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Editorial office
UTC-N – Universitatea Tehnica
28, Memorandumului Str., RO-400114 - Cluj-Napoca, Romania
Phone: +40 264 597254 • Fax: +40 264 592055 • e-mail: lec@mail.utcluj.ro
http://users.utcluj.ro/~lec/journal

INGINERIA ILUMINATULUI - Lighting Engineering - is a publishing media for valuable original scientific papers in the field of lighting engineering. The papers proposed for publication are considered based on their originality, meaningfullness and area of interest. In order to be accepted, the papers have to be remarquable in their field. The papers are evaluated by two independent reviewers. The contributions have to conform to the generally accepted practices for writing scientific papers, with respect to paper organization and style of writing.

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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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LIGHTING EDITORIAL 1.0

Dorin BEU

The 27th Session of the CIE will start in July in South Africa and this mark a change with the elected CIE president Ann Webb, an expert on photobiology. This is the first time that such an event happens in Africa, following the rule of the round-the-world destinations for the CIE Sessions. The elected CIE President strength the importance of Light&Health, the topic of last ten years, which opened new directions for lighting and increased media interest for this area. In October will be held in Madrid the Professional Lighting Designers Convention, an event which is focusing in practical area of lighting.

But, before CIE Session, there were other three events that have marked the new trends: Stockholm Light Symposium (see Ingineria Iluminatului vol. 12 no. 2) - October 2010, Lausanne Daylight Seminar and Romanian Lighting Convention – both in May 2011 (a brief report is presented in this issue). All three marked the new holistic approach to lighting with the presence of architects, engineers, physicist, biologist, psychologist, designers and you name it. These meetings were extremely important as they established a joint vocabulary, as communication is a key issue. Daylight is no more the Cinderella, as the Health & Building Performance, have save it and now architecture is reconsidering the importance. All these three events have shown a new generation of PhD students that need to get in contact and exchange ideas. That is why our review makes a statement of intention in publishing the work of the PhD students related to lighting and make the proposal of preparing a database of PhDs with contacts, main topics and, maybe, a brief description of their work.

The main event in the region was the Romanian Lighting Convention 2011 (www.rlc.org.ro), held in Bucharest between 18 and 20 May, with the intention to be a turning point. In order to bring architects and designers for the first time to a lighting event, beside major European experts in the area, organizers have invited celebrities like designer Gaetano Pesce (excellent speaker which have charmed the audience) and architect Paolo Mendez da Rocha (Pritzker 2006, a poet architect with extraordinary sketches). There were excellent presentation on all major subjects and one problem was that sometimes it was difficult to choose between parallel sections. LED was the main star at the

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exhibition starting from incandescent lamp retrofit to the new LED down-lights (we will see the disappearance of CFL down-lights in a couple of years). Despite that I would like to see more students to this event, it was good to see the first LED Design Contest, which will be excellent to see the follow-up. Last but not least, two major figures in lighting education, professors Cornel Bianchi and Florin Pop, received medals for “Spreading the Light”.

The Convention has show also the importance of the lighting designers; for the moment there are only a few in Central and East Europe. Their importance is increasing as they are the only independent, creative and practical design office which implement what researchers are presenting in the lighting reviews. Our review was not presenting their works till now, but we considered to offer them a way to send their message. We have decided to offer to lighting designers two pages to present themselves, works, ideas and advices for the young generation. There is an important link between architect and lighting designer and in order to promote this connection I can say that “good architecture needs good lighting designer”.

The latest lighting events have also shown that we need to do more to create a lighting culture. What I consider as a problem for lighting, is that the message doesn’t reach the end-users, neither on daylight side nor in electric lighting one. Our lighting associations will have to join forces in this area and have a strong PR which will have to repeat in a simple way what lighting professionals know.

This year there are a lot of change in Romanian education system, with pro and cons, but it is good to see the first Lighting Course for students from Cluj School of Architecture, a Landscape&Light Summer Course and a Guerilla Lighting. The last two events were held in Cluj-Napoca between 23 and 24 June and 54 students from architecture and landscape have participated. Courses were held by Katja Perrey (Romanian Green Building Council) and me, and it was excellent to see their enthusiasm.

In the previous number, Wout van Bommel mentioned his dream about a light box, that collect daylight. My dream is more complicated: that in few years to have a change in public mentality about lighting, starting with lighting course in schools and ending with media coverage, growing number of PhD students in this area, and LED as the most popular solution for lighting.

In the years to come, Ingineria Iluminatului (Lighting Engineering) journal will try to find a position of its own, and we will need the readers opinions. What we can tell you is that it won’t become a glossy one, neither an exclusive scientific one, as in both cases there are excellent reviews. We see it more as an alternative and as the voice of the PhD students. Your ideas and comments are more than welcome!

Dr. Dorin BEU
Director of Lighting Engineering Laboratory
Technical University of Cluj-Napoca
dorin.beu@insta.utcluj.ro

POSSIBILITIES OF NEW LIGHT SOURCES AND SUSTAINABLE ENERGY PRODUCTION IN SUDAN

Ater AMOGPAI
Aalto University, Lighting Unit, Finland

Abstract. *Electricity supply in Sudan is characterized with frequent power breaks due to aged machinery, lack of spare parts as well as increasing costs of new equipment from abroad. Roughly 30% of the total population in Sudan has access to electrical grid. As Soba Arradi area is not connected to electrical grid, diesel generators are the main suppliers of electricity in Soba Arradi area in Khartoum, the capital of Sudan. Incandescent and compact fluorescent lamps are the main light sources in use in this area. This paper analyzes the cost of electricity and lighting in Soba Arradi. Power supply and lighting systems associated with socio-economic issues are introduced. Lighting measurements and solar power required to replace diesel generators are presented. Lighting measurements in a one room house using LED, fluorescent and incandescent lamps were conducted. The costs of efficient lighting and power solutions, such as LEDs, CFLs and PV systems, are discussed. The initial cost for the PV systems proved to be higher than that of diesel generators. PV system can be suitable for electricity generation when its service life is longer (30 years for a solar panel and 10 years for a battery). The study showed that in Sudan: - PV systems can be used without inverters since solar radiation is available throughout the year; - LED lighting combined with PV systems are suitable for lighting; - PV systems have a high potential for electricity generation.*

Keywords: Sudan, electricity, lighting, LED, CFL, IL, solar panel

1 Introduction

Electricity supply in Sudan is characterized with frequent power breaks due to aged machinery, lack of spare parts and increasing costs of new equipment from abroad. Roughly 30% of the total population has access to electrical grid [1]. The majority, of population lives without access to electricity in rural areas. The main sources of lighting in urban areas are electricity and petroleum products, while fuel based lighting is the main source of lighting in rural areas. Electric lighting is mainly centered in Khartoum, central Sudan, and in fifteen independent off-grid towns. Diesel generators are used in these off-grid towns to provide electricity for lighting [2].

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More than 80% of the total electricity generation in Sudan is consumed in the capital of Sudan, Khartoum [3]. However, some parts of the city are (Soba Arradi area) still out of reach of electrical grid. Diesel generators are the main suppliers of electricity in Soba Arradi area (Figure 1). Most of the people in this area have no access to education, healthcare, or infrastructure. Lighting, clean water and communications are considered as the basic needs in Soba Arradi area. All these depend directly or indirectly, on access to electricity.

In Soba Arradi area, lighting is necessary for education, improves the security of communities, and promotes business activities at both night and day-time. Thus, access to affordable domestic lighting systems could contribute to the economic and human development of low income groups living in Soba Arradi area.

The common light sources used in this area are incandescent lamps (ILs) and compact fluorescent lamps (CFLs). Diesel oil and kerosene lamps are not anymore in use in Soba Arradi area. Instead, portable lights (LEDs) and candles are used.

This paper is structured as follows. Section 1 describes the access to electricity and electric lighting consumption in Sudan. Light sources and electric power supply use in Soba Arradi area are also described in Section 1. Electric power supply and lighting systems related to socio-economic of the residents in Soba Arradi are covered in Section 2. Section 3 discusses the illuminance levels measurements and solar power required to replace diesel generators in Soba Arradi. Cost of effective lighting system and power supply solutions are discussed in sections 4 and 5.

Figure 1 Soba Arradi area Khartoum, Sudan.

2 Lighting usage in Soba Arradi area

About 6000 inhabitants living in Soba Arradi area have no access to electrical grid. Diesel powered generators are the only method to generate electricity, for supplying electricity to houses in Soba Arradi. Each of these supplies up to 50 houses with electric energy. Usually, houses with one or two rooms are made of mud mixed with dried cattle dung and grass, and wooden beams (Figure 2).

Figure 2 The one-room house where lighting measurements were conducted in Soba Arradi**.**

In the day-time, electricity is used to power shops, refrigerators, TVs and radios, or mobile phone chargers in healthcare centres. After sunset, electricity is used mainly for lighting applications. Shops, healthcare centres and houses use ILs, fluorescent lamps or CFLs for lighting.

Typically, each room has one lamp, IL or CFL, in the middle or at the edge of the room ceiling. Portable lights and candles are also used.

One house is occupied by several persons living together. It may include a family with three, four or five children and hence it is crowded. Often, cooking is conducted in the room with charcoal or wood fire, but gas is also a very common mean of cooking in Soba Arradi area. The electricity is used for general lighting and for reading or writing.

Most of the diesel generators used in Soba Arradi area are made in China. Usually, no maintenance problems are experienced. The residents are always advice to use energy-efficient light sources such as CFLs.

ILs consume a lot of energy and this can cause load problems for the generators. Yet, the residents use inefficient ILs in their houses. This is due to the high price of CFLs, but, for long term operation and energy saving, CFLs would be the best option.

3 Lighting measurements in Soba Arradi area

The total lighting energy used by lighting depends on the rated power of the lamp and the daily burning hours. The room and the position of the lamp to working area have an effect on the illuminance, and illuminance distribution [4].

An effective lighting system should provide adequate quantity and quality of light. Illuminance and its distribution characteristics can be used for the quantity of light, while for lighting quality several parameters are needed such as luminance, luminance distribution, and colour characteristics [5].

A one room house with dimensions 5 m ×4 m × 2.5 m with two windows, each with dimensions 0.85 m ×1.05 m and one door with dimensions 1.85 m × 1.05 m was chosen (Figure 3). In the day-time there is no need for artificial lighting as enough light gets through the windows and the door.

The lighting measurements were conducted at both night and day-time. The lamps were hung at distance of 0.45 m from ceiling and the measurements were conducted at distance 1.38 m from the lamp to working area at night-time (Figure 3). The working area is a table with height of 0.75 m from the ground. Illuminance values on the working area directly under the light source (centre of the room) and at different distances were measured (Table 1).

It was not possible to perform long measurements for security reasons, since there was no advance permission to conduct such a study in the area. Such arrangements usually need time and advance permission from the authorities (security). The only available one-room house to conduct the measurements in was that in Figure 2. However, the room was full of objects and disorganised and only limited space was available (Figure 3).

The measurements were conducted in one day: during the daytime from 1:00 pm to 2:00 pm and at night from 8:00 pm to 9:00 pm. The main objective was to point out the importance of using efficient lighting. This could be the first step to starting introducing lighting technology combined with PV systems in Sudan.

Results: The day-time measurements showed that the highest illuminance value was measured at the centre of the room (300 lx) and the lowest (75 lx) was measured at the distance of 3.2 m in the corner of the room. The illuminance value (280 lx) was almost as high in the distance of 2.5 m from the centre of the room, since this measuring point was close to the window (Figure 3).

The night-time measurements/results are shown in Table 1. LED provided the highest illuminance level in the centre of the room. CFL provided the highest illuminace at distances 2 m, 2.5 m and 3.2 m, whereas IL and LED provided lower illuminances at the same distances.

The illuminance levels of 25 lx to 30 lx are necessary for normal reading or writing and illuminance levels of 5 lx to 15 lx for general lighting in rural houses [5], [6]. These illuminance levels can also be used in Soba Arradi households. However, the recommended illuminance levels for indoor lighting range between 100 lx and 500 lx [7], [8], [9]. Such illuminances cannot be provided in Soba Arradi area. Unlike in developed countries, standards and guidelines for recommended lighting levels in houses are not yet in use in developing countries [6].

Table 1 Illuminances at the day-time and night-time

	Distance, m			
Light source	Centre	2	2.5	3.5
	Illuminances, lx			
Daytime light	300	190	280	75
IL (60 W)	28	9	4	2.5
CFL (18 W)	19	16	5	5.7
LED (8 W)	32	9	4	2

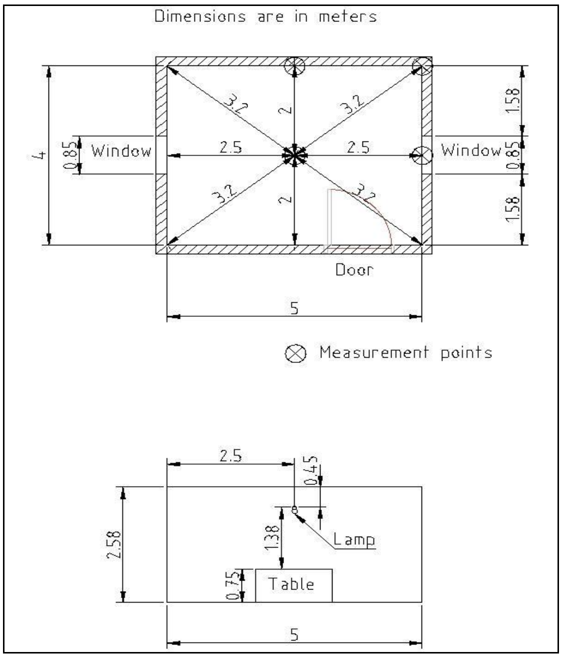

Figure 3 Dimensions of the room used for measurements.

4 Replacement of diesel generators by PV systems

Energy efficiency is especially important when the power supply is limited as is the case of Soba Arradi area. The amount of solar radiation is the main parameter that affects solar panel output. Conversion efficiency depends on the installation position and angle of a solar panel, as well as on the installation's geographical location.

A study of the replacement of a diesel generator by a PV system was conducted in the Soba Arradi area in Khartoum (15.5°N, 32.5°E). The largest amount of solar energy can be produced by using the annual optimum tilt angle. The fixed tilt angle of 15° was chosen to maximise the solar radiation received, because this angle is close to the annual optimum (Figure 4). Optimum tilt angles for Khartoum were collected for the whole year using the NASA statistical data. The daily solar radiations in Khartoum are measured data by the NASA meteorology station [10].

Solar panel area required for different light sources can be calculated based on the data gathered from NASA statistical data (Figure 4). Thus, the size of the PV panel and battery bank required was determined with assumption that solar cell conversion efficiency is 10% [11].

Equations (1), (2), were used to calculate solar panel area and battery bank size required [12], [13]. The solar panel area required A_{req} can be calculated with

$$A_{req} = \frac{1.5E_{daily}}{\eta E_{rad}} \qquad (1)$$

where A_{req} is solar panel area required (m^2); E_{daily} - daily energy consumed (kWh); E_{rad} - daily solar radiation (kWh/m^2/day); η - solar cell conversion efficiency (10%). The required battery bank size can be calculated with

$$B_{bank} = \frac{5 \times 1.5E_{daily}}{12} \qquad (2)$$

where B_{bank} is the battery bank capacity (Ah), and 12 - the voltage value (V).

The daily energy consumption was multiplied by a factor of 1.5 to account system inefficiencies that include wiring and interconnection losses, as well as inefficiency of battery charging and discharging cycles [9].

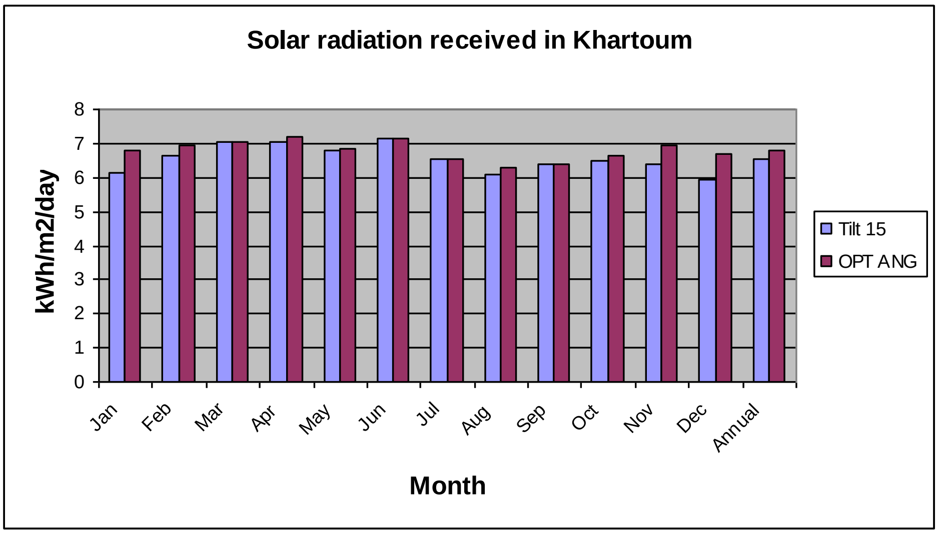

Figure 4 Solar radiation received in Khartoum (15.5°N, 32.5°E) based on optimal tilt and annual angles [10]

Table 2 Energy consumed in 50 houses using different light sources four hours/day

Light source	Lamp power	Total power (50 homes)	Daily energy consumed	Solar panel area required	Battery bank
	W	W	Wh	m^2	Ah
IL	60	3,000	12,000	30	7,500
CFL	18	900	3,600	9	2,250
LED	8	400	1,600	4	1,000

To ensure the PV system design, the minimum solar radiation received in Khartoum (6 kWh/m^2/day) was used (Figure 4). The calculation gives an approximate idea how much solar panel area and corresponding battery bank size is required for lighting devices in Soba Arradi area where sunlight is available throughout the year (Figure 4). Calculation (Table 2) showed that the largest solar panel area and battery bank required were achieved when incandescent lamp was used and with LED light source, the smallest solar panel area and battery bank required were achieved. This means that the higher the energy and power consumed, the larger the solar panel area and battery bank required.

5 Electricity and lighting costs in Soba Arradi area

Diesel generators operate as electricity suppliers to houses. Usually, these generators are own and run by individuals. They can be shop owner or even end-users themselves living in Soba Arradi. For the following cost calculation, a diesel generator with the following specifications was chosen:

Power: 9.9 kW (Maximum)
Operation time per day: 4 hours
Supplies power to: 50 homes
Length of wires to homes: 500-800 m
Initial cost: US $480

A generator consumes 300 liters diesel fuel per month which costs US $120/month and oil, which costs US $20/month. Hence, the total monthly cost of the generator operating for four hours per day is US $140. The cost of electricity for one lamp in Soba Arradi area is US $5/month for IL or CFL. Therefore, the operation cost for a lamp is US $60/year while the operation cost for a diesel generator is US $1680/year. Energy consumed by a lamp does not affect its charge price. This means that energy is wasted just through clear inefficiency and this suggests that saving energy is the most effective way to improve security of electric energy supply. Thus, it could be benefiting for a generator owner and residents to replace their ILs with CFLs, but with subsidized prices. However, the subsidy policy to purchase energy-efficient lights and solar panels is not yet in use in Sudan.

Electricity cost does not include a lamp purchase price, only the electrical energy delivered from diesel generator to light up the lamp is charged. A lamp operation cost depends on lamp price, lamp type, lifetime and time of a lamp change. For example, IL is changed after 1000 hours whereas CFL is changed after 10.000 hours [4]. This means that 10 ILs are changed compared to one CFL per year. In Soba Arradi area, purchase price for IL and CFL is US $0.8 and US $5 respectively. Hence, 10 ILs cost US $8 compared to US $5 for one CFL per year. Replacement of ILs with CFLs is economically viable and benign energy saving for Soba Arradi residents. LEDs are energy saving and can provide cost effective solution but they are not currently in use in this area.

5.1 The cost analysis of PV system

For economics evaluation of a lighting solution system, the cost analysis was carried out for the PV system assuming useful life for 15 years for solar panel and two years life for battery bank. This cost analysis includes initial and variable costs.

Initial costs are costs for the lighting or PV-system design, lighting equipment, wiring and control devices and the labour for the installation of the system. Usually, only the installation costs are taken into account and people are not aware of the variable costs.

PV modules can be purchased for about US $5/W and flooded acid batteries can be purchased for around US $1/Ah [12]. Based on these purchase prices, anything can be estimated, the only issue is to what precision we do the estimation [12]. To design PV system based on the Table 3 parameter's specifications, CFLs are considered because they are currently in use in Soba Arradi area. The subtotal cost of the PV system for CFLs is US $4500 for a solar panel and US $2250 for a battery (Table 3).

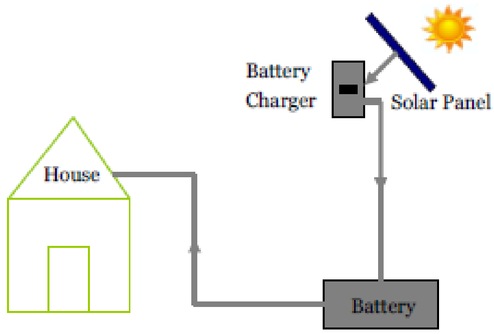

Figure 5 PV power system containing solar panels, charge controller, battery bank and wiring.

Table 3 PV system estimation size and cost for 50 houses.

Light source	Parameter size		Estimated initial cost	
	Solar panel	Battery bank	Solar panel	Battery bank
	W	Ah	US $	US $
IL	3000	7500	15.000	7500
CFL	900	2250	4500	2250
LED	400	1000	2000	1000

To account for mounting structure, wire, fuses, and switches costs, the subtotal cost was multiplied by 1.2 [12]. Therefore, the estimated cost of the PV system is US $5400 for a solar panel and US $2700 for a battery. Such a PV system could be reliable and environmentally friendly and has the potential to contribute to the development of sustainable electricity generation. In long-term operation, a PV system can perform and maintain the quality of electricity generated at a lower cost. The system could be a cost-effective solution in areas where there is no electrical grid, such as Soba Arradi.

The energy costs of the lighting or PV-system installation during the whole life cycle are often the largest part of the whole costs. The initial cost of the PV system is given in Table 3 for both solar panel and battery bank. The annual cost for PV system can be hence calculated from the Equation 3 [4] as follows:

$$C_i = I \times \frac{i(1+i)^n}{(1+i)^n - 1} \qquad (3)$$

C_i = US $486/year for solar panel
C_i = US $1458/year for battery bank
Total annual cost = 486 +1458 = US $1944, where C_i is annual costs of the initial investment; I - initial costs, US $4500 for solar panel, US $2700 for battery; i - interest rate (i=p/100, where p is interest rate in percentage, 4%); n - number of years (service life for a solar panel is 15 years and for a battery it is two years).

The calculation of the costs showed that the annual cost of the initial investment (US $1944/year) for a PV system is higher than the annual costs of the initial investment in a diesel generator (US $43.2). In other words, the initial costs for a diesel generator (US $480) are much lower than the initial costs for a PV system (US $1944), but the variable costs (operating costs) for a diesel generator (US $1680) are much higher than the variable costs of a PV system (US $60). Therefore, the total costs for the PV system are US $2004/year and for a diesel generator they are US $1723.2/year. If they use solar panels combined with CFL, the 50 houses in Soba Arradi can pay US $3000/year. For the Soba Arradi area, the PV system proved to be the higher-cost choice if the service life of a solar panel is 15 years and the service life of a battery life is only two years. However, if the service life of a solar panel is 30 years and the service life of a battery is 10 years, the total cost of the PV system is US $705/year. This is when the battery discharges 20% of its full capacity. Therefore, the choice between the higher and lower cost of the PV system depends on the service life of the solar panel and battery. The longer the service life, the lower the cost. The PV system might be more suitable for electricity generation than a diesel generator in the Soba Arradi area when used for a longer period.

Figure 6 Solar panels with manually adjustable tilt angle.

Use of solar panels instead of diesel generators would eliminate running costs of diesel fuels each year in Soba Arradi area. However, the initial cost of solar panels and batteries respectively are the obstacles for Soba Arradi residents to use PV system. They lack of funding for the higher initial investment related to PV system. Perhaps, also the lack of experience of PV systems is an obstacle for using them instead of diesel generators in Soba Arradi area.

6 Conclusions

Energy savings can be achieved when replacing ILs with CFLs in Soba Arradi area. Furthermore, more energy savings can be achieved by using LEDs, but they are not currently in Sudan's market, their cost being still an obstacle. However, CFLs purchase prices are higher than ILs. Diesel generators are expensive choice for electricity generation in Soba Arradi area. PV systems can offer an effective solution, however their initial costs are the main obstacles for their use. The initial costs for diesel generator are much lower compared to initial cost for the PV system, but its operation costs are higher. In Soba Arradi, PV system is not yet use for electricity generation. However, in the future, PV system might be suitable for electricity generation rather than diesel generator in Soba Arradi area. Diesel generators will still be in use while residents gradually switch to PV system, when their income increase and government provide subsidies and incentives to buy energy efficient products.

In Sudan, public awareness of the solar energy technology is very low, thus it is first necessary to give information about the benefits this technology can offer. In order for solar panels to become widely used, they should be available at affordable prices. Government may subsidize solar energy technology programmes.

Use of solar panels combined with energy-efficient light sources in Sudan may take decades to occur. Subsidy policies might help to encourage residences to switch into energy-efficient light sources and solar panels. The effective lighting and power solutions in Soba Arradi and similar areas in Sudan could be improved by replacing diesel generators with solar panels combined with energy-efficient light sources, such as CFLs and LEDs.

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M.Sc. **Ater AMOGPAI**
Aalto University
Department of Electronics
Lighting Unit
P.O.B13340
00076Aalto, Finland
Ph: +358417095831
E-mail: ater.amogpai@aalto.fi

He received his Master degree in Electrical Engineering in 2007 from Helsinki University of Technology, Finland. His doctoral thesis topic is LED lighting combined with solar panels in developing countries. His studied are also focusing on lightning and energy use in Sudan.

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RATING SPATIAL BRIGHTNESS: DOES THE NUMBER OF RESPONSE CATEGORIES MATTER?

Deniz ATLI, Steve FOTIOS
School of Architecture, The University of Sheffield, UK

Abstract. *Category rating is a procedure for measuring population opinion or evaluation. Many previous studies have used category rating to evaluate spatial brightness and other aspects of the visual environment in order to compare the effectiveness of different lighting conditions such as the spectral power distribution of the light source. There are suggestions in the literature that the number of response categories in a semantic differential rating scale can affect judgements. For example, Dawes' study found that mean ratings of price consciousness were different when recorded with response scales of either 5, 7 or 10 categories. A key question is whether or not the response range should include a neutral (or, middle) category, i.e. an odd or even number of response categories. There is evidence that the presence of neutral categories can enhance response contraction bias and this reduces ability to discriminate between stimuli. However, scale format has not been extensively examined for appraisals of the visual environment. Evaluations were carried out using response ranges of 5, 6, 7 or 8 categories. A range of graphical and statistical methods of analysis were employed, with one approach being to ignore all ratings given to the neutral category in odd scales. It was found that while the response distribution may have changed, the number of response categories did not affect the central tendency of opinion.*

Keywords: semantic differential scaling, response range bias, spatial brightness

1 Introduction

Spatial brightness describes a visual sensation to the magnitude of the ambient lighting within an environment, such as a room or lighted street. Generally the ambient lighting creates atmosphere and facilitates larger visual tasks such as safe circulation and visual communication. This brightness percept encompasses the overall sensation based on the response of a large part of the visual field extending beyond the fovea. Many studies have investigated how spatial brightness is influenced by spectral power distribution (SPD) of the light source and illuminance e.g. [1]-[3].

Category rating is one of the procedures by which subjective evaluations of spatial brightness may be sought. In category rating, subjects are presented with an environment

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lit by a single type of light source and use rating scales to describe the appearance of the space, e.g. a semantic differential scale of brightness, along the bright-dim axis. Different stimuli (e.g. lighting of different SPD and illuminance) are typically evaluated separately, in isolation of other visual stimuli. A range of stimuli may be evaluated in succession by a sample group (repeated measures) or alternatively each test participant may evaluate only a single stimulus (independent samples).

Of 21 previous studies of SPD and spatial brightness using category rating, 12 used 7-point rating scales [4]-[15], for example a scale ranging from 1=dim to 7=bright, and the 7-point scale is commonly used to define the semantic differential rating task [9], [11]. Other brightness studies have used different response ranges; 2-point [16], 5-point [2], [16]-[19], 8-point [20], 9-point [21] and 10-point [11]. In two studies it is not clear what rating scales were used [22], [23]. There is, however, a growing awareness that rating questions may be vulnerable to response style behaviours causing non-random response error [24] which lead Fotios and Houser to suggest that response range is one issue to be considered when screening previous studies of spatial brightness [25].

A key question is whether there are an optimal number of response categories, from both cognitive and statistical considerations: what is needed is a sufficient number of response categories that optimises reliability yet does not cause unnecessary burden upon a respondent [24]. In their review of category rating Fotios and Houser [25] suggested that a response scale of around seven points is about right as more than seven categories can lead to greater confusion for respondents [26] and does not lead to better data recovery [27]. Alwin [28] found the 2-point scale to measure attitude direction as reliably as other response scales, and thus, if the purpose of measurement is to assess only the direction of attitudes the 2-point scale will do as well or better than other forms: longer response scales add information regarding intensity as well as direction but may also encourage rating scale biases.

Dawes [29] presented previous work to demonstrate that changing the number of response categories can affect the relative mean rating and the distribution of judgements. His ratings of price consciousness with a Likert scale (strongly agree to strongly disagree) used three scale formats, 5-, 7- and 10-point response ranges, and this revealed significant effects on the mean rating but not on skewness or kurtosis. In contrast Parducci and Perrett [30] compared ratings of the physical size of squares using semantic differential rating scale of *very large* to *very small* with either 6 or 9 categories and concluded there were no significant differences in the information gained.

Response ranges may offer odd or even numbers of categories. A bi-polar response range with an odd number of categories allows respondents the option of choosing the middle (or neutral) category and not committing to a positive or negative response. The presence or absence of the middle category in a survey question can make a significant difference in the conclusions that would be drawn about the distribution of public opinion on an issue, because such alternatives usually attract a substantial number of people who may be ambivalent about other alternatives offered to them [31]. Poulton [32] suggests that response ranges with middle values enhance response contraction bias, the tendency to avoid using the ends of a scale such that ratings converge toward the centre of the response range, and that this can reduce the apparent distinction between stimuli. People are much more likely to select a middle response alternative on an issue when it is explicitly offered to them as part of the question than when it must be spontaneously volunteered: offering respondents a middle alternative can therefore make a substantial difference in the division of opinion on an issue [31], [33].

Most of the literature discussing response range format refers to social issues [31] so further data are needed to examine any effects on lighting perception. Only the study by Akashi and Boyce [16] presents evidence regarding response range in lighting evaluations because they used two response scale formats to evaluate the same stimuli, a 5-point rating scale and a 2-point (yes/no) response. The 5-point scale, having a middle neutral point marked "0", produced mean ratings around neutral which did not suggest any effect of SPD, whereas the 2-point scale did reveal some significant effects of SPD.

The aim of this article is to raise the question as to whether the number of response categories in a semantic differential rating procedure will affect conclusions drawn about judgements of lighting, thus extending the review by Fotios & Houser [25]. A brief study was therefore carried out to compare evaluations of a room using different response scale formats.

2 Method

A group of 84 university students were asked to provide individual evaluations of environmental aspects of their lecture room. A warm air system provided heating and ventilation; the room had no daylight and was illuminated by electrical lighting, this being set to the dimmed level to enhance visibility of the projector screen.

Evaluations were sought using a questionnaire and this asked for ratings of four items, addressing loudness, thermal comfort, brightness and visual clarity (Figure 1). A written definition of the intended limits of the response scale was given for each question to anchor the response scale: for brightness this was "*Assume the brightest is represented by the light level in an outdoor sports area (when all the floodlights are on) and the dimmest is the light level of an outdoor parking lot at night*" which was the definition used by Vrabel, Bernecker and Mistrick [10].

Q1.Please evaluate the **loudness** of this room from 1 (very quiet) to *X* (very loud).

Q2. Please evaluate the **thermal comfort** of this room from 1 (very cool) to *X* (very warm).

Q3. Please evaluate the **brightness** of lighting in this room from 1 (very dim) to *X* (very bright).

Q4. Please evaluate the **clarity** of lighting in this room from 1 (very hazy) to *X* (very clear).

Figure 1 The four survey questions. The upper limit (*X*) of each range was either 5, 6, 7 or 8, with the same upper limit for all four questions on the questionnaire.

Four different versions of the questionnaire were used and these differed only in the number of response categories, i.e. either 5, 6, 7 or 8 categories. Each response scale thus ranged from 1 to either 5, 6, 7 or 8. All four questions on a particular questionnaire used the same number of response points, and the questionnaires were distributed randomly. The 84 test participants received and completed the questionnaire simultaneously; discussion was not permitted during this task and the lecturer (author SF) did not receive any comments that different rating scales were used. The students were asked to do this as an example of environmental rating during a lecture on thermal comfort and were not informed of the object of the study.

The questionnaire was administered on two separate days, approximately one month apart, to the same class of students. Although this was nominally the same sample it is likely that these were not identical groups, and note also that questionnaires with different response scales were distributed randomly on both days. The lighting was switched to the same setting for both evaluation sessions.

It should be noted that this questionnaire was used specifically to compare results obtained with different response ranges. An alternative design would be used if the primary intention was to evaluate the environment, including reversing the polarity of some response ranges to counter repetitive response ticking, repeated questions addressing the same issue to provide alternate-form reliability [34], and, in the case of repeated measures, ensuring the number of response categories allows the opportunity to distinguish between stimuli [25]. It should also be noted that robust environmental evaluations require parallel use of supplementary procedures: Tiller and Rea suggest that semantic differential scaling experiments are meaningless by themselves, but can serve as the critical first step in developing reasonable hypotheses about proposed higher-order phenomena [9].

3 Results

Table 1 shows the median and mean responses, the standard deviations and sample size for the evaluations of environmental characteristics.

3. 1 First and second evaluation sessions

Initially, the results were analysed to determine whether there were differences between the first and second evaluation sessions (Day 1 vs. Day 2). Table 1 reveals that mean ratings on the second day were slightly higher than the first day in 13 of the 16 cases. Figure 2 shows the distribution of responses for ratings of the four environmental items using the 5-point response scale on the two evaluation days.

The data were assumed to be independent samples and thus the Mann-Whitney and the two-sample Kolmogorov-Smirnov tests were employed [35]. This analysis compared responses gained, e.g., to ratings of brightness using the 5-point scale on Day 1 with ratings of brightness using the 5-point scale on Day 2, and thus there were 16 analyses (4 questions x 4 rating scales). To reduce the incidence of capitalising on chance when carrying out multiple statistical analyses a decision was taken to adopt $p \leq 0.01$ as the critical value for determining significant differences.

Table 1 Results of environmental evaluations

Response range		Q1 (loudness)		Q2 (thermal comfort)		Q3 (brightness)		Q4 (clarity)	
		Day 1	**Day 2**	**Day 1**	**Day 2**	**Day 1**	**Day 2**	**Day 1**	**Day 2**
5- point	Median rating	2	3	3	3	2	3	3	3
	Mean rating	2.41	2.71	2.65	3.25	2.51	2.71	3.03	3.09
	Std Dev	0.68	0.71	0.61	0.85	0.63	0.84	1.11	0.88
	n	29	21	29	21	29	21	29	21
6-point	Median rating	3	3	3	3	3	3	3	3
	Mean rating	2.56	2.86	3.26	3.40	3.00	3.13	3.56	3.81
	Std Dev	0.78	0.63	0.68	0.66	0.60	0.71	1.19	1.00
	n	23	22	23	22	23	22	23	22
7- point	Median rating	3	3	4	4	3	3	4	4
	Mean rating	3.22	3.20	3.76	4.20	2.95	3.25	4.04	4.30
	Std Dev	0.68	0.76	0.72	0.69	0.78	0.78	1.49	1.34
	n	22	20	22	20	22	20	22	20
8- point	Median rating	3.5	4	3.5	5	4	4	4.5	4
	Mean rating	3.50	3.71	3.70	4.71	3.50	4.00	4.50	4.42
	Std Dev	0.84	0.90	1.05	1.14	0.70	1.04	1.50	0.97
	n	10	21	10	21	10	21	10	21

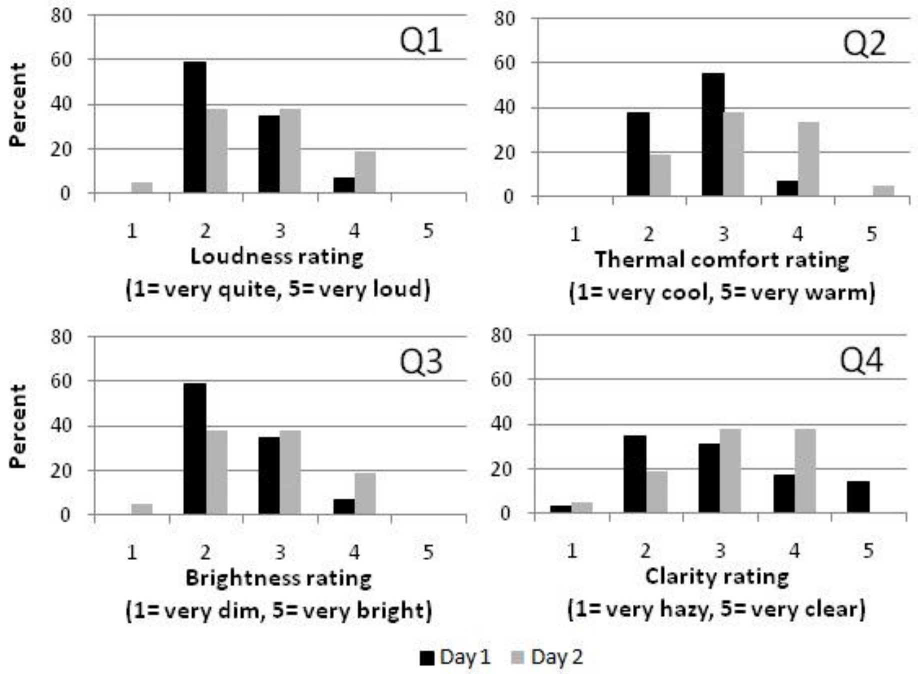

Figure 2 Results of evaluations of the four environmental items using the 5-point response scale on the two evaluation days. The 6-, 7- and 8-point scales suggested lesser difference between the evaluation days than did the 5-point scale.

The Mann-Whitney test suggests differences between the two evaluation sessions in only two of the 16 cases, these being for ratings of loudness (Q1; p=0.008) and thermal comfort (Q2; p=0.011) with the 5-point scale. The Kolmogorov-Smirnov test does not suggest any differences to be significant. The Kolmogorov-Smirnov test tends to have better power than the Mann-Whitney test for sample sizes of less than about 25 per group [35]: Table 1 shows that all groups in the current data had samples of less than 25 except for 5-point ratings on Day 1. It was concluded that similar response were gained on both evaluation sessions and thus it was decided to combine the results gained from the two sessions into a single data set for subsequent analyses.

3. 2 Graphical Comparisons

Figure 3 shows the distribution of responses for the four rating scales across the four evaluation items. To assist direct comparison of the different rating scales these were converted to a common scale: a 10-point range (1 to 10) was chosen so that all four original response ranges were subjected to transformation. Following Dawes [29] the transformation was carried out such that the lowest rating (1) remained unchanged, the highest rating was set to 10, and middle categories were uniformly spaced in between these (Table 2).

Figure 3 does not suggest a strong tendency to choose the neutral value available in the odd ranges as the middle category is the mode response in only three of the eight cases for the 5-point and 7-point ranges. For the eight cases with an even scale and for the five remaining odd cases the mode response is the category just below the middle of the range.

Figure 3 does not reveal any consistent trends for changes in the distribution of opinion with different response ranges. Following Bishop [31], one approach to comparison is to compare the division of opinion between the polar positions – the percentage of judgements above and below neutral. These are shown in Figure 3; responses for the neutral category in the

Table 2 Original response categories and re-scaled values when converted to a ten-point range

Response scale	Original response scales and values when rescaled to a 1-10 scale							
5-point	1	2	3	4	5			
	1.0	*3.25*	*5.50*	*7.75*	*10.0*			
6-point	1	2	3	4	5	6		
	1.0	*2.8*	*4.6*	*6.4*	*8.2*	*10.0*		
7-point	1	2	3	4	5	6	7	
	1.0	*2.5*	*4*	*5.5*	*7*	*8.5*	*10.0*	
8-point	1	2	3	4	5	6	7	8
	1.0	*2.29*	*3.57*	*4.86*	*6.14*	*7.43*	*8.71*	*10.0*

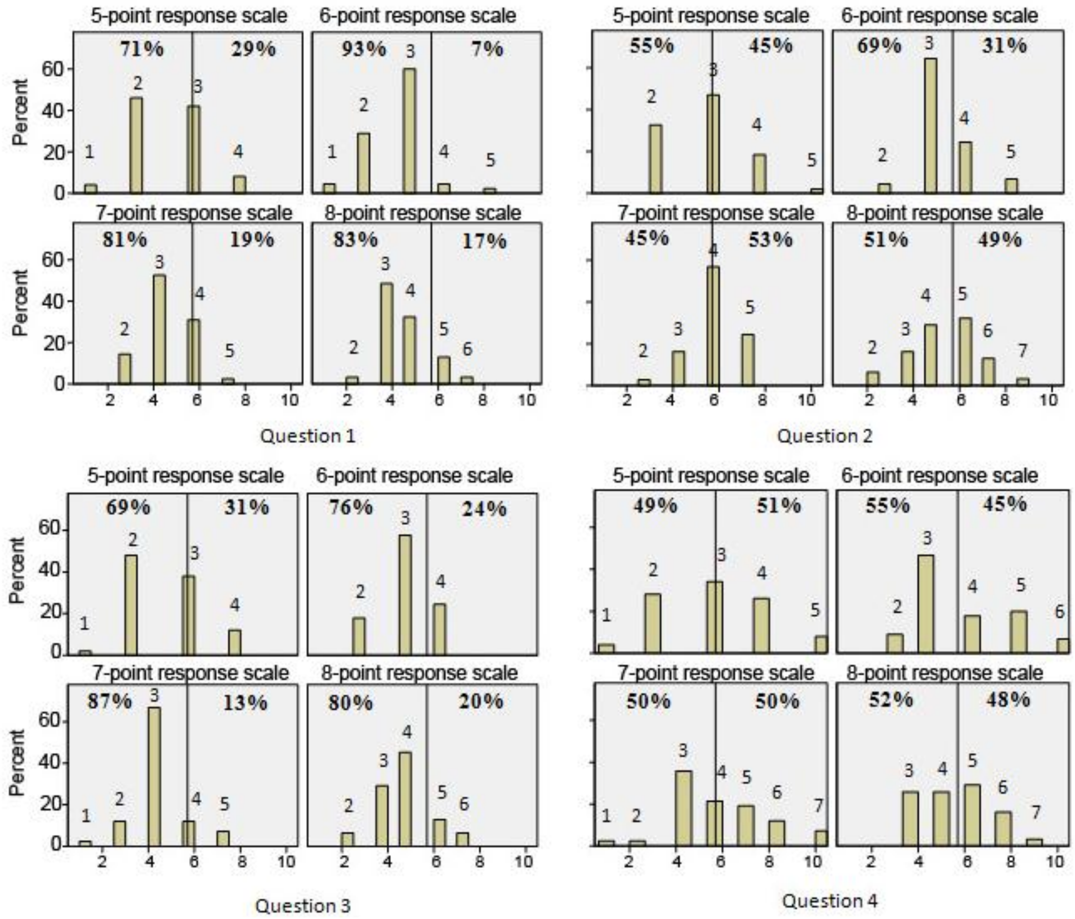

Figure 3 Distribution of environmental evaluations. The original rating scales were converted to a 10-point range: numbers above the bars show the original category number. Percentage values show the distribution of responses to the polar positions, with judgements for the neutral category in the odd scales equally divided.

5- and 7-point ranges were divided equally between the two sides. Comparison of the percentages of judgements for the polar positions does not suggest any consistent trends.

Further analysis was carried out by consideration of the cumulative distributions, as shown in Figure 4. This does not suggest any consistent and significant differences between rating scales, either for the individual response ranges or for the odd versus even ranges. The four parameter logistic equation (4PLE) was used to compare the ratings at which the cumulative frequency would be 50% (R_{50}), and these are shown in Table 3: the 5- and 6-point scales tend to suggest lower values of R_{50} than do the 7- and 8-point ratings.

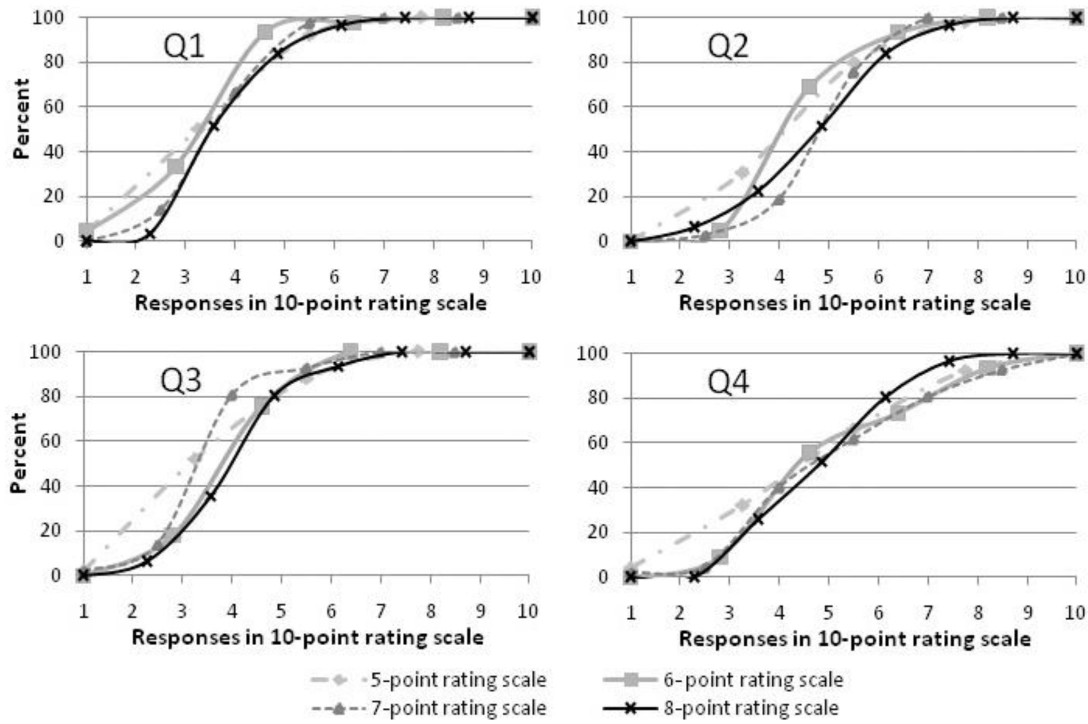

Figure 4 Cumulative frequency of environmental evaluation judgements. The original rating categories have been converted to ten-point ranges.

Table 3. Ratings at which the cumulative frequency would be 50%. These were determined using the four parameter logistic equation applied to the cumulative distribution data, with all response ranges transformed to a common 10-point range.

Rating item	**Rating at which the cumulative frequency would be 50% (R_{50})**			
	5-point	**6-point**	**7-point**	**8-point**
Q1. Loudness	3.24	3.10	3.57	3.49
Q2. Thermal comfort	3.93	4.14	4.77	4.63
Q3. Brightness	3.18	3.70	3.25	3.90
Q4. Clarity	4.19	4.55	4.64	4.62

3.3 Statistical Analyses

The data were considered to be independent samples and were not considered to be drawn from a normally distributed population. The Kruskal-Wallis test was applied to the results of each question to examine the effect of response range: this did not suggest any differences to be significant.

Paired comparisons were also carried out. The Mann-Whitney test suggests the difference to be significant ($p \leq 0.01$) in only one of the 24 cases (4 evaluation items x 6 response scale pairs), and this was between ratings made using the 6-point and 7-point ranges for brightness (Q3). Parametric tests tend to be better at detecting differences than non-parametric tests [36] and therefore the analysis was repeated using the t-test: the t-test did not suggest the effect of response range on ratings to be significant.

What the Mann-Whitney test does is to determine whether there are differences in the location (i.e. central tendency) of two samples, using the difference between mean ranks of the two samples as the statistic. An alternative test for unrelated, non-parametric samples is the two-sample Kolmogorov-Smirnov (K-S) test. The K-S test compares cumulative distributions: if the two samples have been drawn from the same population then these distributions may be expected to be fairly close to each other [37]. If the two samples are too far apart at any point, this being the maximal distance between cumulative frequency distributions of the two samples, this suggests the samples come from different distributions. Thus the K-S test is sensitive to the dispersion of data (e.g. skewness) in the two samples as well as location.

The K-S test suggests some significant differences between rating scales as shown in Table 4. For ratings of loudness, thermal comfort and brightness, differences between response scales are significant in several cases, whereas for ratings of clarity, differences between ratings are not suggested to be significant. Where the differences between ratings are significant, these suggest differences mainly between the 6-point range and the other three ranges.

The difference in conclusions drawn from the Mann-Whitney test and the K-S test arise because the two samples (different response scales) yield the same central tendency of judgement (e.g. whether an item is considered to be too much or too little) but may affect the distribution profile [29], [37].

That these data suggest response range affects the dispersion of data but not the central tendency is in contrast to Dawes'[29] findings using Likert scale ratings of price consciousness which suggested significant effects on the mean rating but not on dispersion. There was agreement between the Mann-Whitney and K-S tests when analysing the Day 1 vs. Day 2 data, which implies that ratings made

Table 4. Level of significance for differences between pairs of response scales as determined using the two-sample Kolmogorov-Smirnov test. Differences considered to be significant ($p<0.01$) are highlighted in bold.

Response scale pairs	Q1 (loudness)	Q2 (thermal comfort)	Q3 (brightness)	Q 4 (clarity)
5-6	**≤ 0.001**	**0.004**	0.015	0.144
5-7	**0.006**	0.046	**0.006**	0.063
5-8	**≤ 0.001**	0.133	**0.001**	0.037
6-7	0.016	**≤ 0.001**	**≤ 0.001**	0.026
6-8	**0.005**	**0.001**	**0.009**	0.061
7-8	0.019	0.036	**0.001**	0.447

using the same response scale and evaluation item but on different days yield the same distribution of responses; the different distribution profiles in the results were caused by the response scale format and the evaluation item rather than being an affect of the respondents.

3.4 Ignoring neutral ratings

To compare ratings recorded using their 4- and 5-point rating scales, Nowlis et al used a procedure in which judgements awarded to the middle category of the 5-point scale were ignored and they compared the four remaining points directly with the points of the 4-point response scale [38]. Ratings of 4 or 5 in the 5-point scale were thus shifted to ratings of 3 or 4 respectively in the quasi 4-point scale. For the current data, this provides a means of comparing results from the 6- and 7-point scales. Following Nowlis et al, all neutral responses in the 7-point scale (i.e. all judgements at category point 4) were ignored, and ratings of 5, 6 and 7 were shifted to ratings of 4, 5 and 6. Figure 5 shows ratings gained using the 6-point range and the transformed 7-point range.

Figure 5 does not suggest that removal of the neutral ratings affects the distribution profile except for the ratings of thermal comfort (Q2) where the mode rating has moved from slightly below neutral with the 6-point range to slightly above neutral with the transformed 7-point range.

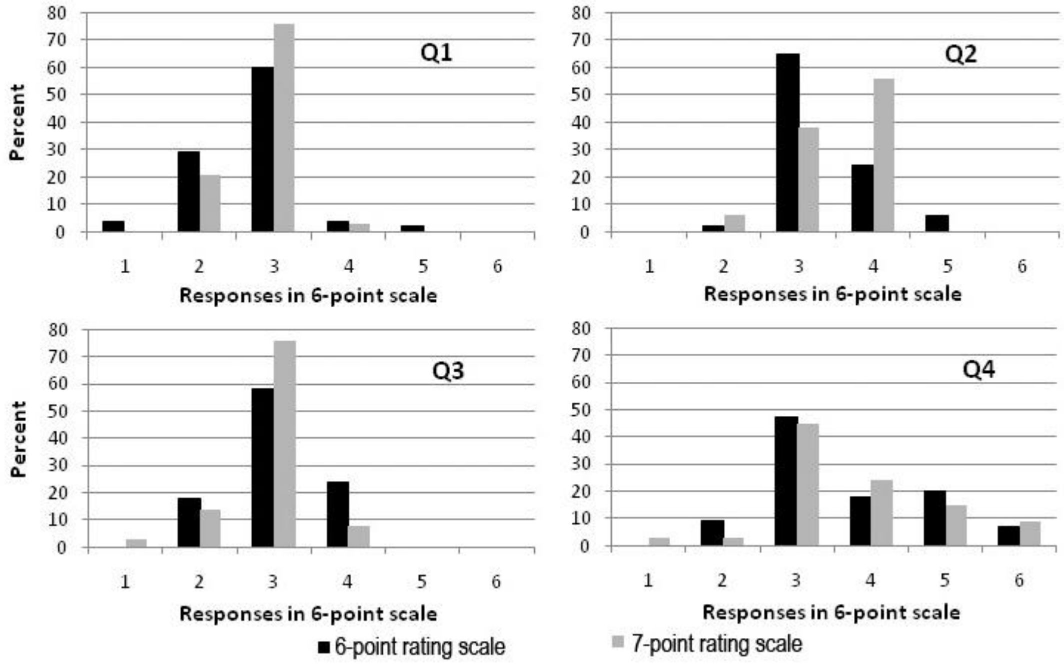

Figure 5 Evaluations of questions Q1-Q4 in 6-point and 7-point response ranges. These graphs show responses gained with the original 6-point scale and also the 7-point scale with the neutral responses omitted, the higher categories shifted, and the remaining frequencies normalised to 100%.

For Q2 the mode response with the 7-point range was the neutral category (4) but it was the category below neutral (3) for the other three questions. The neutral category of Q2 accounted for 57% of judgements and thus removal of these and normalisation of the remaining data to 100% forced more attention to be paid to the tails which were previously far less significant.

Neither the Mann-Whitney test nor the K-S test suggest the 6-point scale and the transformed 7-point scale to be significantly different. This is different to comparison of the original 7-point scale with the 6-point scale, where the Mann-Whitney test suggests a difference in Q3 and the K-S test suggests a difference in Q2 and Q3: the transformation has not affected the central tendency of the data but has reduced differences in data dispersion.

Presser & Schuman [33] reviewed studies which used this approach and concluded that there was not a significant change in distributions once the middle responses were excluded.

These data suggest that omitting the neutral category in a semantic differential response scale does not affect the conclusion drawn from the data. Explicitly offering a middle position significantly increases the size of that category, but tends not to otherwise affect univariate distributions [33].

4 Conclusion

This study was carried out to determine whether the number of response categories in a semantic differential scale would affect conclusions drawn from these data about evaluations of lighting following suggestions from the literature that significant differences may occur.

A survey was carried out in which aspects of the acoustic, thermal and visual environment of a room were evaluated using semantic differential scaling with response ranges of either 5, 6, 7 or 8 points. Previous studies of spatial brightness have used a similar approach [4], [16], [18], [19].

It was concluded that:

(1) The different scale formats do not lead to significant differences in central tendency – the same conclusion as to population opinion about the environment would be drawn with either of these scales. It may be that a greater difference in scale range would lead to significant differences, but large response ranges have not been used in previous studies of spatial brightness.

(2) The different scales lead to different distribution profiles, and this may be associated with whether or not scales offer a middle, neutral category. Whether this is of importance may depend on the questions to be asked of the data.

These data were independent samples using a semantic differential rating scale. Further data are needed to examine whether evaluations of lighting using repeated measures judgements and Likert scales are affected by the response range.

The traditional view suggests that results between odd and even scales will be unaffected since if the respondents are truly neutral then they will randomly choose one or other side of the issue, so forcing them to choose should not bias the overall results [38]. The current data support this opinion.

How then to choose whether or not a scale should allow a neutral opinion? There is some advice from Payne [39]: if the direction in which people are leaning on an issue is the type of information wanted, it is better not to offer the middle category, but if it is desired to sort out those with more definite convictions on the issue then it is better to offer the middle category.

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Deniz ATLI
PhD Student
School of Architecture
University of Sheffield
Crookesmoor Building,
Conduit Road,
Sheffield S10 1FL
d.atli@sheffiled.ac.uk

Deniz ATLI gained her degree in Interior Architecture and Environmental Design in 2008, subsequently graduating with a master's degree in Building Sciences in 2010 following a study of colour and visual perception. She started her studies in the University of Sheffield in 2010.

Steve FOTIOS
Professor of Lighting and Visual Perception.
School of Architecture,
University of Sheffield,
Crookesmoor Building,
Conduit Road,
Sheffield, S10 1FL
+44(0)114 22 20371
steve.fotios@sheffield.ac.uk

Steve FOTIOS gained his degree in Building Services Engineering in 1992, subsequently graduating with a PhD in 1997 following a study of lamp spectrum and visual perception. He joined the University of Sheffield in 2005 where he leads research of lighting in the School of Architecture. He is currently chairman of CIE Technical Committee TC1-80 which is investigating research methods for evaluating spatial brightness.

From September 2011 the address for the University of Sheffield School of Architecture will be:
The Arts Tower
Western Bank,
Sheffield, S10 2TN
U.K.

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ROAD LIGHTING PRACTICES AND ENERGY-EFFICIENCY – SLOVENIA AND FINLAND

Anne-Mari YLINEN[1], **Grega BIZJAK**[2], **Marjukka PUOLAKKA**[1], **Liisa HALONEN**[1]
[1]Aalto University, School of Science and Technology, Finland
[2]University of Ljubljana Faculty of Electrical Engineering, Slovenia

Abstract. *Road lighting practices vary from one country to another. In this study road lighting regulations and laws, used technology and energy efficiency, and experiences of efficient technology in Slovenia and Finland is studied. Despite the differences between both countries, the state of the road lighting and the adopted practices are quite similar. Road lighting regulations are based on European standard EN 13201 in both countries. Slovenia has also adopted a Decree on Limit Values due to Light Pollution of Environment. In both countries the old installations with high pressure mercury lamps are still in use to great extent. For new installations mainly high pressure sodium lamps are used and in both countries first test installations of LED luminaires are in operation. Both Slovenia and Finland need to replace the high pressure mercury lamps in next years due to the ban on this lighting source by Ecodesign Directive. As a consequence, approximately 30% of the electrical energy used for road lighting will be saved. The estimated energy saving potential of 30% can also be used for whole European Union and modernization of road lighting would reduce the use of electrical energy in European Union by 10,500 GWh yearly which means also 4.7 Mt less of* CO_2 *emissions each year.*

Keywords: road lighting, energy consumption, energy saving

1 Introduction

The purpose of road lighting is to make people, vehicles and objects on the road visible without causing discomfort to the driver. Around 30% of the all the road accidents occur during the dark hours. Further, the accident risk is around 1.5 … 3 times greater during the night than during the day time. However, the traffic during the dark hours is around 30% of the daily traffic. Generally, road lighting reduces the accidents by approximately 30% [1].

On the other hand, road lighting is also a large consumer of electrical energy. According to available data around 1.3% of the total produced electrical energy is used for road lighting in European Union (EU) [2]. To reduce the energy use in lighting, the European Parliament and the European Commission adopted different Directives and Commission Regulations in this field.

But the question is, can these documents really bring energy savings connected with road lighting in all EU member countries in spite of their different practice on this field and very different climatic conditions. To answer to this question and to find out how large the energy savings in the road lighting could be, we compared the road lighting practice in two different EU countries: Finland and Slovenia. Finland represents the extreme conditions for the road lighting with two distinctive seasons: light and dark, and large number of days when roads are wet or snowy. Slovenia is somehow close to the European average with different climatic regions from Mediterranean to continental and Alpine. The countries have also rather different history which might be reflected in the road lighting installations as their live-span is 30 years and more.

According to the Slovenian regulations for road planning [3], [4] the road lighting needs to be installed on roads in settlements (urban areas), on brunches and crossroads of major roads outside the settlements, on bus stops, on pedestrian crossings and on sidewalks near them, on gas stations, rest areas and parking lots. The main purpose of the lighting is to assure traffic safety for the road users as well as to decrease the crime rate in residential areas.

The total length of roads in Slovenia is 38,500 km, of which 4,800 km are state owned and the rest belongs to municipalities. The length of the illuminated roads is not known but it is estimated that there are approximately 200,000 road lighting luminaires installed in Slovenia. The road lighting outside the settlements is in competence of State (Slovenian Road Agency) and for the one in the urban areas the Municipalities needs to take care of. That includes also the financing of maintenance and energy costs. After the independence of Slovenia in 1991, a large number of new and rather small municipalities were established. As their budget is not very high and there are a lot of problems they need to take care of, the road lighting was mostly put behind. The installations in city municipalities are newer but in many rural municipalities very old installations with high pressure mercury lamps are not only still in use, but also represent the majority. Consequently, the average energy use for road lighting in Slovenia is rather high. According to data collected in 2008 [5], the annual electrical energy for lighting the roads is 165.2 GWh or more than 84 kWh per capita. Taking into account that average CO_2 emission for production of electrical energy in Slovenia is 530 g CO_2/kWh [6], the contribution of road lighting to the green house emissions is 87,600 tons of CO_2.

According to Finnish law [7] the Finnish Transport Agency is responsible for giving the technical guidelines of roadways. The Finnish Transport Agency is a government agency operating under the jurisdiction of the Ministry of Transport and Communications and it is responsible for the maintenance and development of the transport system overseen by the government. The Finnish Transport Agency is mainly responsible for road lighting installations on highways, main roads, regional roads and connecting roads when lighting is needed for road safety or other lighting issues of the area. The road lighting can also be installed in cooperation with the municipality or the municipality can install lighting at its own cost. The installation of road lighting is based on cost-effective transportation economics [8]. Lighting is installed to high traffic flow roads where the benefit-cost ratio is at least two. In addition road lighting is always installed to tunnels, ferry berths, movable bridges and border stations [8].

In Finland, there are over 78.000 km of roads maintained by the Finnish Transport Agency of which 16% are illuminated. There are also around 26,.000 km municipality maintained roads and approximately 18 000 km of pedestrian and bicycle ways. In addition there are several hundred thousand kilometers of private and forest roads. The estimated amount of outdoor luminaires in Finland is 1.29 million, of which 50% are high pressure mercury luminaires and 45% high pressure sodium luminaires [9]. The rest are metal halide, low pressure sodium, fluorescent lamp or induction lamp luminaires.

The annual electricity consumption in Finland was 80.8 TWh in 2009 [10]. The estimated annual electricity consumption in outdoor lighting in Finland is 800 GWh [9], which is around 1% of the total electricity consumption. The average CO_2 emission for electricity production in Finland is 200 g CO_2/kWh [11]. Thus, the calculated average green house gas emissions for outdoor lighting is 160,000 t CO_2/a.

2 Road Lighting Design – Recommendations, Laws and Practices

Road lighting design, practices and recommendations vary in detail from one country to another. Road lighting design, calculations and measurements in Europe are based on technical report EN 13201:1 [12] and the standards EN 13201:2-4 [13], [14], [15] prepared by the European Committee for Standardization (CEN). The recommendations of the standard EN 13201:2-4 have been interpreted in different manners in different countries. Hence, some differences exist among road lighting recommendations between Slovenia and Finland.

2.1 Recommendations, Laws and Practices in Slovenia

The planning of road lighting is mostly done by the electrical engineers and based on the Recommendations for road lighting published by Slovenian Road Agency and Lighting Engineering Society of Slovenia [16]. The recommendations are based on European standard EN 13201, CIE documents concerning road lighting and some modern standards for road lighting from other countries. The use of recommendations as well as the use of adopted EU standard SIST (Slovenian Institute for Standardization) EN 13201:2-4 is not mandatory. The lighting classes listed in recommendations [16] are very similar to the ones in CIE 115:2010 [17] or EN 13201 [13]. The main classes are M for roads mainly used for motorized traffic, P for pedestrian areas and C for conflict areas. From 6 basic M classes (Table I) two (M3 and M4) are additionally divided into M3a, M3b, M3c and M4a, M4b but the changes are only in longitudinal uniformity U_l.

In the annex C of the recommendations also MEW classes (from 1 to 5) are listed for which the requests include the minimal values for U_0 for wet surface. These classes are listed only informatively and remarked as used only in climatic areas where roads are wet most of the time. They are not intended for use in Slovenia.

Table 1 Requests for M lighting classes from Slovenian recommendations.

CLASS	LUMINANCE OF THE ROAD SURFACE OF THE CARRIAGEWAY			DISABILITY GLARE	LIGHTING OF SURROUNDINGS
	L_m cd/m^2, min	U_0 min	U_l min	TI % max	SR min
M1	2.0	0.4	0.7	10	0.5
M2	1.5	0.4	0.7	10	0.5
M3a	1.0	0.4	0.7	15	0.5
M3b	1.0	0.4	0.6	15	0.5
M3c	1.0	0.4	0.5	15	0.5
M4a	0.75	0.4	0.6	15	0.5
M4b	0.75	0.4	0.5	15	0.5
M5	0.5	0.35	0.4	15	0.5
M6	0.3	0.35	0.4	15	-

According to the measurements [18], [19] most of recent projects are in line with EN 13201 which is not the case with older installations. Where high pressure mercury lamps (HPM) are still in use, the values of luminances or illuminances are mostly too low although the uniformity is good. Measurements show luminance below 0.5 cd/m^2 on roads of classes M4 or even M3. On the other hand, where old luminaires with HPM lamps were replaced by new ones with high pressure sodium (HPS) lamps, the values of luminances or illuminances are mostly too high. They can reach more than two times the recommended value. Measurements show up to 1.9 cd/m^2 on roads of M3 and M4 classes.

In year 2007, the Government of Slovenia adopted also a Decree on Limit Values due to Light Pollution of Environment [20]. The aim of the decree is to protect the living premises from the light trespassing, to reduce the energy used for outdoor lighting and also to limit the influence of the outdoor lighting installations on environment protecting so the nocturnal animals and dark sky. In the field of public street lighting, the decree regulates maximum allowed electrical energy consumption per capita and per year. The allowed per capita amount of energy consumption for street lighting managed by municipalities is yearly 44.5 kWh and additional 5.5 kWh are allowed for lighting of state roads and motorways. Besides that, only the properly mounted luminaires with ULOR (Upward Light Output Ratio) equal zero are allowed. The exceptions are luminaires used in areas protected as cultural monuments (e.g. old city centres), where ULOR<5% is allowed if power of the lamp is less than 20 W and if the illuminance on the ground is less than 2 lx. Also, luminaires which are part of the protected cultural monuments (e.g. old bridges) are allowed if the power of the lamp is less than 20 W. The decree demands that the energy consumption needs to be adapted and all inappropriate luminaires need to be replaced by the end of 2016.

2.2 Recommendations, Laws and Practices in Finland

Road lighting design guidelines and photometric requirements are given in Finnish Road Administration publication Tievalaistuksen suunnittelu [21]. The publication gives photometric requirements to traffic roads of motorized vehicles for medium to high driving speeds as well as for non-motorized ways. Also, recommendations for other road areas such as residential roads, roundabouts, road intersections of some complexity, pedestrian streets and cycle ways, other road areas lying separately or along the carriageway, and etc areas are given. Furthermore, the publication gives guidelines for selection of lighting classes appropriate for the case and layout design of the lighting fixtures for different types or road ways and conflict areas.

Finnish road lighting classes and photometric requirements are based on the European standard EN 13201:2-4 [13]-[15]. The AL lighting classes (Table II) are intended for motorized traffic roads of medium to high speed (at least 50 km/h). The road lighting design is done using standard reflection table R2 for dry roads and W3 for wet surfaces. However, if the road lighting design is made using only dry road surface reflection, ME1, ME2, ME3a, ME4a and ME5 of EN 13201:2 must be used.

The AL classes are similar to MEW series in EN 13201:2 with few additions. Class MEW4 is split into two classes AL4a and AL4b, where the former has average luminance requirement of 1.0 cd/m^2. The longitudinal uniformity requirements for classes MEW4 and MEW5 are given a value of 0.4 and the overall uniformity in MEW5 is raised from 0.35 to 0.4.

Finnish AE lighting classes that are intended for drivers of motorized vehicles and other road users on conflict areas such as intersections and roundabouts, correspond to CE-series in EN 13201:2. Also A-, ES-, and EV- series in EN 13201:2 are used as they are. The K-class corresponds to S-series in EN 13201:2 with the exception that class S7 is not used.

According to Finnish road lighting recommendations the average road surface luminance varies between 0.5 cd/m^2 - 2 cd/m^2.

Table 2 Finnish AL lighting classes for the motorized vehicles on traffic roads.

CLASS	LUMINANCE OF THE ROAD SURFACE OF THE CARRIAGEWAY FOR THE DRY AND WET ROAD SURFACE CONDITION				DISABILITY GLARE	LIGHTING OF SURROUNDIN GS
	Dry condition			Wet condition		
	L_m cd/m^2, min	U_0 min	U_l min	U_0 min	TI % max	SR min
AL1	2.0	0.4	0.6	0.15	10	0.5
AL2	1.5	0.4	0.6	0.15	10	0.5
AL3	1.0	0.4	0.6	0.15	15	0.5
AL4a	1.0	0.4	0.4	0.15	15	0.5
AL4b	0.75	0.4	0.4	0.15	15	0.5
AL5	0.5	0.4	0.4	0.15	15	0.5

The measurements made in the Aalto University Lighting Unit [22]-[24] indicate that average road surface luminance levels for dry road surfaces vary from approximately 0.2 cd/m^2 for poorly illuminated residential streets outside the urban area to around 3 cd/m^2 for better illuminated highways.

Different weather conditions affect the average road surface luminance significantly. For wet road surfaces the luminance levels could be over ten times higher and for snowy conditions up to five times higher compared to dry road surfaces.

3 Road Lighting Technology and Energy Figures

Outdoor lighting consumes a lot of energy and many of the major highways and residential streets are illuminated. The road lighting luminaires are long lasting and therefore many luminaires use old, outdated and inefficient technology. Also, different practices are used to select the luminaires.

3.1 Road lighting Technology and Energy Figures in Slovenia

As part of the former Yugoslavia, Slovenia had well developed lighting industry. The main producer of the road luminaires was Elektrokovina (later bought by Siteco). The most popular luminaire for road lighting was model CD and for the pedestrian areas mostly models UD and UE were used. CD luminaires were originally equipped with one high pressure mercury (HPM) lamp of 250 W or 400 W. There are still a lot of these luminaires along Slovenian roads but most of the ones, placed along state roads, were later refurbished with high pressure sodium (HPS) lamps with 150 W or 250 W. UD and UE models were originally equipped with two 125 W HPM lamps and just few of them were later refurbished with 70 W HPS lamps. More recent road lighting luminaire from the same company is model CX which comes in two sizes and is mostly used with HPS lamps. Most of the road lighting installations built in the last 15 years are made using these luminaires. In the years before the decree was adopted, also luminaires with compact fluorescent lamps (CFL) like Altra from Schréder or Axial from Philips became very popular for pedestrian areas.

Although the linear fluorescent lamps were never used for outdoor lighting in Slovenia the compact ones like Osram Dulux became very popular for pedestrian areas in last 15 years. They provide low cost high efficient solution with white light and good colour rendering. The lighting planners and municipalities are aware of the problems connected with the low surrounding temperatures, especially with the efficiency drop, but the winters in Slovenia are not as hard as in Finland. As this lamps are used only for street and pedestrian area lighting and not for road lighting this problem is not so critical. Anyhow in last years more and more low power metal halide (MH) lamps are used instead.

In some cities the municipalities renewed the road lighting during past years so modern and economic luminaires are currently in use. The light sources are mostly HST lamps for roads and CFL lamps for residential and pedestrian areas.

In such city-municipalities the average energy consumption per capita is usually around the limit of 44.5 kWh/capita set in the decree.

But in many (rural) municipalities rather old luminaires are still in use. Some are even older than 40 years. Although some of these old luminaires are equipped with HPS lamps, in most of them HPM lamps are still in use. For lighting of major roads mostly luminaires with HPM or HPS lamps with high electrical power of 400 W or 250 W are used. For lighting of streets in residential areas smaller luminaires are used and are mostly equipped with one or two HPM lamps with electrical power of 125 W.

In all older luminaires as well as in many new ones with HPS lamps electromagnetic ballasts are used. Electronic ballasts are mostly used with CFL lamps and where dimming is planed.

To show the differences, some data for two municipalities are listed in the Table IV below. Ljubljana is a capital of Slovenia and Medvode is a small town with rather large rural background.

Both cities are trying to reduce the energy consumption in last years by replacing the old luminaires with new ones. On roads the luminaires with HPS lamps are used but for pedestrian areas a white light is preferred so metal halide (MH) lamps or compact fluorescent (CFL) lamps are used. As can be seen from the data in Ljubljana, very few HPM lamps are still in use. In Medvode, the process of replacement is slower although in last two years 185 new lamps (36 W CFL lamps) were installed instead of older, mostly HPM lamps reducing so the electrical power of street lighting by 33.5 kW.

Table 3 Lamp numbers, energy consumption and greenhouse gas emissions of Ljubljana and Medvode in Slovenia.

	Ljubljana	Medvode
number of residents	276,091	15,068
number of lamps	33,237	1,280
number of HPM lamps	1,074 (3%)	234 (18%)
number of HPS lamps	15,407 (46%)	778 (61%)
number of MH lamps	2,537 (8%)	6 (0%)
number of CFL lamps	14,219 (43%)	262 (21%)
installed electrical power of road lighting, kW	3,824	320
annual burning hours of lamps	4,000	4,000
annual energy consumption of road lighting, GWh	15.3	1.3
annual emission of CO_2, t	8,114	677.6
electricity price, €/kWh	0.108	0.113

3.2 Road lighting Technology and Energy Figures in Finland

In Finland, the Finnish Transport Agency owns the lighting on highways and main roads. On regional roads and connecting roads the Finnish Transport Agency owns the lighting if it considers the lighting necessary. Otherwise the municipalities own the lighting. [8]

In Finland, the luminaires on roads maintained by Finnish Transport Agency could be over 30 years old. Over 20 years old street lighting luminaires are checked and the renovation needs are estimated [8]. The older luminaires were provided by several different manufactures for example

Idman (later bought by Philips), Siemens, Philips, Asea Skandia, Orno and Fresta [25]. The light distribution and the maintainability performance of luminaires must be type approved by the Finnish Transport Agency [26]. Thus, the new luminaires are provided by for example Philips, Siteco and Schréder [27]. Municipalities are not required to use the type approved luminaires for the installations they make at own cost, although, mostly they follow the instructions given by the Finnish Transport Agency. For example in Espoo [28] around 50% of the road and pedestrian way lighting luminaires are manufactured before 1990. Half of the luminaires are produced by Idman and the other half with equal shares by Siteco and Elektroskandia. The newer luminaires are produced by Philips (40%), Siteco (40%) and Schréder (20%). The new park luminaires are induction lamp luminaires (99%) provided by Luis Poulsen. There are also many luminaires as old as 60 years in suburban areas in Espoo.

In Finland, the estimated amount of high pressure mercury (HPM) luminaires is 51% of all the outdoor luminaires. The most common wattage is 125 W. High pressure sodium (HPS) lamp luminaires are used 45% of all the outdoor lighting and the most common wattages are 70 W and 150 W. The rest consist of low pressure sodium, metal halide (MH), induction and florescent lamp luminaires. [9]

The used ballasts are mainly magnetic in Finland. The electronic ballast are used in LED luminaires and in induction lamp luminaires.

Table 5 show the differences for two municipalities in Finland. Espoo is the second biggest town in Finland located in the south coast next to capital city Helsinki and Kerava is located around 30 km north of Helsinki.

For energy saving reasons the use of outdoor lighting has been reduced in Espoo and Kerava. Turning off every other luminaire has been used in both cities despite the fact that luminance uniformities are not satisfied. Espoo has also turned off all the luminaires in the summer time.

Table 4 Lamp numbers, energy consumption and greenhouse gas emissions of Espoo and Kerava in Finland

	Espoo	Kerava
number of residents	244,330	33,785
number of lamps	48,200	7,673
number of HPM lamps	10,000 (20.7%)	4,900 (63.9%)
number of HPS lamps	15,407 (66.4%)	2,500 (32.6%)
number of MH lamps	200 (0.4%)	247 (3.2%)
number of other lamps	6,000 (12.4%)	26 (0.3%)
installed electrical power of road lighting, kW	7,000	975
annual burning hours of lamps	3,900	4,000
annual energy consumption of road lighting, GWh	27.3	3.9
annual emission of CO_2, t	5,460	779
electricity price, €/kWh	0.061	0.045

Most of the few complaints from residents considered broken lamps when there were longer lightless sections rather than switching off every other or all the luminaires. Also centralized power reduction has been used in some areas in Espoo. Dimming and switching off every other luminaire is done between 10 pm and 6 am, when the traffic is low. The uniformity requirements are an issue especially during the winter time, when the day is short and dark nights are long. Dimming would be better solution to reduce the power consumption and still satisfy the uniformity requirements.

4 Experiences of Efficient Technology

The Ecodesign Directive will phase out inefficient high pressure mercury lamps used in road lighting by the end of 2015. Energy efficient lighting technologies that could reduce energy consumption already exists and efficient solutions in Slovenia and Finland are already in use.

4.1 Experiences of Efficient Technology in Slovenia

In Slovenia already years ago, in many luminaires high pressure mercury (HPM) lamps were replaced with high pressure sodium (HPS) lamps together with ballasts along major (State) roads. Although the achieved energy savings were considerable the main reason for the replacement was to achieve better lighting conditions. After the energy prices become higher, some municipalities found out that with the investment in road lighting considerable savings in energy (and money) can be achieved. The typical example is city Celje, where with replacement of all 4080 luminaires the energy consumption was reduced from 3706.7 MWh down to 1801.7 MWh [29]. Other possibilities were also considered and used by some municipalities like:

- replacement of HPM lamps with hybrid HPS lamps where replacement of ballast is not needed;
- replacement of residential area luminaires with HPM lamps with luminaires using CFL lamps.

After the adoption of the Decree on Limit Values due to Light Pollution of Environment the municipalities are forced to replace the old luminaires with new ones as the old ones do not comply with the requirements of the decree anymore. For the road lighting, practically only luminaires with HPS lamps are used and for the street lighting in residential areas luminaires with CFL lamps, but also with metal halide (MH) lamps are used. In last year also some luminaires with LEDs were installed, mostly for testing purposes.

In most cases the municipalities just replace the old luminaires with new ones on the same poles. As indicated in examples from Ljubljana and Medvode, HPS and CFL lamps are mostly used. Beside this option some municipalities also try to reduce the energy consumption with measures like:

- reduction of voltage and so also the reduction of energy used;
- use of two-step regulation ballasts to reduce the luminance and power consumption in night time;
- switching off the lighting in night time.

One possibility is also introduction of control systems. This option was considered in last year in some of Slovenian city municipalities and at least in Ljubljana some test installations are already in operation. But we can expect that regulation of luminous flux (dimming) will not be widely used in Slovenia. Due to Decree municipalities need to change practically all the luminaires in next years and due to lack of funds the luminaires are changed on one to one basis. With new luminaires old installations are still in use and in most cases they do not enable use of control systems or even a step reduction of luminous flux in a night time.

As most of the saving measures bring also better lighting conditions, they are well accepted by the citizens. There were some complaints about yellowish light and poor colour rendering after replacement of HPM with HPS lamps. That is why for the residential areas now mostly the CFL and MH lamps are used. There were no complaints of using luminous flux reduction in night hours as practically nobody noticed that. On the other hand, there were rather large complaints on switching off the lighting in night hours so this measure, although it brings large energy savings, will probably not be widely used in Slovenia.

4.2 Experiences of Efficient Technology in Finland

In Finland, on roads maintained by Finnish Transport Agency the need for replacing the high pressure mercury luminaires (41,100 lamps) has been made but no systematic replacement has been made. The high pressure mercury luminaires are so old that the entire illumination will be replaced by more efficient one. Thus, high pressure sodium lamp luminaires compose 79% of the roads maintained by Finnish Transport Agency.

Espoo has made a deal with Ministry of Employment and the Economy to reduce 9% energy usage by 2011. Most of the saving is achieved in buildings by reducing heat losses and using control systems. In road lighting more efficient light sources has been used. Since 1993, only high pressure sodium lamp luminaires have been installed and induction lamp luminaires have been installed since 1999. The replacement of high pressure mercury lamp luminaires in road lighting has been made to old poles by changing only the luminaire. The lamp power has been chosen according to pole spacing. For example 250 W HPM lamp luminaire has been replaced with 100 W HPS lamp luminaire. In park areas, the replacement has been made using induction lamps (55 W, 84 W).

In Espoo, 20% energy savings are also achieved by turning of every other luminaire between 10 pm and 6 am. In Espoo, there are approximately 150 control centers for turning off every other luminaire. Turing off every other luminaire is done year around in control center areas and it has been in use since 1982. There are also approximately 600 autotransformer control centers for dimming the illumination. The autotransformer control centers have been in use since 1995. Autotransformers reduce energy usage 30% - 40%. Also the operating life of lamps increases and luminous flux depreciation has decelerated due to under voltage operation.

Espoo does not have a detailed schedule for replacing the remaining 10,000 high pressure mercury lamps. Around 90% of these lamps are replaced by high pressure sodium lamps. Most of these remaining high pressure mercury lamp luminaires are in areas where the city is improving other public utility services. Thus, high pressure mercury lamps are replaced at the same time.

In Espoo, there are few experimental LED luminaire installations. The installations consist of only a few LED luminaires from different manufactures. The installations have been made by replacing the luminaire into old poles. The power reduction is not significant. However, the luminance level on the road surface has increased. [28]

As an example in Espoo an experimental LED street lighting installation was made where 16 high pressure sodium lamp luminaires were changed to four different types of LED luminaires. The measured power consumption and luminous intensity distribution curves of the LED luminaires and the original HPS lamp luminaire were measured at the laboratory. The LED luminaires were changed to existing poles (average pole spacing 27 m). Table 6 shows the result of the power consumption of each LED luminaire and the reduction in power consumption compared to the original HPS lamp installation. If the pole spacings were optimized, the reduction in power consumption compared to the optimized HPS lamp installation would vary between 28% - 68%. It should be noted, that the optimization was performed using DIALux software with the measured luminous intensity distribution curves. Also, the original HPS lamp luminaire was around 15 years old, whereas the LED luminaires were new. Increasing the luminaire spacing of LED luminaire D from 27 m to the optimized pole spacing 41 m would decrease the power consumption by 49%.

Kerava has some ideas about reducing the power consumption and the CO_2 gas emissions, but so far no official plans have been made. Also, Kerava does not have any other plans than replacing the high pressure mercury luminaires to more energy efficient ones.

Kerava has started replacing the inefficient high pressure mercury lamp luminaires. The luminaires have been replaced by HPS luminaires; 250 W HPM lamps to 150 W HPS lamps and 150 W HPM lamps to 70 W HPS lamps. The replacement is scheduled to be completed by 2016.

Kerava has some experiences of LED outdoor lighting. Fifteen LED luminaires were tried in street lighting in 2007, but unfortunately they broke in a thunderstorm the following summer. Some LED installations have been made to parks this year, and LEDs have been installed to a small residential road.

In Kerava, LED technology is seen an interesting solution to outdoor lighting in the future. At the moment the lack of experiences and suitable solutions in the market restrict their wider use. In the future LEDs are also seen as a solution to save energy. Today they use the same amount or even more energy than present efficient technology. [30]

High pressure sodium lamps are preferred mainly for cost reasons to replace HPM lamps in outdoor lighting. The price the high pressure sodium lamp is lower than metal halide lamp, the lifetime of HPS lamp is longer than MH lamps and also the dimming properties favor HPS lamps. Thus, the maintenance costs are lower for HPS lamp luminaires.

Both Espoo and Kerava have not made any user surveys of road lighting.

Generally, people are satisfied with the lighting and the light color of high pressure sodium lamps. In fact, Espoo received positive feedback when the cold color high pressure mercury lamps were changed to high pressure sodium lamps. The complaints usually concern broken lamps in general, or in the case where every other lamp is turned off. Turning off all luminaires was complained by few users who mainly drove during the night time.

Table 6 LED luminaire power consumption and reduction in power consumption [%] compared to the original HPS lamp installation in the case street in Espoo. Reduction in power consumption if the pole spacings were optimized.

LUMINAIRE	MEASURED POWER CONSUMPTION W	REDUCTION IN POWER CONSUMPTION %	REDUCTION IN POWER CONSUMPTION, OPTIMIZED POLE SPACING %
LED A	108	24.5	44.2
LED B	133	7.0	28.1
LED C	140	2.1	48.0
LED D	110	23.1	68.1

5 View of Possibilities to Save Energy

In Slovenia, already before the adoption of the Decree on Limit Values due to Light Pollution of Environment, some municipalities realized that with the investments in the modernization of road lighting the cost for the electrical energy can be significantly reduced. And with the adoption of the decree, the municipalities are practically forced to modernize the road lighting and so to reduce the energy consumption. As the main obstacle in many municipalities is the lack of investment funds they are trying to finance the investments through the achieved savings.

The amount of electrical energy, which municipality can save bringing the road lighting in accordance with the requirements of the decree is dependent of the state of the lighting and saving measures already taken by municipality before the decree was accepted. The practice shows that the energy consumption can be reduced by 10% to 50%. Taking into account the present energy consumption for road lighting in Slovenian municipalities, we calculate that around 58.6 GWh or 35.4% yearly can be saved which represents 31,058 t of CO_2 less each year.

In Finland, there are possibilities to save energy by replacing inefficient light sources to more efficient ones. Changing the 110 W high pressure mercury lamps to 70 W high pressure sodium lamps saves energy 36%. By changing the HPM in Espoo the energy savings are 1.6 GWh and the reduction in green house gas emissions is 312 t CO_2/a (5.7%). There is a significant energy saving potential (estimated up to 70%) with the LED lighting [31] together with intelligent control systems in the future [32]. Replacing the HPM, HPS and MH lamps with LED luminaires that would use 50% less energy would bring 31% savings in the total outdoor lighting energy consumption in Espoo. The green house gas emission would reduce be reduced by to 1700 t CO_2/a.

In Kerava, 64% of the lamps are high pressure mercury lamps. Replacing these lamps to high pressure sodium lamps brings at least 35% energy savings. The green house gas emission would reduce by 274 t CO_2/a (35%). Replacing all the luminaires with LED luminaires that would use 50% less energy would bring 50% savings in the total outdoor lighting energy consumption in Kerava. The green house gas emission would be reduced by 390 t CO_2/a.

6 Conclusions

From the results of the comparison one can see that despite of the differences between both countries, the state of the road lighting and the used practice are quite similar. In both countries the old installations with high pressure mercury lamps are still in use to great extend. For new installations mainly high pressure sodium lamps are used and in both countries first test installations of LED luminaires are in operation. We have also noticed that municipalities in Finland as well as in Slovenia are considering the replacement of the old luminaires with new more efficient ones in the next years. The reason is the same; in both countries municipalities will have to replace them due to the ban on high pressure mercury lamps in EU. Additionally in Slovenia municipalities need to replace them also because of the mentioned decree. But the results will be the same, with the replacement of luminaires with high pressure mercury lamps in Finland and with the replacement of luminaires that do not meet the requirements of the Decree in Slovenia, approximately 30% of the electrical energy used for road lighting would be saved.

We believe that the obtained results can also, to some extent, be use for the whole European Union. For recent road lighting installations up to date technology is used in all countries which means luminaires with high pressure sodium lamps but also some testing LED installations as well as testing installations of lighting control systems. The same can be stated also for state of the old installations. All over the EU still a large number of old luminaires with high pressure mercury lamps are in use. And due to the ban on this light source, it will need to be replaced in the next years. That means that the estimated energy saving potential of 30% can also be used for whole EU. Modernization of road lighting would thus reduce the use of electrical energy in EU by 10.500 GWh yearly which means also 4.7 Mt less of CO_2 emissions each year.

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Authors' information

Anne-Mari YLINEN
PhD Student
*
ph: +358 50 3160985
e-mail aane.ylinen@aalto.fi

Anne-Mari Ylinen got her Master degree from Department of Electrical and Communication Engineering, Helsinki University of Technology, Finland in 2007. She is a PhD student at the Lighting Unit and her interest areas of research include road lighting, road pavements, mesopic vision, and energy efficient lighting.

Grega BIZJAK
Associated Professor,
Dr.Sc. (Tech.)
University of Ljubljana
Faculty of Electrical Engineering
Tržaška ulica 25
SI-1000 Ljubljana
ph: +386 (01) 47 68 446
grega.bizjak@fe.uni-lj.si

Grega Bizjak received his doctorate in electrical power engineering in 1997 from University of Ljubljana, Faculty of Electrical Engineering. Currently he is an Associated Professor and Head of Laboratory of Lighting and Photometry at University of Ljubljana. He is active in the field of lighting and photometry as well as in the field of electrical power engineering. His main research interests in lighting are energy efficient indoor and outdoor lighting, use of daylight, LEDs in lighting applications and photometry. Prof. Bizjak in president of Slovenian National Committee of CIE, representative of Slovenia in CIE Division 2 and member of IEEE.

Marjukka PUOLAKKA
Dr.Sc. (Tech.)
*
ph: +358 50 3269549
marjukka.puolakka@aalto.fi

Marjukka Puolakka earned her doctorate in illuminating engineering in 2005 from Helsinki University of Technology, Finland. Senior Research Scientist in the Lighting Unit of Aalto University in Finland. Leader of the research team 'Outdoor Lighting and Visual Effects of Light'. Her interest areas include outdoor lighting, visibility at low light levels, mesopic photometry and LEDs in outdoor lighting.

Liisa HALONEN
Professor, Dr.Sc. (Tech.)
*Aalto University, School of Science and Technology
P.O.B. 13340
00076 Aalto, Finland
ph: +358 500 423232
e-mail: liisa.halonen@aalto.fi

Liisa Halonen earned her doctorate in illuminating engineering in 1993 from Helsinki University of Technology, Finland. She is the head of the Lighting Unit in Aalto University, School of Science and Technology, Finland. She has managed numerous national and international research projects. She is responsible for the Master- and Post-graduate education in illuminating engineering at Aalto University. Professor Halonen is the Operating Agent of Annex 45 Energy Efficient Electric Lighting for Buildings. She is the Finnish representative of CIE Div 3 and is working in several CIE technical committees.

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A HOLISTIC APPROACH FOR ACHIEVING ENERGY SAVINGS USING MODERN LIGHTING TECHNOLOGIES. AN ILLUSTRATION WITH LED SYSTEMS FOR OUTDOOR LIGHTING

Georges ZISSIS[1], Florin POP[2]
[1]Université de Toulouse, LAPLACE UMR 5213 CNRS-INPT-UPS, France
[2]Universitatea Tehnică din Cluj-Napoca, Lighting Engineering Laboratory, Romania

Abstract: *Currently the next revolution in lighting is taking place: Solid State Lighting (SSL). In the long term SSL, inorganic and organic light emitting diodes, could become the next generation light sources. In fact, LEDs, with a continuous growth of their luminous efficiencies, establish themselves as breakthrough solutions. Street lighting is considered as an important issue for this technology. This paper give some examples of projects and their outcomes in this domain, based on the features of the European LITES project, to prove in real life experimentation that intelligent street lighting using solid-state lights LED drastically reduces energy consumption. The paper presents strategies for increasing the electric energy savings in commercial and office buildings, by implementing the Best Available Techniques and Sustainable Development Strategy, which focus on two factors: the use of the best state of the art technology available and the environment protection, while the human needs are meet. Two case-studies are presented, with the purpose of emphasizing the importance of applying energy efficiency techniques in office buildings: the first takes into consideration two different solutions for upgrading the existing lighting installation in an office room: up-lamping and re-lighting; the second analyzes the upgrading process for an office building, where three scenarios are considered for the replacement of the existing installations.. The selection between different lighting systems is made at each designing step, with the final purpose of establishing the optimal solution regarding the energy efficiency, the user satisfaction.*

Keywords: LED, lighting systems, quality, best available techniques, sustainable development strategy

1 Introduction

Artificial light sources play an indispensable role to daily life of any Human being. Electrical light sources are responsible for an energy consumption of around 2650 billion MWh per annum. This represents almost 19% of worldwide electricity production [1]. On the one hand, street lighting represents 8% of the above stated quantity. On the other hand, street lighting should guarantee security (traffic and pedestrians), well being and beautify the city.

Although classic lighting technologies are now mature, the luminous efficiency of the light sources together with their quality of light have not quite reached their limits: there is still room for innovation. Today, there are many opportunities for enhancing not only the efficiency and reliability of lighting systems but also improving the quality of light as seen by the end user. However, despite many scientific and technical progresses in the field of the electrical discharge light sources, the maximum efficiency of these systems has reached its limits, since the seventies, to about 125-130 lm/W. Overcoming this barrier is possible through intelligent use of new technologies, a deep scientific understanding of the operating principles of light sources and a good knowledge of the varied human needs for different types of lighting in different settings.

Currently the next revolution in lighting is taking place: Solid State Lighting (SSL). In the long term SSL, inorganic and organic light emitting diodes, could become the next generation light sources. In fact, LEDs, with a continuous growth of their luminous efficiencies, establish themselves as breakthrough solutions.

However, two questions arise:

- What are the absolute limits for white light production
- Is any new way to generate light beyond known methods?

To another point of view, in order to achieve considerable savings from lighting, a coherent strategy is required to transform the lighting market in both International and National levels. The paper emphasises the importance of taking a holistic view in the development of lighting systems in order to obtain high quality lighting that is need for ensuring quality of life, health and security of end-users.

What are the challenges and also the limitations of new technologies? What is the impact on the environment, health and security? All these will be discussed during the presentation.

The installation of LED luminaries in the context of a long term public and street lighting project with well-defined performance commitments in terms of light quality, failure rates and levels of power saving is not possible without an exhaustive technical and economical assessments of the products. This should provide guarantees in terms of performance levels of luminaries and the evolution that they undergo over time.

At first instance we will present a LED quality charter proposed for evaluating system quality in France. Then, two street lighting projects are here sited as examples for the evaluation of LED use for this application.

2 LED quality Charter for street lighting [2]

CITELUM group, the LAPLACE laboratory and the LED ENGINEERING DEVELOPMENT design bureau have pooled their knowledge and experience in the field of public lighting and in LED technology to draw up a highly precise statement of requirements in the form of a methodology for the inspection and assessment of LED luminaries. In the absence of standards this document will serve as a set of references for the qualification of LED luminaries offered by suppliers.

An analysis of the performance of LED luminaries must be undertaken in the same way as for luminaries with discharge lamps, by characterising the light flux and global energy consumption combination, the photometric performance as well as the lifespan and reliability of the lamp, but also considering new analytical criteria such as the quality of the electrical power supply, control and management of heat dissipation.

These technical criteria must be considered in the context of a broader technico-financial analysis which also takes into account the economic performance, the maintenance constraints, the environmental impact and the competitiveness of the commercial proposal – which can be used to judge the suitability of the choice of a LED luminary in comparison with others or with conventional solutions such as discharge luminaries.

Today, there is therefore a multitude of performance analysis criteria to be considered when choosing LED luminaries for a street lighting project. The evaluation methodology proposed in this document defines a pragmatic approach based upon all of these performance criteria. Its objective is to enable:

- Objective qualification, from the technical standpoint, of the LED luminaries on offer by suppliers in order to comply with the contractual performance levels on which the Group has commitments with its customers.
- The conducting of technico-financial analysis to enable objective comparisons to be made between LED luminaries and conventional luminaries.

When buying LED Luminaries for a street lighting project, products should be submitted to all the electrical, mechanical, thermodynamic and photometric tests specified in this document. The tests are to be conducted at the supplier's cost and by a recognised laboratory or failing that, by the CITELUM Photometric Laboratory, LAPLACE Laboratory and LED.

Additionally, it is important that buyers have access to the information required for evaluation of the technical, industrial and financial choices having a direct impact on the economic performance of the product (marketing and maintenance). The following figure shows graphically the 19 evaluation criteria within 6 fields.

3 The LED-VILLE roundabout project [3]

In this project supported in France by ADEME, a global study of a LED lighting system for an urban roundabout (LED-VILLE) has been performed. A study of the photometric performances of the LED used has been performed in our laboratory. Furthermore, average illuminance, uniformity and luminance have been measured and compared to recommended data. Environmental footprints of this lighting system (carbon operation, life cycle analysis and light pollution) has been evaluated and compared to equivalent solution widely used to date. Finally, a social approach of the LED street lighting has been achieved: the visual perceptions felt by driving or walking users through the roundabout have been collected and analyzed.

The lighting research and development has accelerated to implement light sources more energy efficient and less polluting. Among these techniques, the LED technology seems a promising solution. However, if the LEDs begin to be widely used in interior lighting, many difficulties have still to be overcome before an extended use of LEDs can be extensively used in outdoor public lighting.

After the installation of a functional equipment using LED technology to illuminate a roundabout located on Le Séquestre (Tarn, France), the "Syndicat Departemental de l'Energie du Tarn" (SDET) has proposed to pilot an applied research project on the theme of LEDs street lighting.

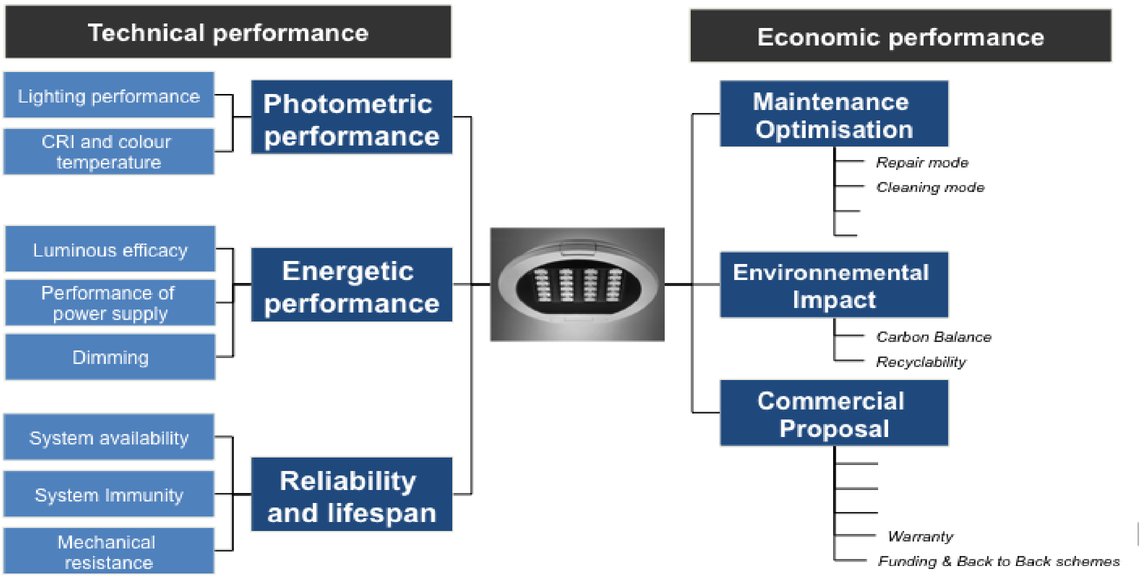

Figure 1 The scheme of the applied research project LED-Ville on the theme of LEDs street lighting.

This project, called LED-Ville, aims to produce:

- Quantitative studies conducted in laboratory and real conditions of operation
- Qualitative studies to provide data on the perception of road users (service rendered lighting LED)
- A "product" analysis of the technology and the possibilities of its evolution.

In 2007, a demonstrator has been installed. It consisted of four luminaries, each equipped with 9 opto-units. Each opto-unit is a set up of three 4.7 W LEDs (Stanley). At this occasion the following studies have been carried out:

- The characterization of LEDs in laboratory
- In situ evaluation of the lighting system
- Environmental impact and system LCA
- Social study for evaluating the acceptability form the population

Our main conclusions were that data characterizing the performances of LEDs systems for public lighting are lacking. The purpose of this work is to evaluate all the aspects of a specific product in operation. If the LED technology does not perform quite adequately the lighting recommendations, there are promising trends with the fast growing of LEDs products. The following figure shows a photo of the studied roundabout.

Figure 2 The roundabout lighting LED system

4 The European project LITES

The main objective of the LITES project is to prove in real life experimentation that intelligent street lighting using solid-state lights LED drastically reduces energy consumption. More especially, the technical objectives of the LITES project are:

- Development of LED-based smart street lighting system,
- Development of a central management system and monitoring,
- Ensure local management through networking built-in sensors,
- Energy saving with adapted lighting profile,
- Individual energy metering (per pole),
- Alarms and events collections,
- Remotely maintenance capability.

The lighting service delivered is compliant with road classes CE2-CE5, S- and A- according to the standard of EN13201. That means that our device can be installed in Secondary Street, commercial access, allotment, pedestrian way, and cycle track. It is compliant with all electric standards for luminaires general requirements and tests as well. The core element of the solution is the dimming of the lamp depending on the environment; a set of embedded sensors measure ambient light, temperature, current, and detect motion. Output data of sensors is then processed by the embedded intelligence allowing optimum regulation of light levels. The members within the consortium have been carefully selected to cover the entire value-chain of the project and the standardization as well. They are all convinced about the prosperous future for this technology, its significant energy saving potential up to 70%, environmental and economical benefits and the increased level of traffic safety for the public. The objectives will be achieved by the manufacture of a lantern specially designed to receive the LED array and the embedded intelligence. The piloted, full members of the consortium as well, will procure their sets of lanterns to a subcontractor of the consortium in charge of the industrialization of LITES. To obtain significant change in the demand for intelligent street lighting, current facts and results about LITES will be presented in conferences, in fairs, in scientific and non-scientific magazines, on website, in three video presentations on technical, financial, and organizational issues on LITES technology implementation.

5 The Best Available Techniques and Sustainable Development Strategy in lighting design

The light delivered in the commercial sector was provided, in 2005, by [4]: linear fluorescent lamps (76.5%), incandescent lamps (7.2%), tungsten halogen lamps (2.2%), compact fluorescent lamps (7%) and HID (7.2%). From the total light delivered, only 7.7% is provided by efficient lighting technologies. In a comparison between existing office lighting and new office lighting in three European countries (Belgium, Germany and Spain), it was found that existing office lighting still has a large number of other lamps than fluorescent. [5] There are many new developments in the lighting industries, in both technological equipment and approaches to lighting design. The lighting system is adapted to current use of space, with new luminaires/lamps/lighting controls. This approach provides the best results immediately, with the largest energy savings, but with higher initial costs. The implementation of the newest lighting equipment technology, with the possibility of using lighting controls, is critical for minimizing lighting energy consumption and maximizing space functionality and user satisfaction.

The concept of Best Available Techniques is not aimed at the prescription of any specific technique or technology, but at taking into account the technical characteristics of the installation concerned, its geographical location and the local environmental conditions. The main considerations that need to be taken into account generally or in specific cases when determining Best Available Techniques, bearing in mind the likely costs and benefits of a measure and the principles of precaution and prevention, are [1], [6]: costs and benefits of the measure and the principles of precaution and prevention; technological advances and changes in scientific knowledge; use of low-waste technology use of less hazardous substances; recovery and recycling of substances generated and used in the process and of waste; comparable processes or methods of operation already tried with success on an industrial scale; nature, effects and volume of the emissions concerned; length of time needed to introduce the best available technique; consumption and nature of raw materials used in the process and their energy efficiency; need to prevent or reduce to a minimum the overall impact of the emissions on the environment and the risks to it; need to prevent accidents and to minimize the consequences for the environment.

The Renewed EU Sustainable Development Strategy, 2006, sets out how the needs of present generations can be meet without compromising the ability of future generations to meet their needs. The Sustainable Development Strategy deals in an integrated way with the economic, environmental and social issues.

Care must be taken in upgrading a lighting installation at other factors that can influence the energy consumption: environment temperature, line voltage, lamp voltage, power factor compensation (low power factor loads increase losses in a power distribution system and result in increased energy costs), or poor power. The best lamp, if used with poor or incompatible luminaire or ballast, loses most of its advantages. Combining good lamp, ballast and luminaire in a wrong installation may not meet the user needs or provide lighting service in an inefficient way. Combination of a good lighting system in a well designed installation takes strong advantage from control devices (implementing daylight availability and occupancy). In the case of new buildings, the integration of daylight is important in order to reduce the energy consumption. A right maintenance schedule needs to be provided in order to maintain the visual performance and comfort of the room. Also, the lighting user has a very important impact on the energy consumption of the lighting system. [7]

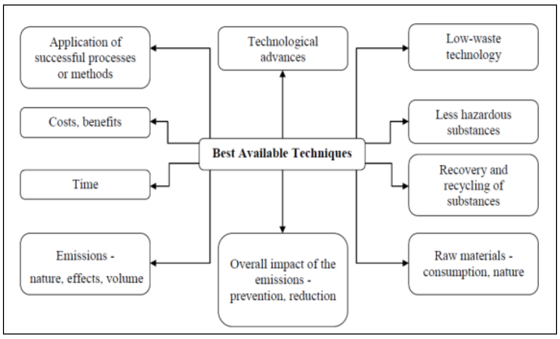

Figure 3 The Best Available Techniques steps

The environmental impact of lighting is caused by the energy consumption of lighting, the material used to produce lighting equipment, and the disposal of used equipment. Emissions during the production of electricity, the burning of fuel in vehicle lighting and in fuel-based lighting are responsible for most of the lighting-related greenhouse gas emissions.

Efficient lighting has been found in several studies to be a cost effective way to reduce CO_2 emissions. The Inter-governmental Panel on Climate Change for non-residential buildings concluded that energy efficient lighting is one of the measures covering the largest potential and also providing the cheapest mitigation options. Among the measures that have potential for CO_2 reduction in buildings, energy efficient lighting comes first largest in developing countries, second largest in countries with their economies in transition, and third largest in the industrialized countries. [8]

A variety of types of lighting are available to satisfy for every type of activity and room situation. To ensure the right standard of lighting for a specific room use, the right balance needs to be accomplished also between visual performance, visual comfort and visual ambience. The emphasis can be on [8]: visual performance (defined by lighting level and glare limitation), visual comfort (influenced mainly by colour rendering and harmonious brightness distribution) and visual ambience (influenced by light colour, direction of light and modelling).

Selecting the right type of lighting involves finding the right balance between visual performance, visual comfort and visual ambience. This compliances with the requirements of the technical regulations which establish the lighting levels, harmonious brightness distribution, direct and reflected glare limitation, direction of light, modelling, light colour and colour rendering required for the relevant activity. [9]

Performance, efficiency and comfort determine the efficacy of lighting, the impact on the people and the impact on the natural environment. Each different project and location requires a specific study to balance the three components. [10]

Case Study - Lighting systems in office room.

A case study has been made for a 60 m^2 office room (height of 3 m). The technical requirements imposed by the room characteristics consist of: the room surfaces reflection factors (set to 0.20/0.50/0.70), the work-plane height (established at 0.80 m) and the illuminance value at working plane (equal to 500 lx).

The case study analyses the best upgrading solution for the lighting system in the room. The luminous and electrical characteristics of the light sources are determined by measurements at the Lighting Research Unit, Aalto University, Finland [11].

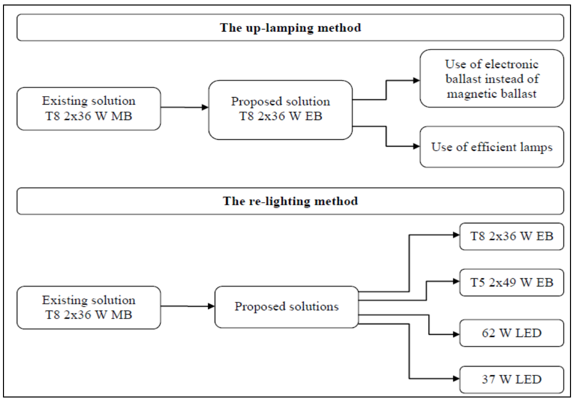

Figure 4 The upgrading analysed methods

Two different methods are considered - Figure 4: the up-lamping method (the replacement of currently existing lamps, gearing and luminaires with a better quality lighting equipment, without any modifications to the luminaires or to the structural lighting installations) and the re-lighting method (the replacement of current lighting equipments with state-of-the-art ones and redesigning the lighting installation according to the latest solution).

At first, a light system composed of 12 luminaires equipped with 2x36 W standard fluorescent lamps with magnetic ballast is presumed to be installed in the room. The up-lamping method considered the lamps replacement with improved ones and the use of electronic ballast, while maintaining the luminaires physical characteristics and positions in the room. The luminous characteristics of the light sources are presented in Table 1.

Table 1. Lighting characteristics of the light sources

Light source	Active power	Luminous flux	Luminous efficacy
	W	lm	lm/W
T8 2x36 W MB	85	5700	67.06
T8 2x36 W EB	76	6700	88.16

The up-lamping lighting solution design is considering a maintain illuminance level close to 500 lx. The total power drops by 10%. At the same time, the luminous flux of the lighting installation increases by 15% - Table 2.

Table 2. Lighting characteristics of the office room

Study case	Units	Luminous flux	Active power	Specific installed power		Average illuminance (DIALux simulation)
		lm	W	W/m^2	W/m^2/100 lx	lx
1 (T8 2x36 W MB)	12	68,400	1020	17.0	3.12	545
2 (T8 2x36 W EB)	12	80,400	912	15.2	2.37	641

The next four lighting solutions refer to the re-lighting method, using the 2x36 W T8 fluorescent lamps with electronic ballast, 2x49 W T5 fluorescent lamps, 62 W LED and, respectively, 37 W LED luminaires.

The luminous characteristics of the light sources, the lighting characteristics of the office room and the illuminance levels at the working plane, for each analyzed scenario, are presented in Tables 3 and 4.

Table 3. Lighting characteristics of the light sources

Light source	Active power	Luminous flux	Luminous efficacy
	W	lm	lm/W
T8 2x36 W MB	85	5700	67.06
T8 2x36 W EB	76	6700	88.16
T5 2x49 W	108	8600	79.63
LED 62 W	62	3625	58.47
LED 37 W	37	2000	54.05

Table 4. Lighting characteristics of the office room

Study case	Units	Luminous flux	Active power	Specific installed power		Average illuminance (DIALux simulation)
		lm	W	W/m^2	W/m^2/100 lx	lx
1 (T8 2x36 W MB)	12	68,400	1020	17.0	3.12	545
2 (T8 2x36 W EB)	9	60,300	684	11.4	2.10	542
3 (T5 2x49 W EB)	6	51,600	648	10.8	2.04	531
4 (LED 62 W)	15	56,250	930	15.5	2.80	553
5 (LED 37 W)	20	40,000	740	12.33	2.29	539

Table 5. Total costs for the lighting solutions

Study case	Initial cost	Operational cost	Energy costs	Amortization period
	Euro	Euro	Euro	years
1 (T8 2x36 W MB)	2480	15,927	14,243	-
2 (T8 2x36 W EB)	3685	11,845	10,471	5.9
3 (T5 2x49 W EB)	3488	10,076	8860	3.4
4 (LED 62 W)	22,590	14,095	12,595	219.6
5 (LED 37 W)	11,120	12,057	10,357	44.6

To establish the best solution with the re-lighting technique, the investment payback period is calculated, since state of the art light sources have a higher initial price, but a longer lifetime - Table 5 and Figure 5. The annual operational time for the lamps was selected to be 2513 hours, equal to the weighted average operational time for open plan office buildings. [12] The analysis takes into consideration the reporting period of 20 years, the inflation equal to 3%, and the energy costs equal to 0.07 Euro/kWh.

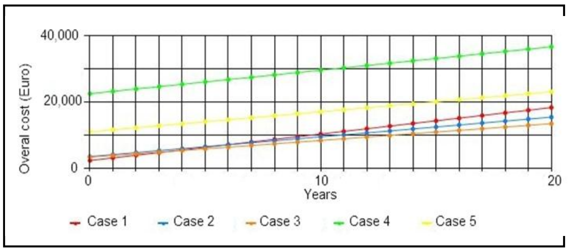

Figure 5 The cumulative costs during the reporting period

Case Study - Lighting systems in office building

An office building of 6450 m^2, divided in 10 floors was selected for the second case study. Each floor is composed of three identical office rooms with a surface equal to 57 m^2, four identical office rooms that have a surface equal to 38 m^2, two lobbies, bathrooms and utility rooms. The technical requirements imposed by the building characteristics consist of: the room surfaces reflection factors 0.20/0.50/0.70, the work-plane at 0.80 m for the office rooms and at 0.10 m for the lobbies; the iluminance values at working plane at 500 lx for the office rooms, and 100 lx for the lobbies. The case study analyzes the available strategies of refurbishment the existing lighting installation using modern light sources.

Table 6 presents the lighting solutions for the office building. The proposed solution 1 and 2 are the most energy efficient - Table 7.

Table 6. Lighting characteristics and number of light sources selected for the office building

Lighting solution		Light source	Characteristics			Units
			Power	Luminous flux	Luminous efficacy	
			W	lm	lm/W	
Existing installation		2xTL8-36 W MB	85	5700	67.06	620
Solution 1		2xTL5-28 W EB	62	5200	83.87	640
Solution 2	office rooms	2xTL5-28 W EB	62	5200	83.87	510
	lobies	37 W LED	37	2000	54.05	180
Solution 3	office rooms	62 W LED	62	3750	60.48	720
	lobies	37 W LED	37	2000	54.05	180

Table 7. Lighting characteristics of the office rooms and building

Lighting solution	Office rooms	Office building		
	Average illuminance (DIALux simulation)	Luminous flux	Power	Specific installed power
	lx	lm	W	W/m^2
Existing installation	503	4,154,000	52,700	10.52
Solution 1	509	3,328,000	39,680	7.92
Solution 2	509	3,012,000	38,280	7.64
Solution 3	501	3,060,000	51,300	10.24

Table 8. Total costs for the lighting solutions

Lighting solution	Initial cost	Operational cost	Energy costs	Amortization period
	Euro	Euro	Euro	years
Existing installation	105,503	403,370	298,610	-
Solution 1	175,466	311,711	217,937	15.3
Solution 2	241,075	308,137	214,577	28.4
Solution 3	1,184,250	396,256	303,256	232.5

To select the best solution between the proposed ones, the investment payback period is calculated. The initial costs, the operational costs, the energy costs for the entire period and the amortization period are presented in Table 8 and Figure 6.

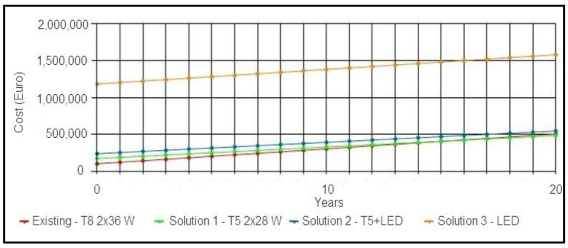

Figure 6 The cumulative costs during the reporting period

6 Conclusions

To implement light sources more energy efficient and less polluting, like the LED technology, seems to be a promising solution. However, if the LEDs begin to be widely used in interior lighting, many difficulties have still to be overcome before an extended use of LEDs in outdoor public lighting.

The right light at the right place in the right quantity stimulates and increase the sense of well-being. In office and administrative buildings in particular, lighting management plays a central role, providing the regulation needed to produce light that activates, motivates and helps maintain contentment and concentration. It also ensures the optimal visual comfort and maximum visual performance that most activities require for effective work. The selection between different available solutions for a considered lighting installation is made at each designing step, with the final purpose of establishing the optimal solution regarding the energy efficiency, the user satisfaction and the environmental protection.

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Prof. Georges ZISSIS
Director of L&M Research Group
LAPLACE - Universite
Paul Sabatier - Toulouse III
118, rte de Narbonne
F-31062 Toulouse Cedex 9
FRANCE
e-mail: georges.zissis@laplace.univ-tlse.fr
http://www.laplace.univ-tlse.fr

Georges ZISIS, **MIEEE'92, SMIEEE'06**, born in Athens in 1964, is graduated in 1986 from Physics Dept of University of Crete in general physics. He got his MSc and PhD in Plasma Science in 1987 and 1990 from Toulouse 3 University (France). Today, he is full professor in the Electrical Engineering Dept of Toulouse 3 University.

Prof. ZISSIS is deputy director of "LAPLACE" (Laboratory of Plasma and Conversion of Energy. He is working in the domain of Light Sources Science and Technology. He acted as Chairman of the European Union COST-529 "Efficient lighting for the 21st century" network, and was Chairman of the Industrial Lighting and Displays technical committee (ILDC) of IEEE-IAS. President of the Regional Branch of the French Illuminating Society (AFE) and National Secretary of the same society.

Prof. ZISSIS won the 1st Award of the International Electrotechnics Committee (IEC) Centenary Challenge for his work on normalization for urban lighting systems - 2006, and the Energy Globe Award for France and he got the Fresnel Medal from the French Illuminating Engineering Society - 2009.

Dr. Florin POP
Lighting Engineering
Laboratory UTC-N
24, Memorandumului Str.
RO-400114 Cluj-Napoca,
Romania
e-mail: florin@florinrpop.ro
http://florinrpop.ro

Dr. Florin POP retired as professor from the Technical University of Cluj-Napoca - 2009. He is the editor-in-chief of the journal Ingineria Iluminatului (Lighting Engineering) and was the chairman of the international conferences ILUMINAT 2001-2009.

Prof. Florin POP is the vice-president and director of Division 1 at the CIE National Committee of Romania. He was elected as member of the LUX EUROPA Board of Directors - 2009.

The paper is based on the Invited Paper at the Romanian Lighting Convention RLC 2011,
18-20 May 2011, Bucharest, Romania.

ROMANIAN LIGHTING CONVENTION 2011

Dorin BEU
Chairman of the RLC 2011
Universitatea Tehnica din Cluj-Napoca, Lighting Engineering Laboratory, Romania

Since 2001 the ILUMINAT conferences took place in Cluj-Napoca every two years. The ILUMINAT conferences marked a different approach in the area of lighting. Until 2009 speakers like, Wout van Bommel, Janos Schanda, Liisa Halonen, Axel Stockmar and many others have come to Cluj-Napoca and delivered excellent presentations. Also in 2009 a Lighting Exhibition was held in Bucharest, so the idea to combine these two events in a major one appeared, which would help promoting the importance for lighting for communities.

Four new ideas (comparing with the previous conferences) were at the base of a new concept for the convention:

- bring architects and designers and share experience;
- introduce the profession of lighting designers;
- rediscover the importance of daylight for health and energy performance;
- feedback from LED applications.

For a convention it was important the industry to be present, so an exhibition was organized to promote the changes induced by LEDs.

Romanian Lighting Convention RLC 2011 was held in Bucharest at JW Mariott Hotel, during 18-20 May 2011. The organizers of this event were Technical University of Cluj-Napoca – Lighting Engineering Laboratory, Ion Mincu University of Architecture and Urbanism of Bucharest and DK Events. The silver sponsor was Velux, the gala dinner sponsor was Energobit Schreder and Philips was also present as sponsor. The conference was organized under the auspices of CIE - Comission Internationale de l'Eclairage and CNRI - CIE National Committee of Romania.

Among the personalities presented at RLC 2011 we mention here (in alphabetical order):

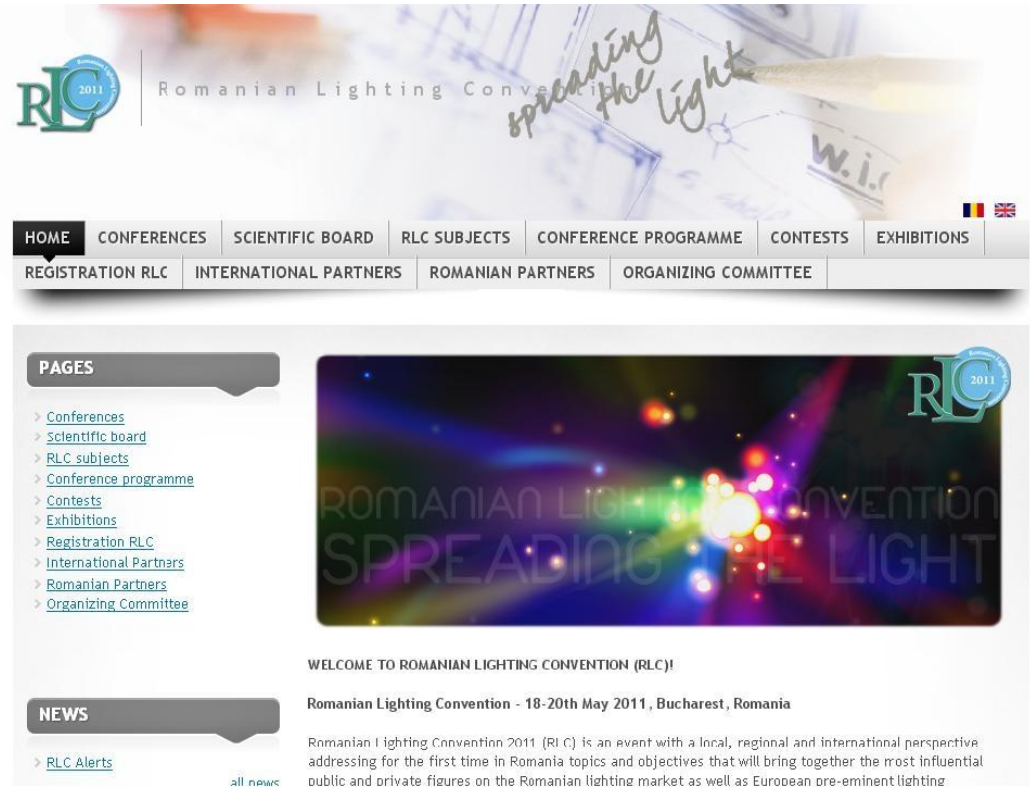
- Cornel Bianchi, president of Romanian Lighting Committee
- Grega Bizjak, president of Slovenian Lighting Committee
- Wout van Bommel, former CIE president
- Peter Dehoff, president of Austrian Lighting Committee
- Jan Ejhed, director of the Architectural Lighting Design master course, Stockholm
- Dan Hanganu, the most famous Romanian born architect, working now in Canada
- Martin Lupton, former president of PLDA
- Paulo Mendez da Rocha, Pritzker Prize 2006
- Roger Narboni, conceptor of Paris Lighting Master Plan
- Gaetano Pesce, famous designer

- Emil Barbu Popescu, president of the Ion Mincu University of Architecture and Urbanism
- Cristian Şuvagău, BC Hydro, Canada
- Frangiskos Topalis, director Lighting Lab, Athens
- Şerban Ţigănaş, president of Romanian Chamber of Architects
- Ann Webb, CIE elected president
- George Zissis, director of Research Center “Light and Matter”

In order to increase the students interest for this RLC 2011 the Osram LED Design Contest was organized, where the first prize went to a table luminaire (prototype could be seen there). The winner was a student from the Design School of Iaşi.

The major lighting professors, Cornel Bianchi and Florin POP, received the prize “Spreading the light” for their lifetime achievements in the field of Light and Lighting.

More details at http://www.rlc.org.ro



THE 5TH INTERNATIONAL CONFERENCE ON SOLAR RADIATION AND DAYLIGHTING SOLARIS 2011

Jitka MOHELNÍKOVÁ
Brno University of Technology, Czech Republic

The 5th international conference **SOLARIS 2011** will take place at the Faculty of Civil Engineering, **Brno University of Technology in the Czech Republic, 10-11 August 2011**. The conference is organized under the auspices of the **Dean Prof. Ing. Rostislav DROCHYTKA, CSc**.
http://www.fce.vutbr.cz/pst/solaris/

The SOLARIS tradition was founded by Professor Tariq MUNEER from Edinburgh Napier University, UK who is an international authority on the subject of solar radiation and daylight illuminance modelling and the application of windows in buildings.

Solaris conferences represent meetings of light and solar radiation specialists with seven year-long tradition (Edinburgh, United Kingdom 2003; Athens, Greece 2005; Delhi, India 2007; Hong Kong, China 2009). The next conference will be organised in Brno in 2011. Brno is a university centre and the second largest city in the Czech Republic.

The Solaris 2011 conference meeting will be held on the following topics:
- Light and health
- Daylighting in buildings
- Indoor visual and solar thermal comfort
- Sky models and daylight measurements
- Solar radiation monitoring
- Solar passive and active systems
- Light pipes and light guide systems

Conference chairman
Prof. Tariq MUNEER, Edinburgh Napier University, UK
Co-chair
Assoc. Prof. Jitka MOHELNÍKOVÁ, Brno University of Technology, Czech Republic

Honorary guests
Ing. Rut BÍZKOVÁ, Environmental expert, CR
Prof. Brian NORTON, President of Dublin Institute of Technology, Ireland
Mr. Nigel BELLINGHAM, Director of British Council CR
Dr. Otakar FOJT, Senior Science & Innovation Adviser, British Embassy, CR

Scientific committee
Dr. David CARTER, The University of Liverpool, UK
Prof. Dorota CHWIEDUK, Warsaw University of Technology, Poland, ISES Europe
Dr. Stanislav DARULA, Slovak Academy of Sciences, SR
Prof. Liisa HALONEN, Aalto University, Finland
Prof. Jozef HRAŠKA, Slovak Technical University, Slovak Republic
Assoc. Prof. Jiří HIRŠ, vice-dean, Brno University of Technology, CR
Dr. Harry KAMBEZIDIS, National Observatory of Athens, Greece
Prof. Richard KITTLER, Slovak Academy of Sciences, SR
Dr. Miroslav KOCIFAJ, Slovak Academy of Sciences, SR
Prof. Jorge KUBIE, Edinburgh Napier University, UK
Dr. Avraham KUDISH, Ben-Gurion University of the Negev, Israel
Dr. Danny Hin Wa LI, City University of Hong Kong, China
Dr. John MARDALJEVIC, De Montfort University, UK
Assoc. Prof. Miloslav NOVOTNÝ, vice-dean, Brno University of Technology, CR
Assoc. Prof. Jiří PLCH, Czech Lighting Society, CR
Prof. Florin POP, Technical University of Cluj-Napoca, Romania
Prof. Karel SOKANSKÝ, Czech Lighting Society, CR
Prof. Gopal Nath TIWARI, Indian Institute of Technology, India
Prof. Peter TREGENZA, The University of Sheffield, UK
Prof. Ling ZANG, The University of Utah, USA

Accepted abstracts

Authors	Institution	Title
Altan, H. et. al.	The University of Sheffield, UK	Indoor climate comfort in university buildings
Bosch, J.L, Batlles, F.J., López, G.	CIESOL, Universidad de Almería, Universidad de Huelva, Huelva, Spain	Mapping Solar Radiation Over Complex Topography Areas Using Artificial Neural Networks And Meteosat Images
Budiaková, M.	Slovak University of Technology, Slovakia	Solar systems of passive office building
Celik, A.N.	Abant Izzet Baysal University, Faculty of Engineering and Architecture, Bolu, Turkey	Analysis of solar radiation data measured at the southern region of Turkey and conversion from horizontal to a sloped surface
Chang-Ren Chen, Wu Zhong Nan, Nguyen Vu Lan	Kun Shan University, Tainan, Taiwan	Temperature stabilizing and energy saving for the cooling system of a large-scale laser printer
Chang-Ren Chen, Omar Ramirez, Nguyen Vu Lan	Kun Shan University, Tainan, Taiwan	Analyzing and modeling thermal insulation effect of transparent thin film
Chwieduk, D.	Warsaw University of Technology, Poland, ISES Europe	Availability of solar energy on a building envelope
Dudová, J, Doležalová, H.	Masaryk University, Czech Republic	Requirements for Lighting in Legal Regulations
Jadraque Gago, E.,Ordóñez García, J., Espín Estrella, A., et.al.	Universidad de Granada, Spain	Solar PV roof systems at housing sector in Andalusia
McGilligan, C. Natarajan, S. Nikolopoulou, M.	The University of Bath, The University of Kent, United Kingdom	Comparing energy savings from adaptive comfort standards in future UK climates using a new metric: the Adaptive Comfort Degree-Day
Grün, K.	European Solar-Shading Organisation (ES-SO), Germany	Automatic shading systems as for positive energy management
He, J.Z., Ng, E.	The Chinese University of Hong Kong, China	Using satellite data to predict sky types and zenith luminance in Hong Kong
Hraška, J.	Slovak Technical University, Slovakia	Criteria of daylighting and sunlight access in sustainable construction evaluation systems
Huang, J., Zang, L., et al.	The University of Utah, USA	Interfacial Engineering of Organic Nanofibril Heterojunctions into Highly Photoconductive Materials
Garnier, C.	Edinburgh Napier University, UK	Solar thermal collector module for houses and flats.
Ivanova, S.	University for Architecture, Civil Engineering and Geodesy in Sofia, Bulgaria.	Estimation of solar radiation for complex architectural layouts
Kalousek, M	Brno University of Technology, CR	Solar house
Kambezidis, H.D. et al.	National Observatory of Athens, Athens, Greece	The solar dimming effect over the Mediterranean region
Khalid, A., Anjum, S.	NED University of Engineering and Technology, Karachi, Pakistan	Photovoltaic Based Electricity Production Potential Assessment of a Pakistani City
Kaňka, J.	Czech Technical University, Prague	Czech Technical Standard ČSN 7305 81 Insolation of Buildings and Outdoor Spaces - Method for Determining Values
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Köster, H.	KÖSTER Lichtplanung, Frankfurt am Main, Germany	Dynamic Daylighting Architecture
Kudish, A. Evseev, E.G.	Solar Energy Laboratory, Ben-Gurion University of the Negev, Israel	The beam and diffuse fractions of solar UVB radiation and its implication regarding outdoor sun protection
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Li, D.H.W., Lam, T.N.T., Cheung, K.L.	The City University of Hong Kong, China	Average daylight factor under various skies and external environments
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Mayhoub, M., Carter, D.J.	The University *of* Liverpool, United Kingdom	Simple methods to estimate diffused luminous efficacy based on satellite data
Mayhoub, M., Carter, D.J.	The University *of* Liverpool, United Kingdom	Simple methods to estimate global luminous efficacy based on satellite data
Minea, A.	Technical University Gh. Asachi, Romania	CFD Techniques for Outlining Convection and Radiation in a Closed Domain
Muneer, T, Tham, Y.W.	Edinburgh Napier University, United Kingdom	Solar radiation projections for the UK building industries
Novotný, M., Šuhajda, K.	Brno University of Technology, CR	Doctoral study at the Institute of Building Structures, Faculty of Civil Eng, BUT
Ostrý, M.	Brno University of Technology, CR	Passive solar CPM materials
Plch, et. al.	Czech Lighting Society, CR	Tubular light guides
Plšek, D.	Hydro Building Systems GmbH Germany	Computer model of natural ventilation through double turn outward parallel window
Pop, F. et al.	Technical University of Cluj-Napoca, Romania	Passive tubular daylight guidance and photovoltaic systems - Energy Saving Potential in Residential Buildings in Romania
Sokanský et.al.	Czech Lighting Society, CR	Lighting and light pollution
Stravoravdis, S., North, R., Bulleyment, A.	Cardiff University, United Kingdom	An assessment of LED lighting compared to conventional fluorescent lighting in the office environment
Šikula, O.,, Plášek, J., Měrka,V.	Brno University of Technology, CR	Simulation of the influence of shielding surrounding to use solar energy for air conditioning
Šikula, O., et al.	Brno University of Technology, CR	Thermal evaluation of tubular light guides
Škramlik, J., Novotný, M.	Brno University of Technology, CR	Distribution of moisture in building construction
Yu, X., Su, Y.	The University of Nottingham, United Kingdom	Evaluation of energy saving from daylighting for an educational building
Zahiri, S., Altan, H.	The University of Sheffield, UK	Optimizing Daylight Distribution in School Buildings in Iran
Zapletalová, M.	Czech Technical University, Prague	Spectrum of light and its influence to the human health and impact to the legislative and buildings

LIGHTING IN THE NEW WORLD

Cristian ŞUVĂGĂU
BC Hydro, Vancouver

LIGHTFAIR 2011

For the annual Lightfair tourist, the 2011 edition brought a clear message: America is coming out of the economical crisis; or at least the Lighting Industry could be a providential safety floating device. The 22nd consecutive edition of LIGHTFAIR International (LFI) broke all records for attendance and exhibit space at the Pennsylvania Convention Center in Philadelphia, May 17-19.

LFI, which is the premier event for the lighting industry in North America and became the world's largest annual architectural and commercial lighting trade show and conference, featured this year 1,600 booths and covered 20,000 m^2 of exhibits in its largest-ever trade show floor. Out of the 500 manufacturers, 10% were first-time exhibiting companies. Attendance also top all the past editions with 23,700 designers, lighting, architectural, engineering and energy professionals from around the globe representing 75 nations.

The Conference Program

Seminars. LFI impressed the lighting practitioners with over 200 hrs of accredited courses provided during the conference. Sponsored by the International Association of Lighting Designers and the Illuminating Engineering Society of North America the event provides an incredible venue to accomplish the mission to disseminate information about art and science if illumination.

There were in total 35 seminars (at 90-minute each) on diverse topics designed to educate attendees on the industry's latest trends, innovations and business solutions, and, pragmatically speaking, give everybody the CEUs / Learning Units they need. As you probably guessed, like for the show room floor, the lion share of seminars was taken by Solid State Lighting (SSL), a whopping 40% of the seminars' topic.

Advanced Education. As in the previous years, LFI preceded the event with a few full-day courses, a solid approach at advanced lighting education:

- LIGHTFAIR International Institute – the lighting industry's most renowned educational program – a complete 3-level lighting series (total of 27 courses and workshops) was introduced with the addition of a new 2-day Advanced Lighting course to enhance the existing Basic Lighting and Intermediate Lighting 2-day immersion courses.
- Daylighting Institute - also provided (in parallel) 12 courses and workshops on

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daylighting management tools, metrics, harvesting and control systems.

- Design Symposia – a new for this year - offered four 90-minute design-related courses from conventional topics like museum and landscape lighting to newer trends like healing light therapy and biomimicry (emulating nature's time-tested forms, processes and ecosystems to create more healthy and sustainable designs).

The modern Lightfair is also an excellent networking forum that allows today's leaders to connect to the industry's future in innovation and education. After three successful years, LFI offered again the *LFI Student Outreach Program* with the addition of *Design With Light*, an exclusive student lighting design competition. *The Student Outreach Program* allows students to receive hands-on experience and exposure to the industry by offering numerous educational and volunteer opportunities at the trade show and conference.

The Trade Show

Awards. The highly coveted LFI 2011 Innovation Awards received over 200 submissions for the 14 designated categories for products making their debut on the 2011 trade show floor. Each product was judged by an independent panel of renowned lighting professionals. The 2011 key award winners are:

- ***Most Innovative Product of the Year*** - *Revel*™ by Acuity Brands, a 5-panel modular OLED ceiling mounted system of 6.5 W, 4" square panels at 60 lm/W and 85 CRI. This is the program's highest award, recognizing the most innovative new product.
- ***Design Excellence Award*** - *Low-Voltage LED Wall Wash/Flood* by Tech Lighting-Generation Brands, a 10 or 20 Watt single or double 12 Volt wall wash track head producing 600 or 1,200 lumen dimmable to 10% in flood or asymmetric optics. The award recognizes outstanding achievement in design.
- ***Technical Innovation Award*** - *LUXEON A* by Philips Lumileds, a hot-tested LED with tight binning at 85 lm/W providing 170 lumen at 2,700 and 3,000 K with 80 CRI. The award recognizes the most forward-thinking advancement in lighting technology.
- ***Judges' Citation Award***: - *IESNA Lighting Handbook 10th Edition*. 10 years after the previous rendition, the new Handbook edition features 37 chapters, a full-colour reference entirely new in format, scope, and depth.

LFI has also awarded nine exhibitors that excelled in visual booth display and product presentation.

Here is a short overview of the main lighting categories of products introduced at LFI 2011.

Alignment to general service lamp regulation (2 yrs phased banning of omni-directional incandescent lamps between 40 W - 100 W) saw few notable halogen lamps (from 20 W to 53 W) being pushed in the market under "Eco friendly" labels.

High wattage CFLs (65-180 W) were also present to challenge the HID lamps with one notable 180 W product able to function directly in the HID socket without by-passing the ballast.

T5HO can now reach 60,000 hrs and some also are getting “slimmer” (49 W vs 54 W).

Not to be left behind, however, fluorescent and induction lighting manufactures are taking the advancement of LED technology as impetus to continually improve their products' rated lifetimes and light output to remain competitive. Birchwood Lighting is even offering a “color changing” fluorescent solution which packs individually controllable red, green, blue, and white fluorescent tubes in a single fixture to allow color mixing.

HIDs were dominated by enhanced CMH lamps and electronic ballasts. Noted was Philips’ Allstart series of CMH replacement lamps that can work on either a probe or pulse start magnetic ballast and save 20% energy.

With few exceptions, of inductive and electronic-ballasted MH products, the street and area lighting world at LFI was simply made of LEDs. From retrofit kits to full fixtures, LED are an aggressive invading species that now is getting more resilient and smarter, ready to conquer the world. More ergonomically and photo-metrically challenging shapes are pushed on the market with for-ever burgeoning lumen (and thermo-management issues) packages reducing the gap to conventional HID luminaires. Throw on this a 0-10V ready electronic dimmable driver and adaptive lighting opportunities show a promising future for solid state lighting on exterior applications (currently the most valued and fast growing LED lighting market in North America).

LEDs continue to drill their ways into the theatrical and entertainment market with a category winner (RGB LED) from Visa Lighting able to reach 9,000 lm and 325,000 cd beam power, challenging at 130 W the conventional light projectors; and of course, a sea of wall-washers, floodlights and tap, string products.

LED luminaires (still) make their timid approach to replace linear fluorescent for general illumination with a category winner (recessed luminaire) for patient rooms that offers multiple-outputs (not just your simple, conventional dimming solution) and a blue-light therapy and RGB mood colour-changing.

The world of pot lights has been taken completely by LEDs with an award winning product matching their CFL counterparts in output and efficacy but with 40^0 adjustable and hi-low positioning gears, to control light distribution and glare.

The same seems to go for the architectural accent and track luminaires with many manufacturers featuring LED inter-changeable modules/engines with integral drivers. SSL track lights, although with average efficacy still lower than for SSL recessed downlights, can significantly outperform conventional incandescent track lighting products.

In the case of the general service (omni-directional) LED lamps, pathways blazed (and still lead) by Philips, one can see a few more snow cone styled lamps that can really challenge the 40 W - 60 W incandescent bulbs now including candelabras. Even if the bulky form factor of thermal management cases remained unchanged for the last years for directional lamps (MR, PAR, AR), choices were more numerous and lumen packages improved. Overall, the dimming ability is becoming a default now, warm CCT products are predominant, efficiency is pushed up to 80-90 lm/W and few PAR products sport outputs close to 3,000 lm at 85 CRI.

Controls are getting more sophisticated and reliable, with a lot of wireless and remote monitoring options. Such is Lutron's remote-mount dimming retrofit module for personal control, occupancy and daylight harvesting, Eldoled's one-button DMX controller to set dim levels, colour and show for LED drivers or NXP Semiconductors' wireless control chipset that can be inserted into the socket of a CFL or LED bulb. I want tot point though to two revolutionary products with a lot of potential. The SpaceStation occupancy sensor product from Concealite can be installed completely out of sight behind any ceiling material (aside from metal) and will detect motion via super high frequency electromagnetic waves and the Doppler Principle. The LED company Lighting Science Group teamed up with the internet giant Google to develop an open source wireless protocol that can be used to roll out inexpensive hardware for mesh networking so consumers will be able to control these LEDs with their Android (phone) devices. Compared to Z-Wave and Zigbee (that use the same 900MHz band), there's far less technical expertise needed to start automating things in your home and things could actually become affordable not only to millionaires. Just imagine if it had the impact on home energy conservation that the iPod had on listening to music.

As a general impression, other electronic industry giants have made their debut at this year's LFI: Korean LG and Samsung. The arrival of them as major players in SSL is important for lowering cost (one of the principal barriers for solid state lighting adoption). LG and Samsung have massive operations combined with equally large channels.

The rise and acceptance of LEDs beyond entertainment, accent, and decorative lighting was reflected in the LFI Innovation Awards where several LED-based products took prizes (see above). However, for LEDs to change the industry the real challenge is to explore new forms of delivering the light, otherwise they will be trapped in the socket world for a long (life) time.

Cristian ŞUVĂGĂU
Dr., P.Eng., LC, CEM, MIES, MCIE
BC Hydro PowerSmart,
900, 4555 Kingsway
Burnaby, BC, V5H4TB
Canada
e-mail: cristian.suvagau@bchydro.com

He holds a Ph.D. from the Technical University of Construction in Bucharest, Romania for his thesis on improved calculations methods. He has been practicing and teaching architectural lighting design and energy efficiency in Europe and North America for over 25 years. A senior lighting and energy management engineer with BC Hydro, he focuses on lighting efficiency and DSM programs and research. He is also a member of the Canadian NC of the CIE and Past President of the BC chapter of IESNA.

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