or white CCT using RBG LEDs.

- **Integral Controls** – the example of the Hue bulb is the best example of how controls could actually change the old lighting (lamp-switch) paradigm. Wired or wireless but for sure digital, controls can now co-exist in synergy with the SSLs and be the motor not an afterthought of the lighting design, adapting dynamically for convenience. Diming drivers cost a fraction of the fluorescent or HID diming electronic ballasts and will become a default feature, while the miniaturization of sensors will economically enable their integrations with LED luminaires. In a not-so distant future (SSL) lights will comprise a complex communication network where sensors and controls join forces to maximize convenience, safety and save energy, resulting in such features as road lights that brighten when a fire engine approaches and interior lights that react in a similar fashion when someone enters the building.

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Cristian holds a Ph.D. from the Technical University of Construction in Bucharest, Romania. He has been practicing and teaching architectural lighting design and energy efficiency in Europe and North America for over 25 years. He is also a member of the Canadian NC of the CIE and Past President of the BC chapter of IESNA.

The CIE - ROMANIAN NATIONAL COMMITTEE ON ILLUMINATION CNRI – COMITETUL NAŢIONAL ROMÂN DE ILUMINAT

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Professor Janos SCHANDA and the CIE Centenary celebration

When I read the Invitation letter signed by Ann WEBB, President of the CIE, and Cyril CHAIN, President of the CIE-France related to the CIE Centenary Conference - CIE Celebrating its 100th Birthday - Paris, April 12-19, 2013, one of the first names in my thoughts was that of Professor Janos SCHANDA. Because he dedicated more than half a century to Light&Lighting.

Dr. SCHANDA is the Honorary President of the Lighting Society of Hungary, member of the Optical Society of America, of The Society for Imaging Science and Technology and of several Hungarian Societies in the fields of light and lighting and optical measurements, past vice-president of the Board of the International Colour Association (AIC) and of the CIE. He is on the editorial/international advisory board of Color Res. & Appl., USA, Lighting Research & Technology, UK, Light & Engineering, Russia, Journal of Light & Visual Environment, Japan and Ingineria Iluminatului - Journal of Lighting Engineering, Romania, member of the Advisory Board of the Colour & Imaging Institute, Art & Science Research Centre, Tsinghua University, China (since 2010), recipient of the Newton Medal of the British Colour Group (2010) and the de Boer Pin award (CIE 2011).

Janos is and will always be in my memory as one of the foreign professors understanding well our needs, offering us his strong professional support. I am honoured to have a friendship relation with him.

The day when I opened the letter with his Invitation to join the international lighting field on the 1992 CIE Seminar of Computer Programs for Light and Lighting changed my life for ever. That was my first participation at a lighting conference organized in the Western world, after the political changes in my country (*see Pop, F., Pop, H.F., 1992, LID - Computer Programs for Lighting Installations Design, Proceedings of the CIE Seminar of Computer Programs for Light and Lighting, Vienna, Austria, October 5-9, Publ. No. CIE x005, pg. 80*).

There and then I met my future friends, professors or professionals working in lighting field, people supporting our further steps to enhance lighting knowledge and to uphold Romanian lighting development.

Professor SCHANDA assisted all our efforts to promote ILUMINAT conferences 2001-2009 and INGINERIA ILUMINATULUI - Journal of Lighting Engineering - (since 2001), with lectures and technical papers.

Professor Janos SCHANDA graduated in physics at the Loránd Eötvös University in Budapest (1955). His PhD thesis dealt with the "Spectroradiometric Investigation of Electro-luminescence". After graduation he worked for three years at the Hungarian Office for Measures, then he joined the Research Institute for Technical Physics of the Hungarian Academy of Sciences, where he worked as scientific co-worker, later as head of the Department for Optics and Electronics. He retired from the Institute as Head of the Department of Optics and Electronics and joined the University of Veszprém (now University of Pannonia) as professor of informatics. He headed there the Department of Image Processing and Neurocomputing. Since retirement, he is Professor Emeritus and heads at present the "Virtual Environment and Imaging Technologies Laboratory".

He worked for the International Commission on Illumination (CIE) as its General Secretary and later technical manager - the nineteen eighties and nineteen nineties. He functioned also in a number of honorary positions of the CIE. Between July 2007 and 2011 he served as the Vice President Technical of the Commission, chaired and chairs several Technical Committees, among others dealing with fundamentals of photometry, colorimetry and colour rendering.

He is author of over 600 technical papers and conference lectures.

Many happy returns to you, Janos, and a long and fruitful life!

Florin POP
December 1st, 2012

Information from the CV of Dr. János Schanda, 2012.11.18, and www.create.uwe.ac.uk/jschanda.htm.

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