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The journal **INGINERIA ILUMINATULUI - Lighting Engineering** - is affiliated to the CNRI - Romanian National Committee on Illumination, member of the CIE - Commission Internationale de l'Eclairage. It has a scientific presentation and content, targeted to the continuing education in the lighting field.
The objectives of the journal consist of the presentation of the results of the lighting research activity, the dissemination of the lighting knowledge, the education of the interested people working in public administration, constructions, designers, dealers, engineers, students and others.
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LIGHTING EFFICIENCY AND QUALITY: HAND IN HAND

Wout van BOMMEL

This issue of Ingineria Iluminatului has many papers about efficiency of lighting. It not only deals with artificial lighting, such as office lighting and road lighting but also with daylighting. I think it is a must to include daylighting in an issue devoted to efficiency in lighting. Too many “artificial lighting professionals” forget that daylight can offer an important contribution to both energy efficiency and to the quality of lighting installations. It is interesting to note that in road lighting a long forgotten method to increase the efficiency of road lighting installations, the use of high reflective road surfaces, gets renewed attention. Also here the benefits are not restricted to energy efficiency only. There are chances to improve the overall quality of the installation as well, by having better contrasts. The methods described in this issue not only relate to energy efficiency but more general to sustainability, a subject that receives already some years worldwide attention.

In 1972 the Club of Rome, a small international group of professionals from the fields of diplomacy, industry, academia and civil society, produced its report “The limits to growth”. This report showed for the first time the contradiction of unlimited growth in material consumption in a world of finite resources. It brought, especially after the subsequent (first) oil crisis of 1973, the issue to the top of the global agenda. I remember that the world was shocked and it took some time before we reacted appropriately, for example by reconsidering our lighting standards and developing more energy efficient lighting products. The first energy efficient alternative for the incandescent lamp, the compact fluorescent lamp, was for example only introduced to the market in 1980, 8 years after the publication of the Rome report. Of course since then, we have learned to react quicker, especially also since in the nineties of the last century next to shortage of availability of resources, also the negative consequences of CO_2 emissions on climate change became apparent. Today indeed sustainability is the key word. For lighting, sustainability can be defined as: “balancing the positive effects of lighting on living beings with the negative impacts of that lighting on the environment”. This definition means that energy efficient lighting should go hand in hand with providing safety, security, performance, health and well-being.

The paper of **Albu, Halonen, Tetri and Pop** elaborates on possibilities to save energy by dimming light sources with a minimum of distortion of the voltage supply. Both conventional light sources like fluorescent tubes and noval, solid state, LEDs are considered. Different simulation programs are used to show the impact of dimming of these different types of light sources.

Bianchi and Biro show in their contribution that it is possible to reduce energy consumption without decreasing visual comfort. Indeed it is essential when studying possibilities to save energy in lighting systems to do that with a sharp eye on keeping the qualitative aspects of the installation, in both performance and comfort terms, good enough. They describe intelligent daylight linking systems.

One of the alternative methods to reduce energy consumption from artificial lighting is to transmit daylight into the depth of buildings. The paper of **Ţicleanu** compares the capacity of daylight transport by light-pipe systems, on the one hand collecting daylight from the façades (horizontal pipes) and, on the other hand, collecting daylight from the roof of buildings (vertical pipes).

In addition to the two papers dealing with the use of daylight in building interiors this issue also describes what has been discussed about daylight and solar radiation at the Stockholm conference, Light Symposium 2010. An announcement is made about a 2011 conference in Brno on solar radiation and daylighting. The readers of Ingineria Iluminatului are given in this way a good possibility to stay updated on the important subject of daylight and energy efficiency. Once again, a must for each "artificial lighting professional".

In the paper of **Măierean** it is discussed that both quality and energy parameters of road lighting installations can be influenced by the "behavior" of road surface pavements. As they state: *"the road surface reflection characteristics are the starting point for the design of an optimized road lighting installation"*. Where this was the normal accepted situation some 30 years ago when worldwide the luminance concept of road lighting was accepted, this today is too often forgotten. This paper, that is based on today's situation, offers therefore an important contribution to saving energy in the outdoor environment.

I now have more than 40 years in lighting and I can guarantee that I had a fantastic interesting and challenging time. One of the things that made this time in lighting so interesting is the many important developments in lighting technology culminating in the introduction of solid-state light sources. I am sure it is not the end of it. The paper of **Şuvăgău** "Lighting in the new world – LED promise: are we there yet?" points to both positive and negative factors connected with the changeover to LEDs. It also shows that alternative light sources will remain important and that we still may expect intriguing developments in light sources.

My dream: when I leave my home in the morning I put a box in my garden that collects the daylight as light. When I return in the evening to my home I take the box indoors and when I need light I open it to let the daylight out. Dream or reality?

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OFFICE LIGHTING WITH OLD AND NEW LIGHT SOURCES

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Abstract. *With increased global warming concerns, considerable attention is being given toward reducing the energy consumption in the field of lighting. As office buildings represent one of the biggest light energy consumers, many studies are done in this sense. Between different approaches, two are used more frequently: the use of different light controls or the switch of old light sources with better ones in terms of luminous efficacy. This paper presents light and power quality measurements for different light sources that are suitable for office buildings. Using different simulation programs, the impact of dimming on four types of light sources, that have already been measured, is presented.*

Keywords: *dimming, LED luminaires, luminous efficacy, power quality*

1 Introduction

According to the European Union, 40% of all electric energy produced in Europe is used to power commercial and residential buildings [1]. From this percentage, around 30% of the total electricity consumption was due to lighting [2]. Because of the increased regard on environmental and economic issues, energy-saving methods and initiatives are being intensively promoted. Regarding light sources, there are two ways of reducing the energy consumption: either by increasing the luminous output corresponding to the same amount of power, and therefore, using less light sources, or by reducing the power consumption.

For the first case, different approaches are available: the use of tri-phosphor fluorescent lamps instead of halo-phosphate fluorescent lamps [3], the replace of magnetic ballasts with high-frequency (HF) ballasts with a typical 10% efficacy gain [4], reduction in initial cost by replacing T8 fluorescent light systems by T5 fluorescent light systems and also energy savings of up to 35% [5]. The introduction of LED in office buildings is becoming a more viable solution, with the closer availability of top-class LED component products with lighting efficacy exceeding 100 lm/W [6], and also the proliferation of new LED luminaires for office buildings by different manufacturers [7].

A different approach in energy savings refers to the use of lighting control systems and daylight contribution. One study that compares different light control methods used in private office rooms concludes that by using an occupancy sensor 20÷26% of energy savings are made and by using automatic daylight dimming controls savings of 21% are achieved, compared to manual switching [8]. A different study conducted on open-plan offices shows reduction in electric energy consumption of 35% if occupancy sensors are used alone, 20% for light sensors and 11% individual dimming. Also, if all three controls are used, a reduction of the average daily peak power demand of 65÷70% is achieved, compared to a conventional lighting system [9]. Electric energy savings are highlighted for an office building in [10], where different rooms have different lighting control techniques employed. The average energy consumption savings of 40% are achieved if occupancy and daylight dimming control are used and 22%, if occupancy and manual dimming control are employed, compared to a room without dimming and occupancy control.

One direct effect of using light dimming controls is a decrease in the power factor, as shown in [11]. Here the results of testing the dimming effect on eighteen ballasts, used for T5 fluorescent lamps of 28 W, 49 W and 54 W are presented. The decrease in the power factor is attributed to the increase in the Total Harmonic Distortion of the Input current waveform (THDI) during dimming.

2 Office characteristics

2.1 Light requirements in office buildings

The standard EN 12464-1:2002 [12] recommends that "*adequate and appropriate lighting*" should be provided in buildings, in order to *"enable people to perform visual tasks efficiently and accurately".* The lighting requirements specified by the standard are determined by the satisfaction of three basic human needs: visual comfort (the workers have a feeling of well-being), visual performance (the workers are able to perform their visual tasks) and safety.

For the majority of office work activities, the illuminance required levels recommended by [12] are set between 300 lx and 500 lx, with differences regarding room designation. The Unified Glare Rating (UGR) limits are set between 16 and 25, depending on the room peculiarity. Also, the standard recommends that lamps with a Color Rendering Index (CRI) lower than 80 should not be used in interiors where people work or stay for longer periods.

A study conducted in [13] shows that the change in the correlated color temperature (CCT) and illumination level is affecting the visual appeal of a space in office buildings:

- 2000 lx was preferred to 500 lx for the impressions of comfort, spaciousness, brightness, and saturation evaluation;
- 4000 K CCT was preferred to 2700 K for the impressions of comfort and spaciousness, while 2700 K was suggested for relaxation and the saturation evaluation.

2.2 Power quality requirements in office buildings

A significant part of the equipment that exists in office buildings (electronic and computer devices) requires a good power quality. At the same time, the same equipment often causes distortion of the voltage supply in the installation, because of its non-linear characteristics (it draws a non-sinusoidal current when supplied with a sinusoidal supply voltage). Therefore, maintaining a satisfactory power quality is a responsibility that concerns both the electric supplier and the electricity user. The electric energy supplier is responsible for maintaining a stable and continuous voltage at the point of common coupling. In this sense, Standard EN 50160 [14] gives the main voltage parameters and their permissible deviation ranges for public low voltage and medium voltage electricity distribution systems, under normal operating conditions. The power quality problems generated by the user equipment are summarized in the EN 61000 series standards, in which limits of power quality disturbances are characterized. The harmonic limits for lighting equipment are contained in Standard EN 61000-3-2, with different particularities according to the active power of the lamp. [15]

Most of the problems that electronic equipments generate refer to low power factor, harmonics and unbalance in three phases - four wire systems. A study that presents power quality measurements made in a small size office building shows that lighting equipment has a contribution in lowering the power factor and increasing the THDI, but with much smaller effect then other office appliances. [16]

3 Light sources in office buildings

3.1 Proportion of different light sources

A study conducted in 2005 [2] describes the differences in the estimated regional share of light output by source in the commercial building sector from different parts of the world - Figure 1. The large majority of the light delivered in the commercial sector is

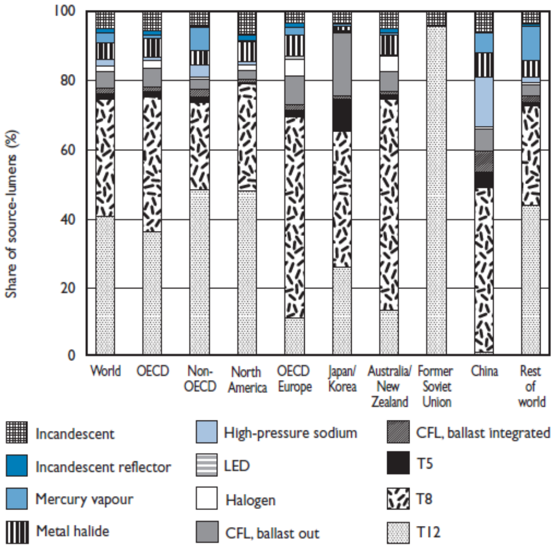


Figure 1 Estimated regional share of light output by source in the commercial-building sector in 2005 [2]

determined by linear fluorescent lamps (accounting for 76.5% of the total), followed by a mixture of incandescent, compact fluorescent and HID lamps. The consequence of this fact is that the average luminous efficacy of commercial lighting in the OECD countries is 51 lm/W.

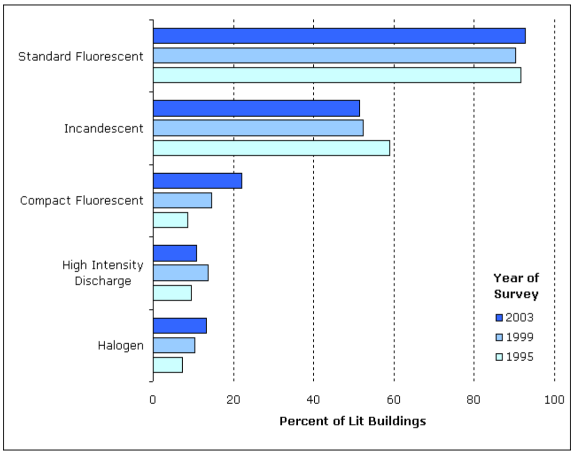


Figure 2 The percentage of lit buildings by different light sources. [17]

A different study based on surveys in different commercial buildings shows that the percentage of commercial buildings with lighting remained unchanged between 1995 and 2003. [17] The compact fluorescent lamps and halogen lamps had a significant increase, while the use of incandescent lamps declined. Figure 2 presents the comparison between different light sources.

A recent study [18] discusses about the trend of light sources in Japan: the incandescent, general lighting purpose halogen lamp and linear fluorescent lamps production and sales decreased compared to the previous year, while compact fluorescent lamp had a significantly growing trend as to the previous year. The increase attention for the LED light sources is underlined. As Japan is among the major exporters of lighting equipment [2] along European Union and China, the trend could be generalized as a global trend.

The general requirements that a “good” lamp should have are presented in [19]: a high efficacy, a high color rendering index, a long life, to produce a stable light level during its lifetime, to avoid flickering, to produce its nominal flux instantaneously when turned on, to be exchangeable with other types of lamps, to be compact and light, to avoid harmonic distortion feedback to the electric network, to avoid environmental harmful materials, to avoid electromagnetic interference with any other electronic equipment, to avoid excessive heat and UV rejection, to be recyclable and to be inexpensive.

In office buildings almost exclusively fluorescent lamps are installed, due to their low cost and high light output.

3.2 Fluorescent lamps

The advantages of using magnetic ballasts are the simplicity, low initial cost and reliability. The main drawbacks consist of low displacement power factor and flicker possibility. Efficacy increases rapidly with high-frequency operation for electronic ballasts until 20 kHz; efficacy is constant in the range from 20 to 100 kHz.

There are several types of electronic dimming ballasts available on the market, with different particularities in the control methods: Pulse Width Modulation (PWM), phase control and low-voltage control (typically 1-10 V DC).

The PWM control is the least used, as it utilizes a high-frequency square-wave signal over separate control wires to dim lamps down to approximately 10% of maximum output. The main advantage of PWM control is its ability to control a large number of ballasts per controller.

The phase control method gives the user more flexibility since it dims lamps to 1%. Other advantages are the very uniform dimming and the lamp stability. Its main drawback is the high initial cost for equipment and installation.

The third control type uses a DC voltage sent to ballasts through separate control leads. A single control device can control 60 to 80 ballasts, with a stable dimming range of 100% to 20% or lower, depending on the low level capability of the ballast. [21]

The effect of dimming on lamp life and lumen maintenance factor, as showed in [22], is not an obstacle to the combined use of daylight and artificial lighting. The study concludes that, when lamps are burned continuously at low dimming levels, the lumen maintenance factor is larger than for the undimmed lamps.

To achieve the highest possible energy savings with modern lighting, it is recommended to use luminaires with dimmable electronic ballasts, daylight control systems and presence detectors. [23]

According to [19], the trend in linear fluorescent lamps is towards producing higher energy savings performances and mercury free products.

3.3 LED lamps

A report released in May 2010, from Pike Research Institute, states that LED lighting will become an increasingly important segment of the market and, by 2020, it will achieve a 46% penetration of the U.S. market for lamps in the commercial, industrial, and outdoor stationary sectors. [24]

The most used techniques in dimming white light LED systems are the continuous current reduction and the PWM.

The current dimming scheme exploits the linear section of the current-voltage relationship. The technologies used include variable resistors or a voltage regulator with a variable programmable output. Dimming LED by simply varying the drive current may cause some LED chips to appear as a different color, while other may simply stop illuminating entirely.

The PWM dimming systems can effectively control the pulse width and duty cycle, causing the LED chip to vary its luminous intensity. This technique is realized by turning the LED off for a very short period. The method provides the ability to increase the dimming range by achieving lower current levels and linear control of light intensity down to zero percent. The implementation of microcontrollers for the PWM LED dimming circuits provides greater application flexibility and requires fewer external components.

Phosphor-converted white LEDs exhibit very little chromaticity shift when the light was changed from 100% to 3% using both dimming schemes, while mixed-colors LEDs have very large chromaticity shifts. [25] The spectral and luminous efficacy change in high-power colored and phosphor-converted white LEDs under the same dimming techniques was experimental quantified. [26]

One or more of the following will occur when phase dimmers are connected to typical commercially LED lamps: visible pulsing of LEDs; audible noise from LED light bulbs; LEDs never fully turn on; LEDs turn on when the dimmer is turned off. [27]

4 Measurement study

Different types of light sources were measured with the purpose of finding the effects of dimming, in terms of light and power quality characteristics. Each light source was tested with and without the employment of dimming process. The measurements were done in the Lighting Unit, in Aalto University TKK, with the use of a Yokogawa DL708E Digital Scope, a Yokogawa WT130 Power Meter and a Labsphere LPS-200-H. The amplitudes of the current harmonics have been compared with the Standard EN 61000-3-2 limits [15]. For clarity in the figures, the current wave-shapes are multiplied by 250 times in regard to the voltage wave-shape.

4.1 Luminaire equipped with T8 36 W fluorescent lamp

A luminaire equipped with a T8 36 W fluorescent lamp and electronic dimmable ballast has been tested. The dimming process was performed using a 1÷10 V DC signal. The signals were given by a DC power supply, with set values of: 1, 2.5, 5, 7.5, 10 V DC.

The characteristics of the lamp and the ballast are:

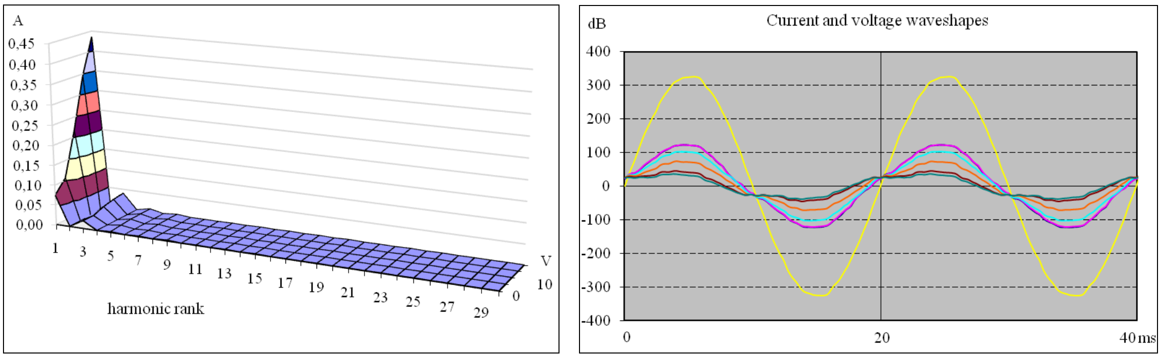
Lamp: DuraLamp 36 W/830 3000 K;

Ballast: Helvar Electronic ballast EL1x36 W HFC 230-240 V, 50-60 Hz.

The measurement results are presented in Table 1. Figure 3 shows the amplitude variation of the current harmonics of the light source during the dimming process (a), and the voltage and current wave-shapes (b).

Table 1 Electric and luminous parameters

Parameter	Unit	Not dimmed	Dimmed 1÷10 V DC				
			10	7.5	5	2.5	1
Active power	W	38	38.1	32.2	21.4	11.5	9.1
Reactive power	VAR	7.5	7.4	8.0	8.4	8.5	8.5
Apparent power	VA	38.7	38.8	33.0	23.0	14.3	12.4
Voltage amplitude	V	232.8	231.5	234.5	234.4	233.6	233.6
Current amplitude	A	0.166	0.168	0.141	0.1	0.062	0.054
Frequency	Hz	50	50	50	50	50	50
Power factor		0.98	0.98	0.97	0.93	0.84	0.73
THDI	%	9.05	9.18	9.33	12.88	18.40	19.01
Luminous flux	lm	1750	1750	1450	820	220	83
CRI		85.8	85.8	86.0	86.0	86.0	85.6
CCT	K	3000	3000	3000	3000	3000	3000
Luminous efficacy	lm/W	46.05	45.93	45.03	38.32	19.13	9.12



(a) (b)

Figure 3 The amplitude variation of the current harmonics of the light source during the dimming process (a), and the voltage and current wave-shapes (b): voltage wave-shape - yellow; current wave-shapes for the not dimmed case – blue, and for the mentioned dimming levels (dimmed with 10 V DC - purple; dimmed with 7.5 V DC - light blue; dimmed with 5 V DC - orange; dimmed with 2.5 V DC - brown; dimmed with 1 V DC – green).

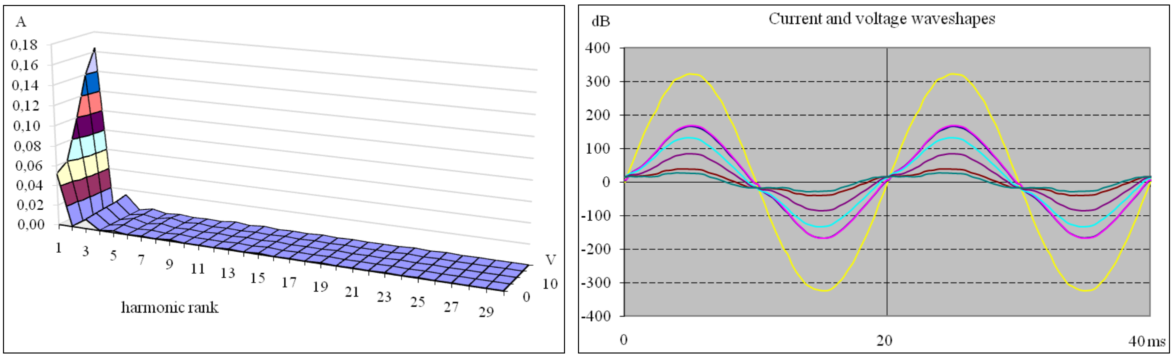
4.2 Luminaire equipped with T5 2x49 W fluorescent lamps

Similar measurements were made on a luminaire equipped with a T5 2x49 W fluorescent lamps and electronic dimmable ballast, by using a 1÷10 V DC signal, rated at the same levels: 1, 2.5, 5, 7.5, 10 V DC. The measurement results are presented in Table 2. Figure 4 shows the amplitude variation of the current harmonics of the light source during the dimming process (a), and the voltage and current wave-shapes (b).

The CRI and CCT do not suffer variations during dimming. The amplitude of the current for different harmonic ranks is relative constant throughout the dimming process - Figures 3 (a) and 4 (a). Thus, the increase of the THDI value is due mostly to the decrease of the fundamental current harmonic amplitude.

Table 2 Electric and luminous parameters

Parameter	Unit	Not dimmed	Dimmed 1÷10 V DC				
			10	7.5	5	2.5	1
Active power	W	136.5	136	111.6	81.2	54.2	46.7
Reactive power	VAR	31.5	31.6	33.0	34.5	35.2	36.2
Apparent power	VA	140.2	140.2	116.4	88.4	64.7	58.8
Voltage amplitude	V	230	230	230	230	230	230
Current amplitude	A	0.608	0.61	0.506	0.384	0.28	0.258
Frequency	Hz	50	50	50	50	50	50
Power factor		0.97	0.97	0.96	0.92	0.84	0.79
THDI	%	8.72	9.32	10.69	14.26	19.07	26.87
Luminous flux	lm	6720	6720	5170	2820	650	120
CRI		80.6	80.6	80.0	80.0	80.0	80.0
CCT	K	4100	4100	4000	4000	4100	4100
Luminous efficacy	lm/W	49.23	49.41	46.33	34.73	11.99	2.57



(a) (b)

Figure 4 The amplitude variation of the current harmonics of the light source during the dimming process (a), and the voltage and current wave-shapes (b): voltage wave-shape - yellow; current wave-shape for the not dimmed case – blue, and for the mentioned dimming levels (dimmed with 10 V DC - purple; dimmed with 7.5 V DC - light blue; dimmed with 5 V DC - orange; dimmed with 2.5 V DC - brown; dimmed with 1 V DC – green).

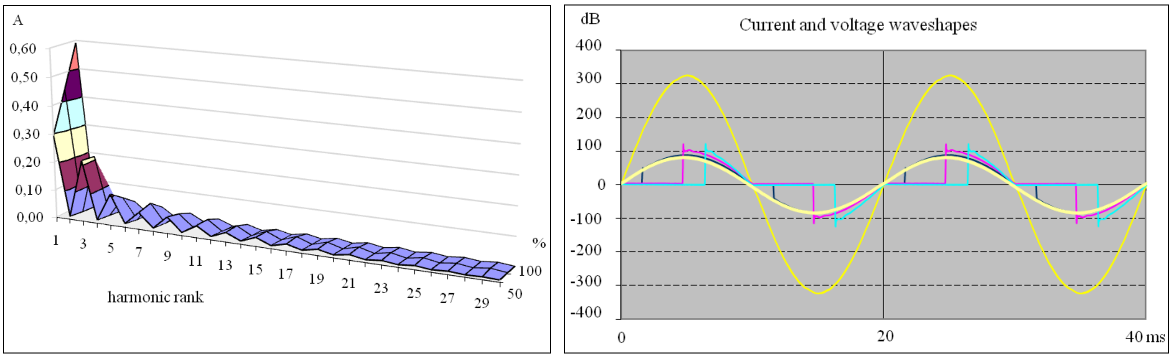
4.3 Luminaire equipped with 150 W halogen lamp

The dimming process was done with the use of a triac dimmer (CO/TECH EMD 200, 40-300 W, 230 V). The electric, luminous and power quality characteristics are given in Table 3. Figure 5 shows the amplitude variation of the current harmonics of the light source during the dimming process (a), and the voltage and current wave-shapes (b) for the not dimmed case and dimmed at different voltage levels, with the employment of the triac dimmer.

The power factor value did not suffer changes, maintaining a value of 100% through the dimming process - Table 3. Also, the reactive power had an unchanged value, equal to zero. The CRI and CCT presented lower values, as the voltage amplitude dropped. The current amplitude corresponding to the odd harmonic ranks increase as the light output decreases.

Table 3 Electric and luminous parameters

Parameter	Unit	Not dimmed	Voltage level, % of fundamental		
			100	75	50
Active power	W	149.9	142	93.3	48.5
Reactive power	VAR	0	0	0	0
Apparent power	VA	149.6	141.9	93.3	48.5
Voltage amplitude	V	233.8	225.3	172	112.6
Current amplitude	A	0.641	0.63	0.542	0.43
Frequency	Hz	50	50	50	50
Power factor		1.00	1.00	1.00	1.00
THDI	%	0.52	13.78	57.21	91.73
Luminous flux	lm	2082	1944	740.1	164
CRI		99.3	99.4	99.4	98.1
CCT	K	2950	2950	2650	2300
Luminous efficacy	lm/W	13.89	13.69	7.93	3.38



(a) (b)

Figure 5 The amplitude variation of the current harmonics of the light source during the dimming process (a), and the voltage and current wave-shapes (b): voltage wave-shape - yellow; current wave-shape for the not dimmed case – light yellow, and for the mentioned voltage levels, with the employment of the triac dimmer (100% of the fundamental voltage - dark blue; 75% of the fundamental voltage - light red, 50% of the fundamental voltage - light blue).

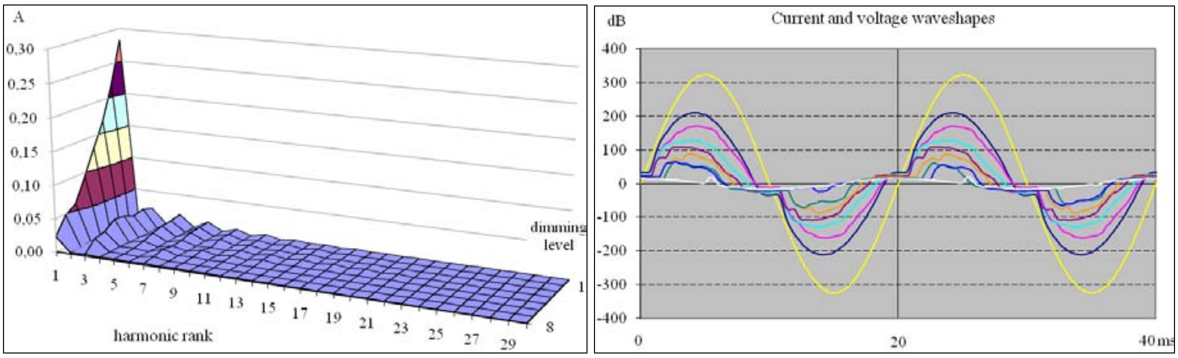
4.4 LED 62 W luminaire

The LED luminaire is manufactured by GreenLux (62 W GLP 6060-30 Lighting Panel), and it is driven by a PWM driver. The dimming levels (2÷8) are appointed by manufacturer, and the selection between different levels is done with the use of a remote control. The measurement results are presented in Table 4. Figure 6 shows the amplitude variation of the current harmonics of the light source during the dimming process (a), and the voltage and current wave-shapes (b).

As the light output is decreased, the current amplitude, the active power, the apparent power, the reactive power and the power factor have lower values. The increased values of THDI are due mostly to the decrease of the fundamental current harmonic amplitude - Figure 6 (a). The voltage level, CRI and CCT do not vary during dimming.

Table 4 Electric and luminous parameters at different dimming levels

Parameter	Unit	Not dimmed	Dimming levels, set by the remote control						
		1	2	3	4	5	6	7	8
Active power	W	62.3	48.4	35.8	27.7	18.7	9.5	7.4	0.7
Reactive power	VAR	19.2	18.5	17.8	16.1	14.5	12.8	11.5	6.8
Apparent power	VA	65.2	51.8	40.1	32.1	23.7	16.0	14.0	6.8
Voltage amplitude	V	230	230	230	230	230	230	230	230
Current amplitude	A	0.283	0.225	0.174	0.139	0.103	0.07	0.06	0.03
Frequency	Hz	50	50	50	50	50	50	50	50
Power factor		0.956	0.93	0.89	0.86	0.79	0.60	0.54	0.10
THDI	%	11.45	15.85	18.61	26.20	37.37	41.58	40.31	0.40
Luminous flux	lm	3460	2840	2200	1700	1150	530	400	0
CRI		56	56	56	56	56	56	56	-
CCT	K	3000	3000	3000	3000	3000	3000	3000	-
Luminous efficacy	lm/W	55.54	58.68	61.45	61.37	61.50	55.79	54.05	-



(a) (b)

Figure 6 The amplitude variation of the current harmonics of the light source during the dimming process (a), and the voltage and current wave-shapes (b): voltage wave-shape - yellow; current wave-shape for the not dimmed case (level 1) - dark blue, and for the mentioned dimming levels (level 2 - purple; level 3 - aqua blue; level 4 - brown; level 5 - orange; level 6 - green; level 7 - blue; level 8 – white).

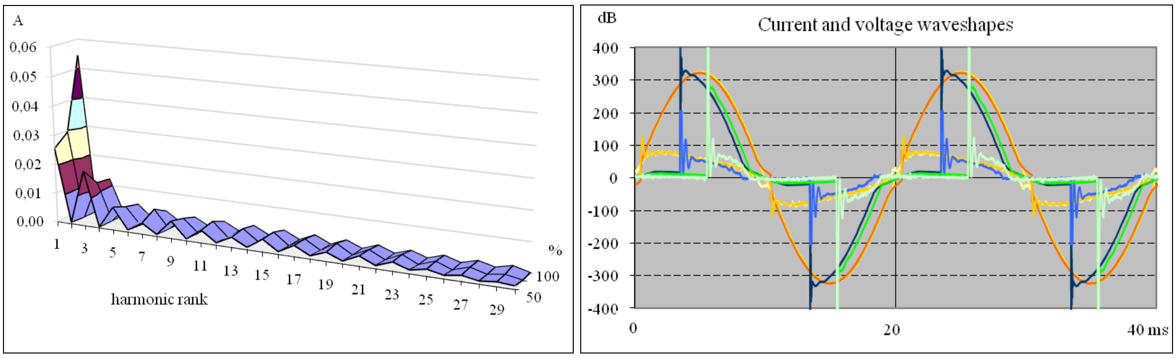
4.5 LED 12 W Thorn luminaire

Next, a 12 W LED luminaire, manufactured by Thorn (BaseLed 165 MRE 1x12 W LED) has been tested; the dimming process was achieved with the use of a triac dimmer (CO/TECH EMD 200, 40-300 W, 230 V). The electric, luminous and power quality characteristics are presented in Table 5. Figure 7 shows the amplitude variation of the current harmonics of the light source during the dimming process (a), and the voltage and current wave-shapes (b) for the not dimmed case and dimmed at different voltage levels, with the employment of the triac dimmer.

The CRI and CCT do not suffer variations during dimming. The odd current harmonics have increased amplitudes (especially the third order), as the voltage amplitude is decreased.

Table 5 Electric and luminous parameters

Parameter	Unit	Not dimmed	Voltage level, % of fundamental		
			100	75	50
Active power	W	11.8	11.6	8	5.6
Reactive power	VAR	5.4	4.8	12.3	7.1
Apparent power	VA	13	12.5	14.6	9
Voltage amplitude	V	230	229.3	172.5	112.6
Current amplitude	A	0.056	0.054	0.085	0.08
Frequency	Hz	50	50	50	50
Power factor		0.92	0.92	0.55	0.62
THDI	%	22.34	28.46	65.70	94.28
Luminous flux	lm	640	638	330	195
CRI		96.4	96.4	96.4	96.4
CCT	K	3450	3450	3450	3450
Luminous efficacy	lm/W	54.24	55.00	41.25	34.82



(a) (b)

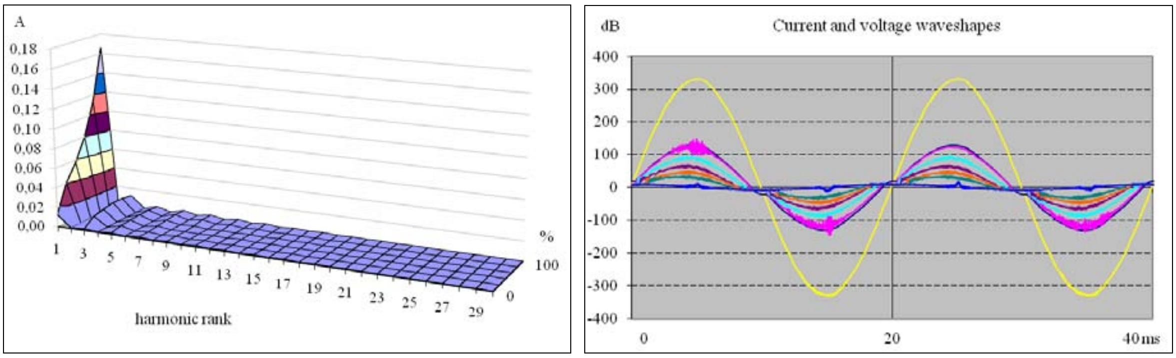
Figure 7 The amplitude variation of the current harmonics of the light source during the dimming process (a), and the voltage and current wave-shapes (b): for the not dimmed case (voltage wave-shape – yellow, current wave-shape – light yellow), and for the mentioned voltage levels, with the employment of the triac dimmer (100% of input voltage: voltage wave-shape – orange, current wave-shape – light orange; 75% of input voltage: voltage wave-shape – blue, current wave-shape – light blue; 50% of input voltage: voltage wave-shape – green, current wave-shape – light green).

4.6 LED 37 W Thorn luminaire

A different LED luminaire from the same manufacturer (Thorn BaseLed Cruz 160 LED 37 W L830 HFX) has been tested. The dimming process was achieved with the use of a DALI interface. The measurement results are presented in Table 6. Figure 8 shows the amplitude variation of the current harmonics of the light source during the dimming process (a), and the voltage and current wave-shapes (b). As the input signal level drops, the current amplitude, the active power, the reactive power, the apparent power and the power factor have lower values. At the same time, the THDI value is increasing. Through the dimming process, the amplitudes of odd current harmonics are low, and have relative constant values. The CRI and CCT do not suffer any variations.

Table 6 Electric and luminous parameters

Parameter	Unit	Not dimmed	Dimming levels, set with the DALI system, %					
			100	80	60	40	20	0
Active power	W	39	38.9	26.5	18.2	12.8	8.5	0.5
Reactive power	VAR	8.7	8.3	8.4	8	7.5	7.1	4.9
Apparent power	VA	39.8	39.8	27.7	19.9	14.8	11.1	5.1
Voltage amplitude	V	230	230	230	230	230	230	230
Current amplitude	A	0.174	0.173	0.12	0.087	0.064	0.048	0.022
Frequency	Hz	50	50	50	50	50	50	50
Power factor		0.98	0.98	0.95	0.91	0.86	0.77	0.95
THDI	%	8.34	8.22	13.79	19.35	22.95	25.88	31.87
Luminous flux	lm	1960	1960	1430	1015	675	400	0
CRI		79.7	79.7	79.7	79.7	79.7	79.7	-
CCT	K	3050	3050	3050	3050	3050	3050	-
Luminous efficacy	lm/W	50.26	50.39	53.96	55.77	52.73	47.06	-



(a) (b)

Figure 8 The amplitude variation of the current harmonics of the light source during the dimming process (a), and the voltage and current wave-shapes (b) at different dimming levels: voltage wave-shape - yellow; current wave-shape for the not dimmed case - dark blue, and for the mentioned dimming levels (100% - purple; 80% - aqua blue; 60% - brown; 40% - orange; 20% - green; 0% - blue).

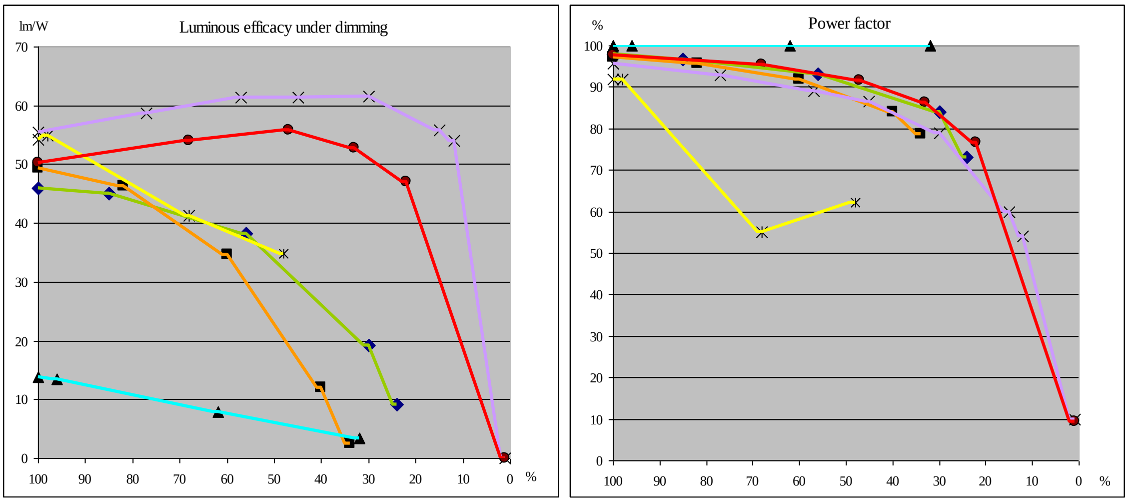
4.7 Measurement conclusions

Different types of light sources that can be used in office buildings were measured in terms of electric, luminous and power quality characteristics.

The luminous efficacy under dimming, for all the measured light sources is presented in Figure 9 (a). On the abscissa, the percent of the luminous flux is represented. If the light sources are not dimmed (the luminous flux is 100%), the luminous efficacy of the LEDs is superior to the luminous efficacy of the luminaires equipped with tubular fluorescent lamps or halogen lamp. Also, in the case of the luminaires equipped with tubular fluorescent lamps, the efficacy of the one equipped with T5 fluorescent lamp is better that the efficacy of the luminaire equipped with T8 fluorescent lamp. The measurements also show that the luminous efficacy of the luminaire equipped with T5 lamps has lower values for lower dimming levels than the luminaire equipped with T8 fluorescent lamps.

If the luminous flux is decreased, for the LED luminaires dimmed using PWM technology and DALI interface, the luminous efficacy has greater values throughout the dimming process. In the case of 12 W LED luminaire dimmed using a residential triac dimmer, the luminous efficacy drops linearly; similar trend can be seen in the case of the halogen luminaire, with the use of the same type of residential triac dimmer.

The impact of dimming on the power factor is presented in Figure 9 (b). The luminaires equipped with fluorescent lamps and the LED luminaires have similar descending trend for the power factor values. The 12 W LED luminaire dimmed with triac dimmer has low values of power factor as the voltage level is decreased; the halogen luminaire presents no changes in the value of the power factor.



(a) (b)

Figure 9 Luminous efficacy (a), and power factor (b) for different light sources under dimming: 62 W LED - purple, 37 W LED - red, 12 W LED -yellow, T8 36 W - green, T5 2x49 W - brown, 150 W halogen - blue

5 Simulation study

An office building of 60 m^2 was chosen for simulation, with four equal windows covering the wall from the North part, each of them having the dimensions of 2 m x 1.8 m (height 1.8 m). The room surfaces have reflection factors of 20/50/70. The task area was established at 0.85 m. From the initial measured light sources, four types are used for simulations: luminaires equipped with T8 36 W and T5 2x49 W fluorescent lamps and electronic ballast, 62 W Greenlux and 37 W Thorn LED luminaires. The illuminance level at working plane was set at 500 lx.

The simulation aim was to compare between different solutions that can be employed in an office room, in terms of luminous and power quality characteristics. The light sources were also dimmed, to find the dimming impact on the electric characteristics for the different solutions. The simulations were done using DIALux and Matlab programs. In all four cases, the luminaires were placed in parallel rows with the windows. Different dimming levels were set for each row.

For the first simulation, the luminaires with T8 2x36 W fluorescent lamps were used. The luminaires are positioned in three rows parallel with the windows. Each row has four luminaires. The row closest to the windows was dimmed for 25% of the luminous flux, the middle row for 75%, and the furthest row, was not dimmed.

In the second simulation, luminaires with T5 2x49 W fluorescent lamps were used. The luminaires were positioned in three rows parallel with the windows, each row containing three luminaires. A similar dimming scheme was applied.

The third simulation was made with the 62 W LED luminaires - Figure 10. The luminaires were positioned in three rows parallel with the windows, each row having five luminaires. The row closest to the windows was dimmed to 33%, the center row - to 63%, and the furthest row was not dimmed.

In the fourth simulation, 37 W LED luminaires were used. The luminaires are positioned in four rows, each row containing six luminaires. The row closest to windows was dimmed to 20%, the two rows in the center - to 60%, and the furthest row was not dimmed.

Figure 10 Room under daylight and artificial light for the third simulation (62 W LED luminaires)

Table 7 presents the measurement characteristics of the light sources used in simulation. The illuminance values from the DIALux simulation study, at the work plane level, for each of the four cases under study are presented in Table 8. Table 9 summarizes the DIALux simulation total illuminance, power and specific installed power. The results are obtained without dimming the light sources. Big differences can be noticed in regard to the luminous flux and active power, between different cases.

Table 7 Measurement lamp characteristics

Light sources	Active power, W	Luminous flux, lm	Luminous efficacy, lm/W	Correlated color temperature, K	Color rendering index	Power factor
T8 2x36 W	76.0	3500	46	3000	86	0.98
T5 2x49 W	136.0	6720	49	4100	81	0.97
LED 62 W	62.3	3460	56	3000	56	0.96
LED 37 W	39.0	1960	50	3050	80	0.98

Table 8 DIALux simulation iluminance levels at work plane level

Light sources	Eav, lx	Emax, lx	Emin, lx	Emin/Emax
T8 2x36 W	625	834	400	0.48
T5 2x49 W	571	898	354	0.39
LED 62 W	529	766	305	0.40
LED 37 W	512	670	356	0.53

Table 9 DIALux simulation results

Light sources	Luminous flux	Active power	Specific installed power	
	lm	W	W/m^2	W/m^2/100 lx
T8 2x36 W	80400	1020	17.0	2.72
T5 2x49 W	77400	972	16.2	2.84
LED 62 W	56250	930	14.8	2.80
LED 37 W	48000	888	14.8	2.80

Table 10 Matlab simulation results

Light sources	Active power	Reactive power	Current amplitude (50 Hz)	Current amplitude	THDI	Power factor	Specific installed power
	W	VAr	A	A	%		W/m^2
T8 2x36 W	621.95	39.78	2.87	2.89	10.63	0.93	10.36
T5 2x49 W	605.84	11.87	2.65	2.66	10.67	0.99	10.09
LED 62 W	590.16	54.56	2.81	2.89	25.18	0.88	9.83
LED 37 W	320.69	44.06	2.14	2.17	15.56	0.64	5.34

The wave-shape of the summed current signal, corresponding to all the light sources present in the room, and the electric characteristics can be revealed, using the Fast Fourier Transform (FFT) for the initial signals. In frequency domain, the signals at different dimming levels are summed. The wave-shape of the summed current signal is obtained using the Inverse Fourier Transform (IFFT).

Table 10 presents the Matlab simulation results, regarding the electric characteristics. This simulation considers the used dimming levels. Great difference in the power consumption can be noticed for the each case, if the dimming process is used, by comparing the values from Table 9 and Table 10. It can also be seen how the dimming process affects the THDI and the power factor values.

Figure 11 presents the output results of the Matlab algorithm, in the case of the 62 W LED luminaire:

- (a): the output electric data for signal 1 (not dimmed) and signal 2 (75%).

- (b): the initial signals for two periods. There are 2048 samples on every period. One period corresponds to 20 ms (the correspondent of 50 Hz). For clarity, the current wave-shapes are multiplied for 100 times.

- (c): the voltage and the current wave-shapes are represented for the summed signal. For clarity, the current wave-shape is multiplied for 7.5 times.

- (d): the values of the current amplitude for the fundamental frequency, the THDI value, the current amplitude with the current harmonics contribution, the power factor and the active power are calculated, using the data resulted from the FFT.

- (e): the current amplitude spectrum for the initial signals, in dB.

- (f): the current amplitude spectrum for the summed signal, in dB.

- (g): the voltage and current wave-shapes for a semi-period. The points where the current and voltage wave-shape are passing through the corresponding zero ordinate are used to determine the angle between the voltage and the current.

- (h): the current harmonic amplitudes for the first signals until the 10th harmonic rank are represented, in percent of the fundamental.

- (i): the current harmonic amplitudes for the summed signal until the 10th harmonic rank are represented, in percent of the fundamental.

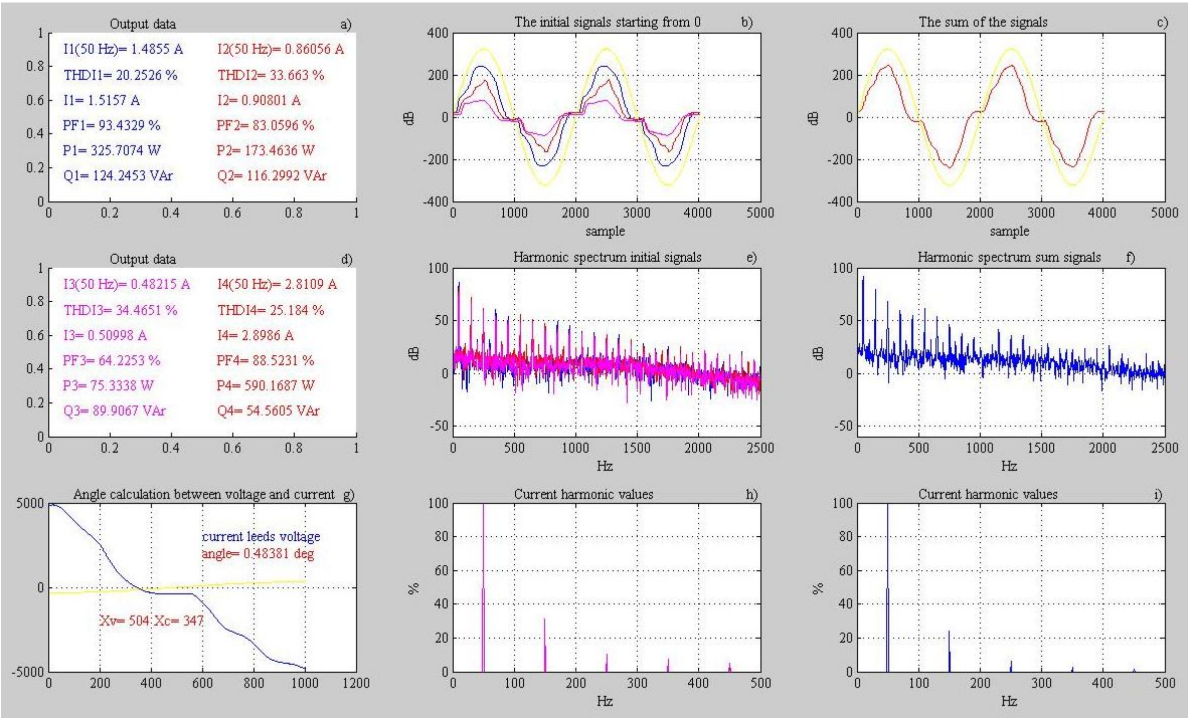


Figure 11 Output of the Matlab program for the 62 W LED luminaire
(b) the voltage – yellow, and the current - blue (not dimmed), red (75% dimmed), magenta (25% dimmed) - wave-shapes;
(c) the voltage - yellow, and the current - red wave-shapes;
(d) the results for the third signal - magenta, and the results for the summed signal - red.

6 Conclusions

The paper presents the results of light and power quality measurements and simulations conducted on different types of light sources. The results show that LED luminaires have a greater luminous efficacy than other types of luminaires equipped with fluorescent lamps that are presently used in office buildings.

Using Matlab simulations, it is showed that different dimming technologies have different impact on the current harmonic amplitudes. The greatest harmonic impact is determined by the use of a low price residential triac dimmer. Other methods (1÷10 V DC, PWM and DALI interface) have lower impact on the power quality of the electric network. Also, it is showed that, if the light sources from a room are dimmed at different levels, the harmonic impact on the final current (corresponding to all the light sources), is lower than if all the light sources are dimmed at the same level.

Acknowledgments

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REDUCING ENERGY CONSUMPTION FOR INTERIOR LIGHTING WITHOUT DECREASING VISUAL COMFORT – A PRESENT-DAY PROBLEM

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Abstract. *Reducing energy consumption of buildings is a present day problem world-wide. This paper presents some of the main aspects and solutions that can lead to energy saving in the case of interior lighting, without reducing visual comfort. The use of natural light is highly assessed together with the importance of integrated (daylight-electric light) design and the implementation of automatic control of the lighting systems.*

Keywords: *energy efficiency, visual comfort, integrated lighting*

1 Introduction

Interior electric lighting is an important component of a buildings energetic structure, as it has been recognized world-wide and also at national level many years ago. Figure 1 shows a scheme of the energetic structure of a building and it contains both the architectural and constructive structure and the functional installation systems that consume energy: heating, air-conditioning, electric lighting, hydraulic installations and other systems (elevators, escalators) that are connected to the electricity supply.

ENERGETIC STRUCTURE OF A BUILDING	
ARCHITECTURAL and CONSTRUCTIVE STRUCTURE is characterized by: HEAT GAIN (during the summer) ENERGY LOSS (during the winter)	FUNCTIONAL INSTALLATION SYSTEMS that ensure the COMFORT required by HUMAN ACTIVITIES: (energy consuming systems) Heating systems Air-conditioning Electric lighting Other installations (elevators, escalators)

Figure 1 Scheme of a building energetic structure

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Buildings designed for intellectual and physical activities world-wide are equipped with automatic, intelligent control systems, shown in Figure 2, that act upon the functional installation systems to ensure the recommended parameters in order to achieve the state of comfort (thermal, air quality, acoustic and luminous) required by human activities.

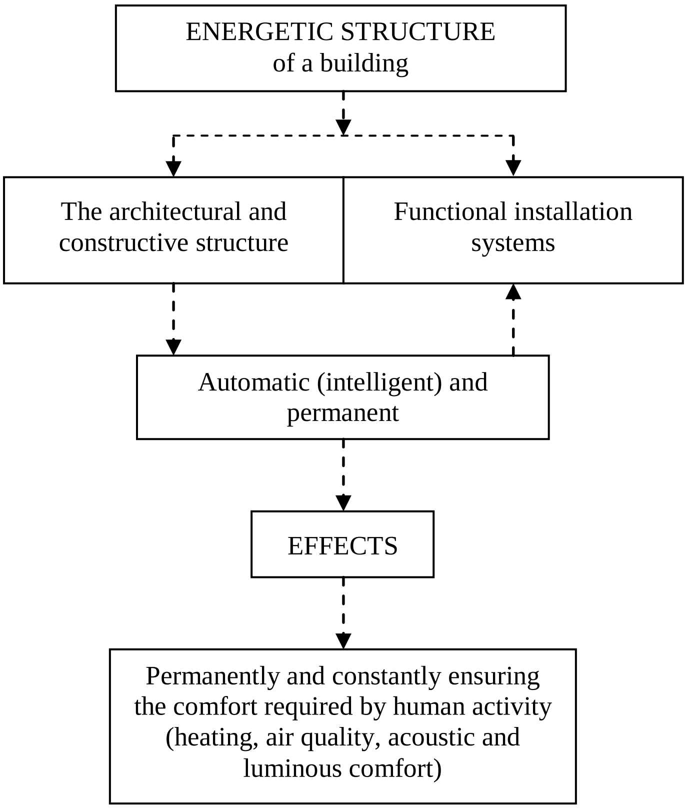

Figure 2 Automatic control scheme for intelligent modern buildings

2 Main factors that contribute to the energy efficiency of buildings

Researches made at global level show that the energy consumption of lighting systems is different in the case of buildings with different functions. Buildings designed for intellectual and commercial activities use up to 40-50% of the total consumed energy, while in the case of industrial buildings the percentage goes down to 20% (in this case, the structures that support the industrial process have a greater importance).

Figure 3 shows that the only way to reduce the energy consumption of interior lighting systems is by implementing modern designs that are based on the integrated use of natural light and electric light.

It must be underlined that the main factor that influences the selection of an efficient modern solution, must be the proper implication of the design team, with a harmonious balance between the specialists who design (create) the different components (architecture – building, lighting and heating system, automations, and so on), that leads to the implementation of the best possible solution.

In order to obtain high efficiency and reduce the electrical energy consumption for the interior lighting system of buildings, regardless of their function (from residential buildings to constructions designed for intellectual or physical work, commercial, cultural, administrative spaces, and so on), the following conditions must be met, which are also presented in Figure 3.

1. A modern design of the interior lighting systems (ILS), based on a balanced and correct examination of the quantity and quality criteria that determine the achievement of a comfortable, functional and aesthetic luminous environment (CFALE), which ensures the conditions required by the specific human activities that take place in the building according to its function. Furthermore, the quantity (level of illuminance and the spatial distribution of luminous flux) and quality (distribution of luminance on the visual task area and in the central and peripheral visual field, linked with the direction and colour of light, essential aspects that are often neglected or mistreated in Romania) criteria must be harmoniously synchronized (the schematic structure of the modern design of interior lighting systems is presented in Figure 4).

2. The correct design of lighting systems based on the international regulations of CIE, that must be followed by the national regulations.

3. The exclusive use of last generation light sources, which have a high quality, a high luminous efficiency and are produced by international manufacturers with a long tradition and a worldwide recognition (new generation fluorescent and compact fluorescent lamps, with high efficiency and long service life – double compared with regular lamps, mercury vapor lamps and metal halide lamps. LEDs can also be used in some cases, depending on the function of the space, after a correct and professional assessment of the situation. The colour of these light sources (neutral white, warm white, cool white) has to be carefully chosen according to the type and duration of the visual task and according to the access of natural light.

4. The exclusive use of good quality luminaries, with a high light output ratio (η_c>0,9) and an appropriate distribution of luminous flux, chosen according to the requirements of the workplace, with limited direct and reflected glare on the visual tasks (especially on PC screens).

5. The lighting solution has to take daylight into account and use it through an efficient and correct integration into the interior lighting systems, in such way, that the two components should permanently ensure the conditions of visual comfort in every part of the room. From this point of view, there are several possibilities, described below.

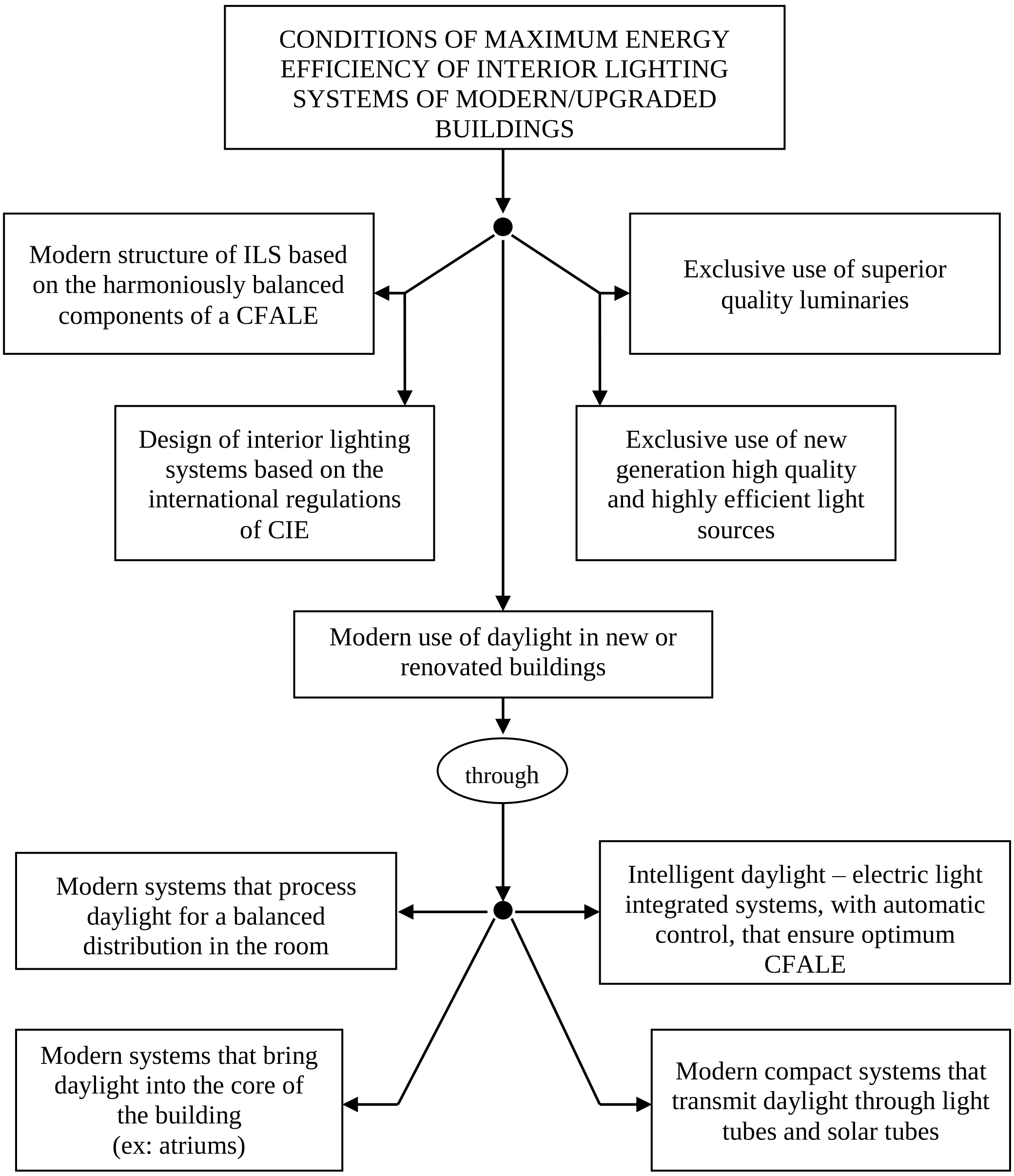

Figure 3 Determining conditions of the energy efficiency of integrated lighting in modern/upgraded buildings

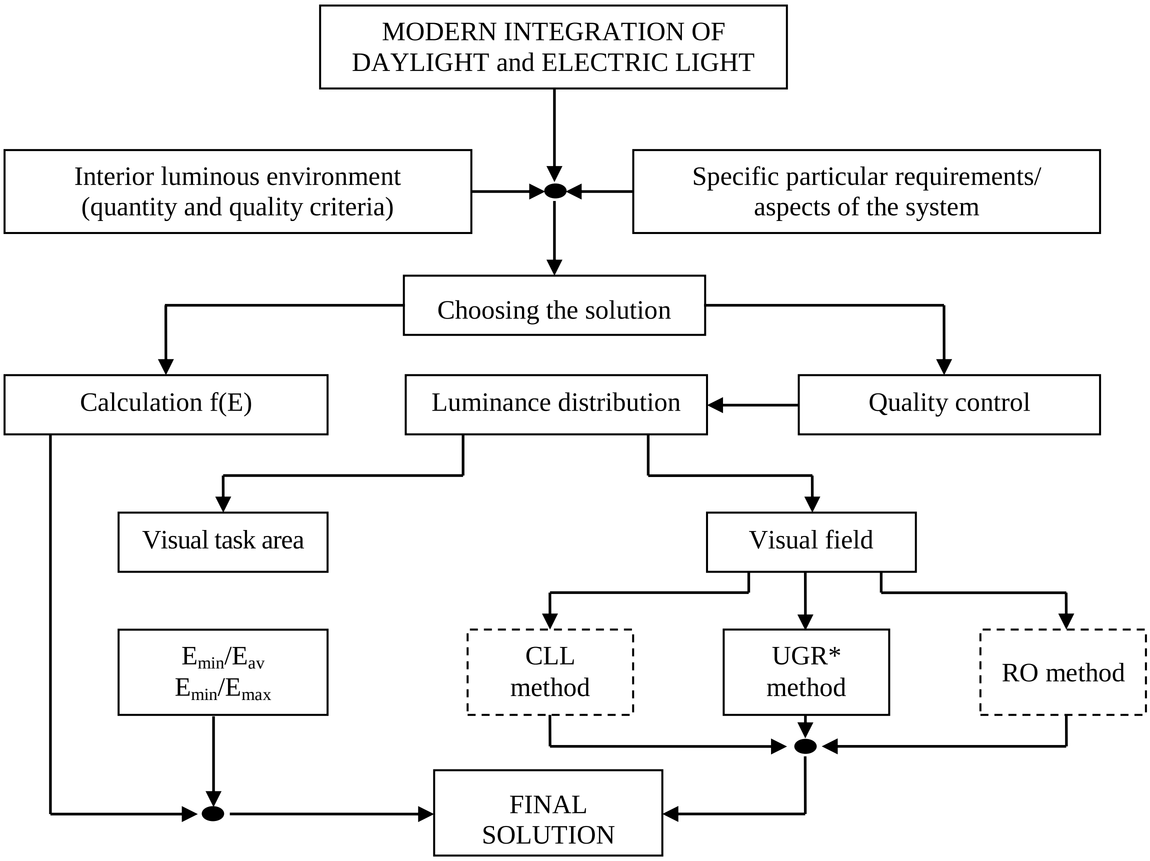

Figure 4 The schematic structure of the modern design of interior lighting systems
**Recommended method*

5. The lighting solution has to take daylight into account and use it through an efficient and correct integration into the interior lighting systems, in such way, that the two components should permanently ensure the conditions of visual comfort in every part of the room. From this point of view there are several possibilities, described below.

5.1. Modern systems that process the daylight that comes in though the windows in order to create a balanced distribution of illuminance and luminance in the depth of the room, which cannot be perfect, but it can be far superior to regular windows.

5.2. Modern architectural systems, like atriums, that bring daylight into the core of the building, and conduct it or not towards the main interest area.

5.3. Modern compact systems that can bring daylight to any part of the building (light tubes and solar tubes)

5.4. Systems that integrate daylight into the electric lighting systems (intelligent control systems or part of a building management system), that have the capacity to control and automatically dim electric lighting based on the daylight available, in order to permanently ensure the conditions of visual comfort, and to balance the permanent variations of daylight, caused by the natural variations throughout the day and by the changing weather conditions (clear sky, cloudy sky). Direct access of unprocessed daylight into modern working spaces is not acceptable.

It has to be mentioned that, according to the current European legislation that came in force since 2009, classical low energy efficient incandescent lamps are not to be used in any location.

Today, with the exception of emergency lighting, it is recommended the use of halogen lamps (HL). Therefore these lamps shall replace the classical incandescent lamps in local decorative lighting systems, and even in emergency lighting, and they can be used when from aesthetical reasons, it is required the possibility to dim the light from 0-100% in certain areas. It must be highlighted that halogen lamps can also be used locally when a perfect colour rendition is required (they have a 100% colour rendition).

Another important aspect in obtaining a comfortable, functional and energy efficient luminous environment is the modern design of the integrated lighting systems (daylight-electric light), based on the European regulations, such as CIE, and on the specific conditions of the interior space, as shown in Figure 4.

Also, the architectural integration of lighting systems is a vital condition for obtaining an aesthetic luminous environment, when the lighting is made using daylight, electric light as well as the combination of the two.

These two light sources cannot be generally used, and their flexibility depends from case to case, on:

- the aesthetic level;
- the possibilities of change in time;
- the destination of the space.

In some particular cases (when change of position is required, or change of destination in time, and so on) it is recommended the use of flexible lighting systems that can be changed in time and space.

3 The structure of lighting systems that are integrated into modern buildings

In Romania, electric lighting systems were and still are generally designed as “static” system, with potential manual dimming possibilities depending on the level of daylight. The new attitude promoted by the Romanian National Lighting Committee (RNLC), the Lighting Department of the Technical University of Civil Engineering Bucharest, dealers and manufacturers consists in the creation of permanently dynamic integrated lighting systems, with the possibility of automatic dimming of electric light depending on the level of daylight.

Figure 5 represents the natural and electric lighting systems in the classical version and in the permanently dynamic modern/integrated version, recommended today, but rarely applied in Romania.

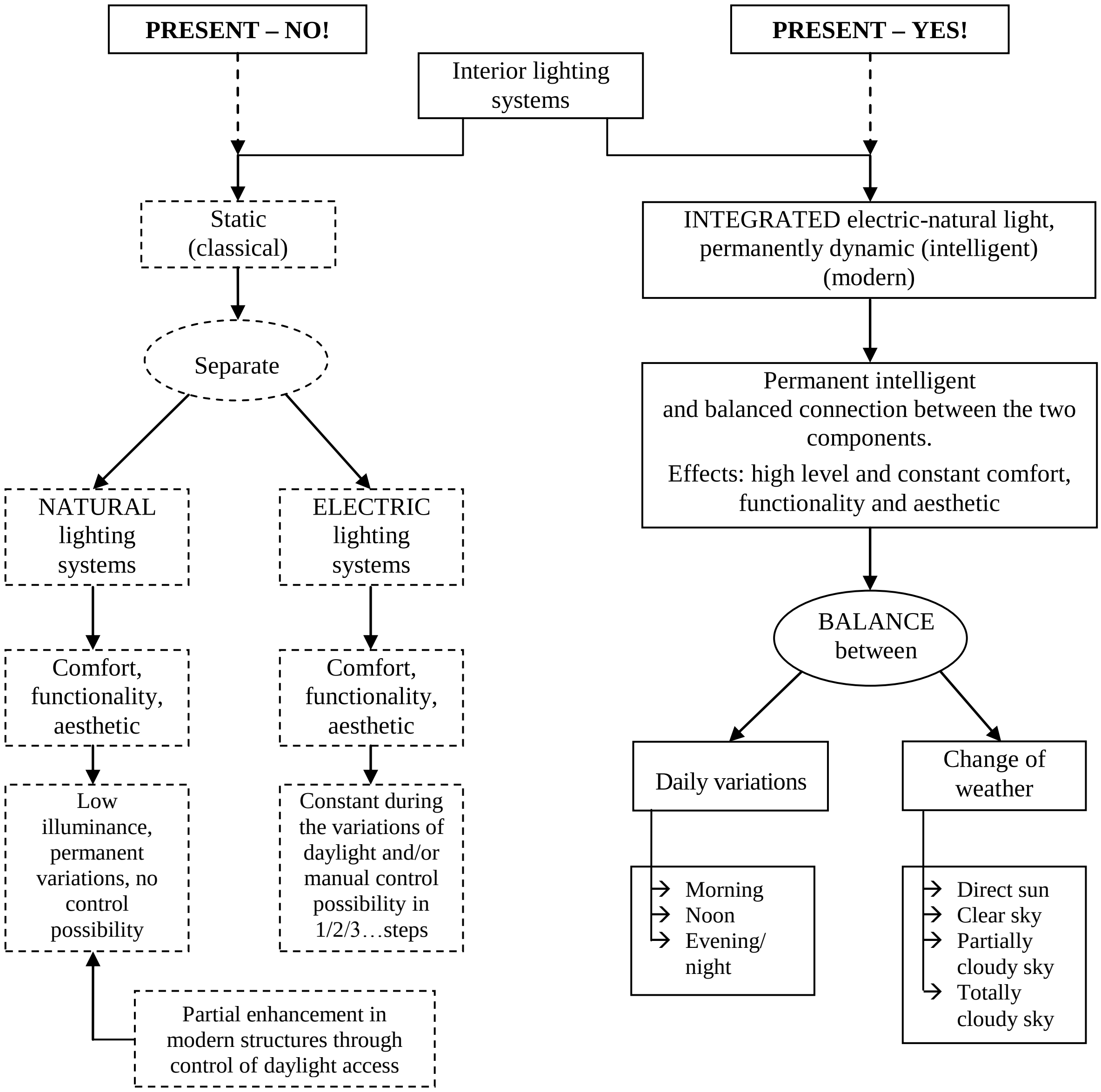

Figure 5 The structure of natural and electric lighting systems in the classical and modern version

In order to ensure the proper integration of the permanently changing natural light, that usually has a totally unsymmetrical access into the interior space (windows are usually provided on only one side of the room, which means that the level of illuminance decreases towards the other side), it is necessary to provide a permanently dynamic electric lighting system, which can only compensate these variations through an automatic process, that can balance the distribution of illuminance on the task area and the distribution of luminance in the visual environment.

When the depth of the room, measured from the side where natural light comes into the room, is 3-4 times larger than its height, then it is necessary to provide a permanent additional artificial lighting in the area that is opposite to the windows, according to the international recommendations (PSALI - Permanent Supplementary Artificial Lighting of Interiors).

The automatic process that balances the quantity of natural and electric light and ensures the reduction of energy consumption for interior lighting refers to:

- the control of daylight access (direct access of the sun into working spaces is unacceptable, due to the high luminance contrasts that it creates);
- the dimming of the components of electric lighting.

It must be pointed out that the fine variation of the luminous flux emitted by discharge lamps fitted with electronic or classical ballasts is limited to approximately 50% of the normal value, and it involves greater costs than the dimming in steps, but it has the advantage of maintaining constant comfort.

The variation of daylight is perceived by properly dimensioned sensors (photocells), the information is sent to the control unit, which transmits the dimming command to the electric lighting components, ensuring the balance of distribution of illuminance and luminance in the interior environment.

If office type environments intended for intellectual work (reading, writing, drawing, computer work), where the use of space varies in time, in order to further reduce energy consumption, automatic control systems can also be used that depend on presence (with presence detectors) and/or a time schedule, especially in the case of large office buildings and lecture halls, which function on a strict schedule. Local or automatic manual control (with presence detectors) is also an option.

The disadvantage of using presence detectors in medium/large/very large spaces is the alternation of highly lit areas, where people are present, and dark areas in the rest of the room, which generates an unacceptable discomfort that disturbs intellectual activity. A remedy for this negative aspect in opens pace offices would be the separation of workspaces into small compartments (cubicles), with light structured walls that go up to a height of approximately two meters and with the lighting system controlled locally and with presence detectors.

4 Conclusions

The aim of this paper is to highlight some of the aspects regarding the necessity of reducing electrical energy consumption for lighting as part of the energetic structure of buildings, by the means of modern solutions that intelligently integrate daylight into the lighting systems, without diminishing visual comfort, especially in the case of classical structures that ensure the access of daylight into buildings.

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INFLUENCE OF THE ROAD SURFACE ON THE EFFICIENCY OF THE STREET LIGHTING INSTALLATIONS

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Abstract. *Having a good knowledge of road surface characteristics can lead to a better quality of lighting installations and cost reductions. It is important to know these characteristics in order to estimate the luminance levels and the light distributions in roadway lighting. Many parameters can be influenced by the "behaviour" of pavements, such as the design of the installation, the choice of the optical system involving the type of light distribution and the amount of light needed to achieve the desired luminance levels. The road surface reflection characteristics are the starting point for the design of an optimized lighting installation.*

Keywords: *road surface, street lighting, efficiency, corrected energy efficiency ratio*

Introduction

In general, the reflection properties of road surfaces depend to an approximate order of importance on:

- their nature (composition, texture, method of construction);
- their physical state (wear, humidity);
- the direction of the illumination, defined by the angles β and γ, and the direction of observation, defined by the angles α and δ.

γ angle of incidence, indicates the angle between the direction of light incidence and the downward vertical.

α angle of observation, indicates the angle, in a vertical plane, relative to the horizontal, at which the light has to leave the point of reflection in order to reach the eye of the observer.

β angle between vertical planes containing the directions of light incidence and observation, indicates the angle through which the incident light has to be turned, away from its original direction, in order for the reflected light to enter the plane of observation.

δ angle between the vertical plane of observation and the road axis.

1 Corrected Energy Efficiency Ratio

In order to make an energy evaluation for a street lighting installation, it has been defined an indicator called Corrected Energy Efficiency Ratio (EER_c).

The indicator has been determined from the indicator already used in assessing outdoor installations - Energy Efficiency Ratio (*EER*), described by the relation (1.1)

$$EER = \frac{P}{S \times L_{ave}} \leq 0.8 \quad \left[\frac{W}{cd}\right] \qquad (1.1)$$

where P [W] is the active power of lamp including electrical control gear losses, S [m^2] – the surface area to be lit, L_{ave} [cd/m^2] – the average level of luminance obtained for the particular configuration.

I consider that *EER* would be a too extensive indicator that by using the measure "average luminance" limits the lighting installation to its purely quantitative aspects.

An important qualitative evaluation criterion in public street lighting is the luminance distribution, expressed by the overall uniformity and by the longitudinal uniformity. In this respect, I put forward for consideration a luminance correction factor that would take into account the already mentioned aspect - the relation (1.4.).

$$EER_C = c \times \frac{P}{S \times L_{avec}} \quad \left[\frac{W}{cd}\right] \qquad (1.2)$$

where c represents the equivalence factor when comparing the two configurations, L_{avec} [cd/m^2] - corrected average luminance.

$$c = \frac{S_{\min}}{S} \qquad (1.3)$$

where S_{min} [m^2] is the minimum area between the two compared configurations.

$$L_{avec} = L_{aveME} \cdot U_0 \cdot U_{l1} \cdot U_{l2} \qquad (1.4)$$

where L_{aveME} [cd/m^2] represents the average luminance minimum maintained for a lighting class, according to SR-EN 13201-2/2004 (2 cd/m^2, 1.5 cd/m^2, 1 cd/m^2, 0.75 cd/m^2, 0.5 cd/m^2, 0.3 cd/m^2), $U_{l1,l2}$ - longitudinal uniformity per lane, obtained for the particular configuration, U_0 - overall uniformity obtained for the particular configuration.

Even some experts in the outdoor lighting field regard the longitudinal uniformity as a less important quality parameter, the author considers the longitudinal uniformity an important parameter for the driver comfort, its appropriate level is a guarantee to reduce eye fatigue caused by "the zebra effect" along the road.

EER_c shall only be used in the case the public street lighting installation meets the average luminance criterion, in accordance to the standard SR-EN 13201-2/2004, for the lighting class selected.

$$L_{ave} \geq L_{aveME} \qquad (1.5)$$

When comparing at least two configurations, EER_c shall be used only if the selected public street lighting installation meets all performance criteria (average luminance and uniformity), in accordance to the standard SR-EN 13201-2/2004.

When comparing at least two configurations, the most efficient configuration will be the one with the lower indicator.

2 Influence of R road classes on the efficiency of the street lighting installations

A system of classifying road surfaces according to their reflection properties that is based on description parameters forms an indispensable aid to facilitate luminance calculations for design purposes.

A classification system for road surfaces groups different surfaces according to the value of the specular factor *S1*. By accepting a certain tolerance, it is possible to characterize all road surfaces by a few classes and one class by only one reflection table typical for that particular class. In other words, each class can be given by a standard reflection table, to be used for luminance calculations for any surface belonging to that class. Of course, the fewer classes a system has, the more practical it will be to work with. The more classes a system has, on the other hand, the more accurate can be the results obtained with it.

In order to obtain a standardization in the information for the calculation performance data, a set of road surface standards R1, R2, R3 and R4 is in common use.

In the case of reflection characteristics S1 and Q_0 can not be measured, an approximate designation of the standard R class can be made as in Table 1.

Table 1 Approximate designation of road surfaces into R road classes (according to Table 6 – CIE 30.2)

Class	Description
R1	Asphaltic road surface with at least 15% of artificial brightener (Grenette, Luxovite, Synopal or similar) or with at least 30% of very bright anorthosites (Arclyte, Labradorite or similar). Surface dressings with chippings where over 80% of the road surface is covered and where the chippings exist for a great deal of artificial brighteners or for 100% of very bright anorthosites. Concrete road surface
R2	Surface dressings with harsh texture and with normal aggregates Asphaltic surface with 10% to 15% of artificial brighteners in the mixture Coarse and harsh asphaltic concrete rich in grave land with gravel sizes up to or greater than 10 mm. Mastic asphalt (Gussasphalt) after dressing in new condition.
R3	Asphaltic concrete (cold asphalt, mastic asphalt) with gravel sizes up to 100 mm but with harsh texture (sand paper). Surface dressings with coarse texture but polished.
R4	Mastic asphalt (Gussasphalt) after some months of use. Road surface with rather smooth or polished texture.

The road surface belonging to R class are more often used in lighting calculations in Romania. Therefore I thought it would be useful to make an evaluation of the influence of these types of road surfaces on the efficiency of lighting installations.

Considering the R classification system, R1 table corresponds to the most diffuse surfaces, R4 table to the smoothest surfaces, and the fact becomes visible when analyzing equivalent value curves-r – "iso-r" diagrams – as seen in Figure 1. The difference in form of the four diagrams is obvious. The smoothest the surface is, the slim "izo-r" diagram is.

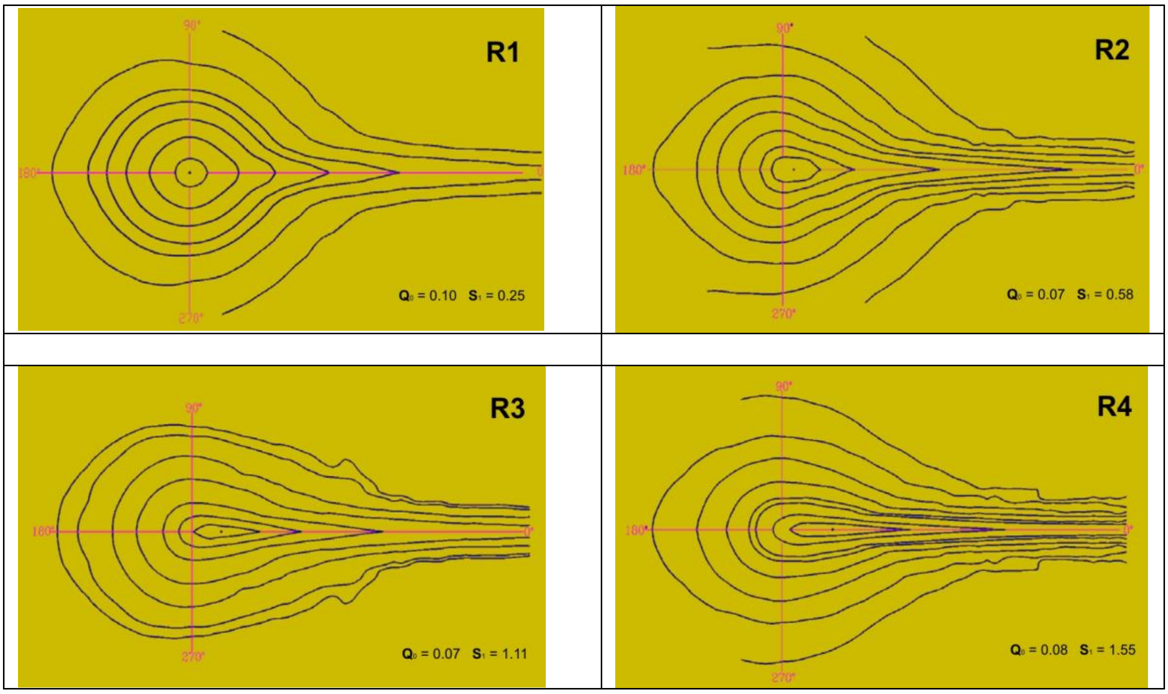


Figure 1 Iso-r diagram for road surface standards R1, R2, R3 and R4

In order to analyze the influence of the road surfaces R1, R2, R3 and R4, over a public street lighting installation, were performed lighting calculations, for the following situation, using the software Ulysse, developed by Schréder Group:

A) The influence of the type of road surfaces over the quantitative and qualitative lighting parameters of a lighting installation;

B) The correlation between the type of road surfaces and the road lighting luminaire intensity;

C) Determining the *EERc* for four street lighting installations, ME3a class, in accordance with SR-EN 13201 – 2/2004.

It has been chosen a two-lane traffic standard road, with poles of 8 m height, one-sided positioned, at a length of 30 m in between two successive poles (see Figure 2).

A) <u>The influence of the type of road surfaces over the quantitative and qualitative lighting parameters of a lighting installation.</u>

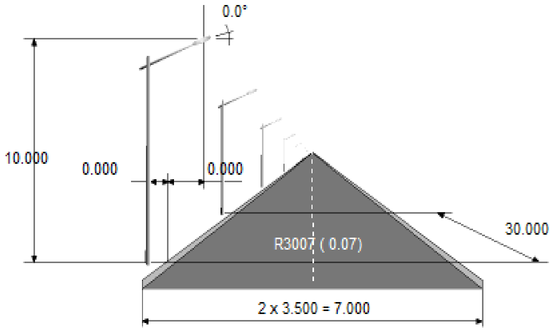


Figure 2 Geometrical configuration of the road

The luminaires are equipped with high pressure sodium lamps 150 W and at a 5^0 angle from the horizontal plane. Figure 3 presents the polar diagram of the lighting distribution intensity of the luminaire, selected for the purpose of lighting calculations.

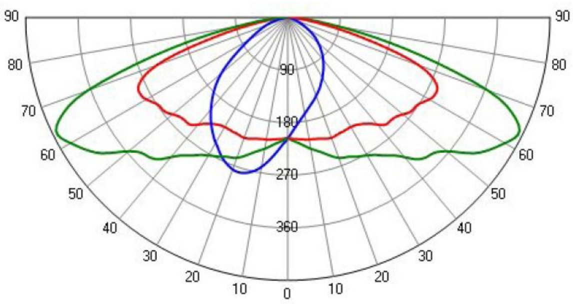


Figure 3 Polar Diagram for the used luminare

The results of the lighting calculations for the above mentioned lighting system and each table-r of the road surfaces belonging to R class are summarized in the Table 2.

Table 2 comprises of the following, for each case studied:

- average luminance - L_{ave} [cd/m^2]
- overall uniformity - U_0
- longitudinal uniformity - U_l
- Izo-cd/m^2 diagrams.

Analyzing the results, the following conclusions are to be extracted:

- as the road surface becomes more and more smooth, the equivalent luminance curves become more and more slim;
- the case of the concrete road surfaces, the resulting average luminance and the overall uniformity are at their maximum, while the longitudinal uniformity is lower than the minimum limit recommended by SR-EN 13201-2/ 2004 for ME 1 class ($U_l \geq 0.70$);
- for R2, R3 and R4 types of road surfaces, the resulted values are in accordance to the standard.

To highlight as complete as possible the influence of the road surfaces in the four cases under discussion, it has been done an energy evaluation for each case, by calculating EER_c.

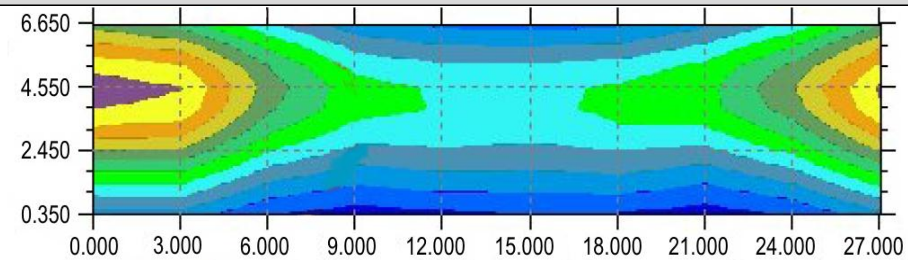
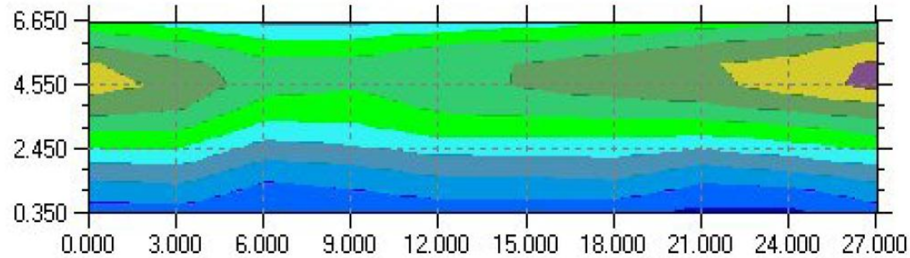
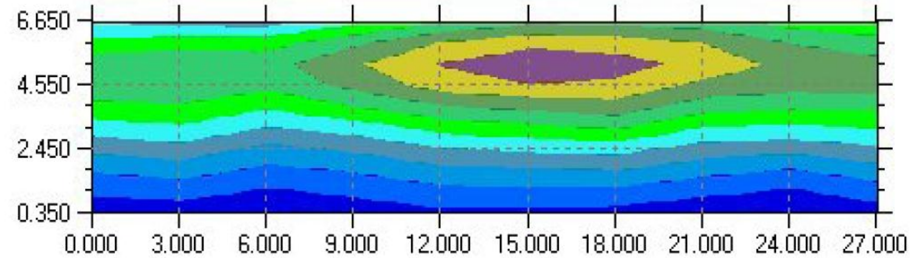
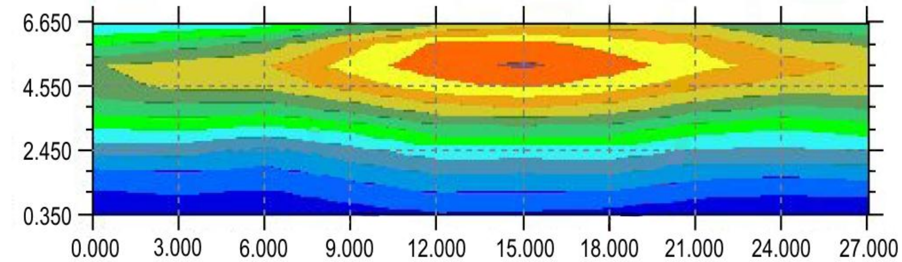
Corrected Energy Efficiency Ratio is to be applied only for the influence evaluation of road surfaces belonging to types R2, R3 and R4, because in the case of R1 surface the installation does not meet all the requirements of standard SR-EN 13201-2/ 2004.

The result of the evaluation is presented below:

	R2	**R3**	**R4**
EER_c [W/cd]	1.063	1.111	1.274

According the EER_c criterion, the street lighting installation under discussion is the most efficient in the case of R2 road surfaces. In other words, the lighting installation under discussion, when the road surfaces is R2 type is presenting a consumption of 1.063 W/m^2, to achieve a corrected luminance of 1 cd/m^2 and is of 4.5% more efficient than for the R3 road surfaces, respectively of 20% more efficient when the road surfaces is R4 type.

Table 2 The influence of R classes on a public street lighting installation

Class	Resulted parameters	Izo- cd/m^2 diagrams
R1	L_{med}=**3.03** cd/m^2 U$_o$=**0.62** U$_l$=**0.62**	
R2	L_{med}=**2.25** cd/m^2 U$_o$=**0.53** U$_l$=**0.71**	
R3	L_{med}=**2.18** cd/m^2 U$_o$=**0.48** U$_l$=**0.75**	
R4	L_{med}=**2.4** cd/m^2 U$_o$=**0.43** U$_l$=**0.73**	

B) <u>The correlation between the type of road surfaces and the road lighting luminaire intensity.</u>

In order to maximize this uniformity parameter, we need to know how the light is reflected by the road surface to be able to "harmonize" the reflector shape according the right way it should send the light on the ground to reach right luminance uniformity level. To make it more simple we can say there are two different main ways to reflect the light: diffuse (concrete) and semi-specular (asphaltic).

Diffuse, Concrete road surface reflection characteristic

This reflection characteristic system is mainly characterized by a high reflection coefficient in the case of vertical incidence of light falling down on the road and lower one in the case of light falling down with a non-vertical angle.

Resulting visual effect on such a road is bright spot just below the pole. To assure good efficiency with such kind of road surface we have to send more light on the mid distance than just under the pole.

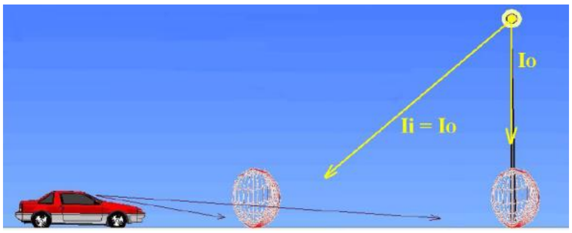


Figure 4 Diffuse, Concrete road surface reflection characteristic

Semi-diffuse up to specular, Asphaltic road surface reflection characteristic

In comparison with diffuse one, this reflection characteristic system is mainly characterised by a lower reflection coefficient in case of vertical incidence of light falling down on the road and higher up to a very higher one in case of light falling down with a non-vertical angle. Resulting visual effect on such a road is bright spot around the mid-distance between poles. To assure good efficiency with this kind of road surface you have to send more light just behind the pole and less light at the mid distance than in the case of concrete.

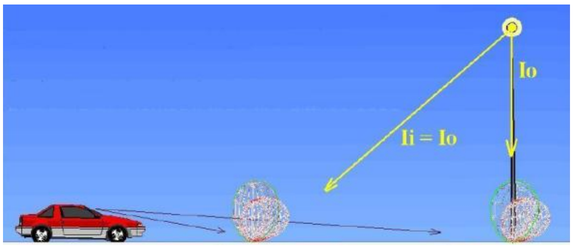


Figure 5 Semi-diffuse, Asphaltic road surface reflection characteristic

The knowing of road surface reflection characteristics allows us to choose in lighting calculation the reflector adapted to their best use on concrete or asphaltic road. The results of this reflector shape adaptation on the calculated luminance uniformity level for R1 and R3 road surface, for the same road configuration are presented in Table 3.

For a street lighting installation to be efficient is very important, since the lighting designing stage, to adequate the lighting distribution of the selected luminaires with the reflexive characteristics of the road surface.

The analysis shows that by using luminaires with lighting distribution that is not adequate to the road surfaces is leading to poor quality lighting, with inappropriate lighting distribution (poor lighting distribution).

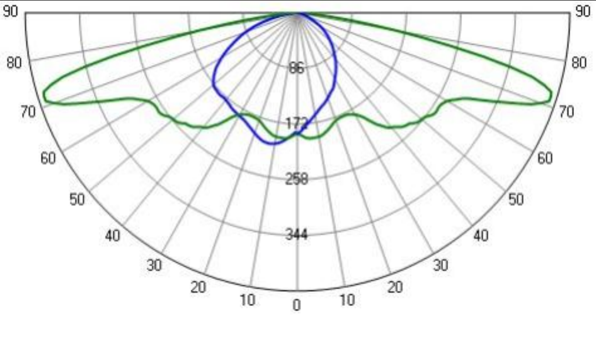
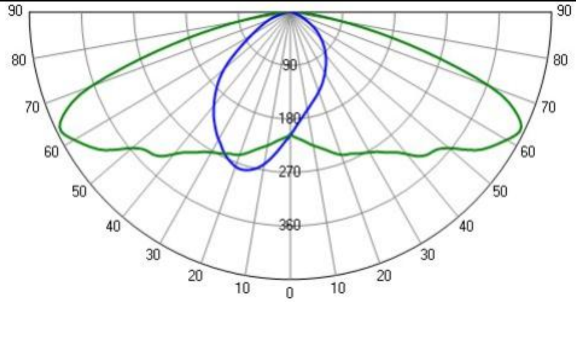
Shape of the reflector will be adapted to push more light on the mid distance and to reduce the quantity of light sent just in front of the pole in case of concrete road.	In case of an asphalted road surface, the reflector shape will be adapted to push more light in the C-90° plane and to reduce the quantity of light send in the main plane at its strict requested quantity that will be lower than for a equivalent spacing concrete light distribution.
	
Efficiency: 79.8% Peak: 537 cd/klm at 68° *Imax* in C-90°=213 cd/klm SON-T 150 W	Efficiency: 82.2% Peak: 443 cd/klm at 69° *Imax* in C-90°=278 cd/klm SON-T 150 W
a)	b)

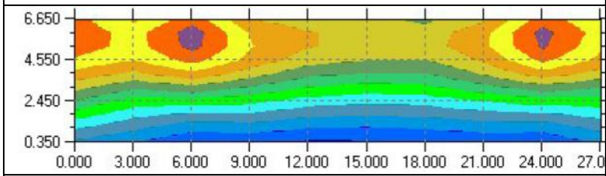
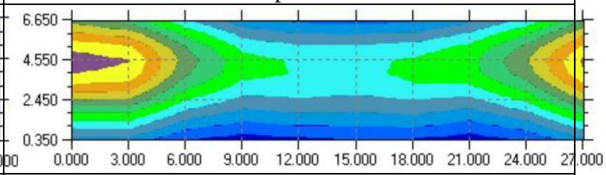
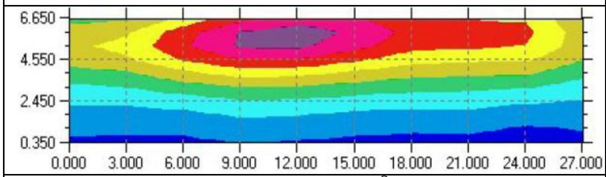
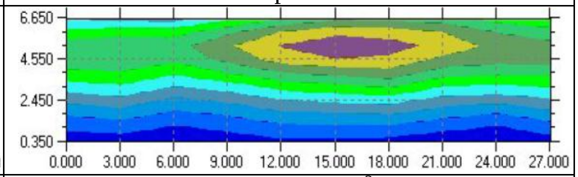
Figure 6 The polar diagram for a typical road lighting distribution adapted (a) to concrete road surface and (b) to asphalted road surface

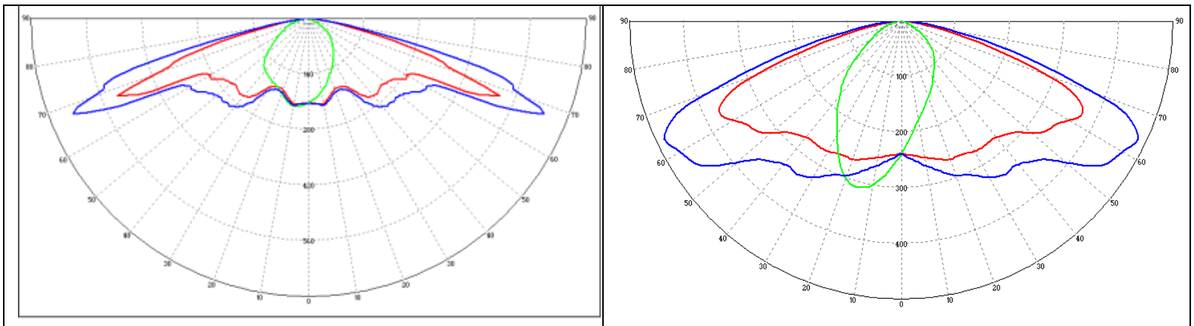
C) <u>Determining the *EERc* indicator for 4 street lighting installations, ME 3a class</u>

The analysis of luminaire lighting distribution, adapted to the road surfaces, will be extended for the situation the MR 3a lighting class has to be obtained, for a 3.5 m two lane traffic road, the distance between poles resulting from calculations.

By this example, it will be proved the correlation between *EERc* and the actual energy efficiency of a public street lighting installation, considering a 500 m road.

Table 3 The reflector shape adaptation on the calculated luminance uniformity level for R1 and R3 road surface

R1 road surface	
Reflector with road lighting distribution adapted to concrete	Reflector with road lighting distribution adapted to asphalted
	
L_{ave}=**2.97** cd/m^2 U_o=**0.50** U_l=**0.77**	L_{ave}=**3.03** cd/m^2 U_o=**0.62** U_l=**0.62**
EER**$_{c=}$1.039**	Having U_l<0.7 the EER_c will not be calculated
R3 road surface	
Reflector with road lighting distribution adapted to concrete	Reflector with road lighting distribution adapted to asphalted
	
L_{ave}=**2.39** cd/m^2 U_o=**0.34** U_l=**0.64**	L_{ave}=**2.18** cd/m^2 U_o=**0.48** U_l=**0.75**
Having U_0<0.4 and U_l<0.7 the EER_c will not be calculated	***EER**$_{c=}$***1.111**



Efficiency: 72.1% Peak: 535 cd/klm at 69° *Imax* in C-90°=207 cd/klm SON-T 100 W	Efficiency: 81.4% Peak: 484 cd/klm at 64° *Imax* in C-90°=309 cd/klm SON-T 100 W
a)	b)

Figure 7 The polar diagram for a typical road lighting distribution adapted to (a) concrete road surface and (b) to asphalted road surface

Table 4 Determining the *EERc* indicator for four street lighting installations, ME 3a class

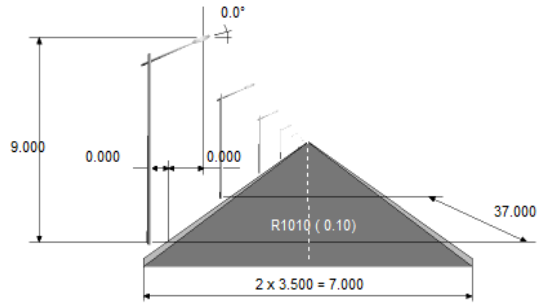
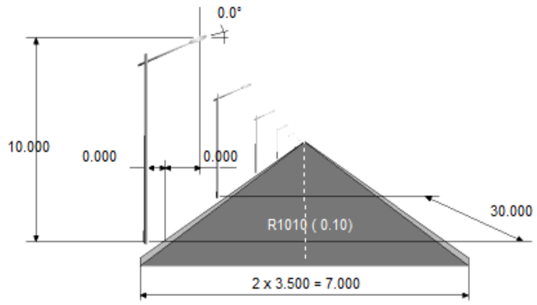
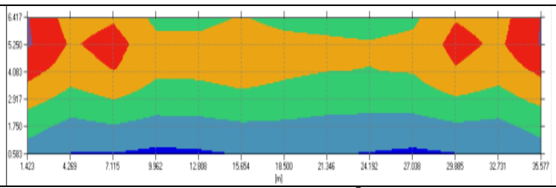
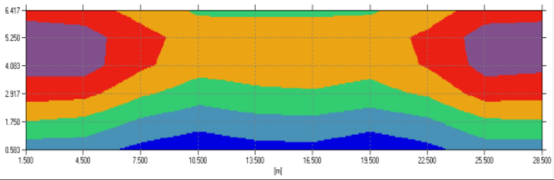
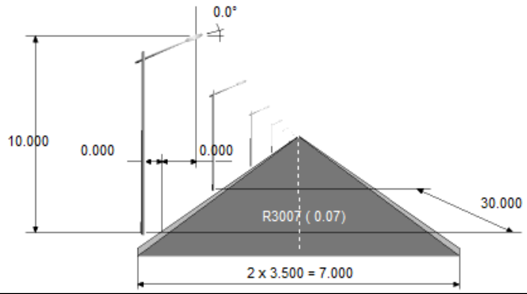
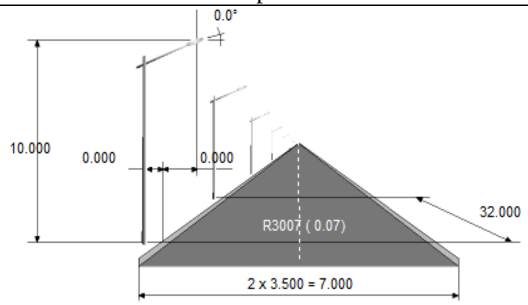
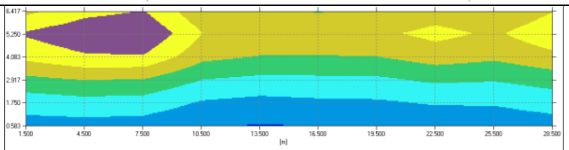
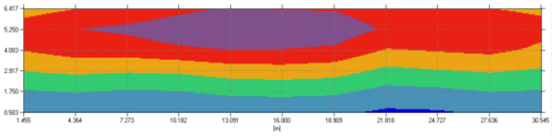
R1 road surface	
C.1 Reflector with road lighting distribution adapted to concrete	C.3 Reflector with road lighting distribution adapted to asphalted
	
	
L_{ave}=**1.16** cd/m^2 U_o=**0.588** U_{l1}=**0.821;** U_{l2}=**0.711**	L_{ave}=**1.52** cd/m^2 U_o=**0.535** U_{l1}=**0.73;** U_{l2}=**0.76**
For a road of **500 m: 15** lighting points **Installed Power=1.71 kW**	For a road of **500 m: 18** lighting points **Installed Power=2.05 kW**
R3 road surface	
C.2 Reflector with road lighting distribution adapted to concrete	C.4 Reflector with road lighting distribution adapted to asphalted
	
	
L_{ave}=**1.04** cd/m^2 U_o=**0.428** U_{l1}=**0.74;** U_{l2}=**0.715**	L_{ave}=**1.01** cd/m^2 U_o=**0.427** U_{l1}=**0.825;** U_{l2}=**0.79**
For a road of **500 m: 18** lighting points **Installed Power=2.05 kW**	For a road of **500 m: 17** lighting points **Installed Power=1.94 kW**

Table 5 presents the values of installed power and the two indicators: *EERc*, respectively *EER*, for the four situations under discussion, in a summarized form. All the four lighting installations meet the requirements of ME 3a class.

In terms of the *EER* indicator, C.3 installation proves to be the most efficient considered under the *EER*. In fact, to obtain the parameters resulting for a 500 m road is to be used 18 lighting points, summing a 2.05 kW power.

It can be noticed that both in terms of quality (lighting distribution) and of energy efficiency, the best performance it has been proved by C.1 installation.

Table 5 The results for the four street lighting installations

	C.1	C.2	C.3	C.4
D [m]	37	30	30	32
No. of lighting points [pcs]	15	18	18	17
Pi [kW]	1.71	2.05	2.05	1.94
EERc [W/cd]	**1.04**	**2.397**	**1.829**	**1.714**
EER [W/cd]	0.379	0.522	0.357	0.504

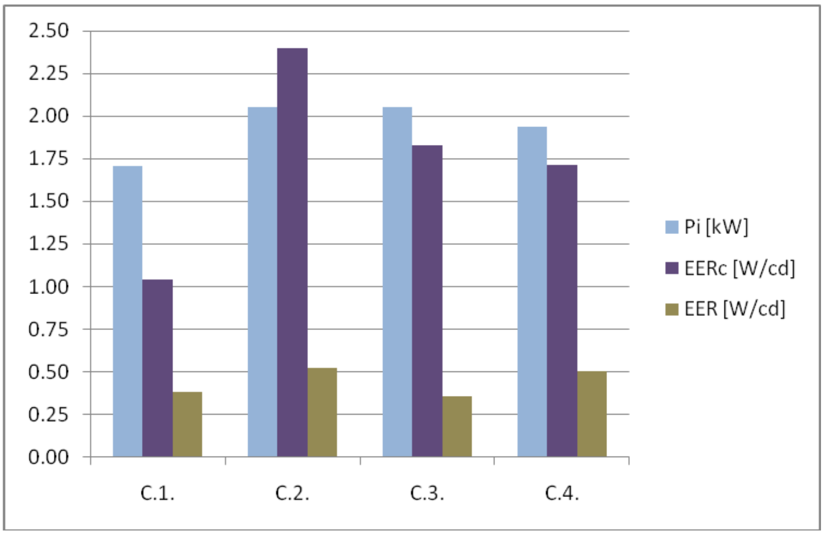


Figure 8 Graphical representation of the main evaluation parameters for the street lighting installations under discussion

The study of EERc indicator will be continued and deepened for several different configurations of street lighting installations.

Conclusions

In the case of urban lighting systems must take into account how the surfaces reflect the light. The importance of road surfaces reflection can be extracted also from the fact that the current quality criteria public lighting is the average luminance, which must exceed a certain minimum level required by the needs of traffic safety and comfort. The average level o luminance depends not only upon the quality of the luminous flux received by the road surfaces, but also on the relation between the lighting distribution of the luminaire used and the reflection diagram of the road surfaces.

The reflection properties of the road surfaces are the starting point in designing and optimizing lighting systems. A better knowledge of the reflection properties of the road surfaces leads to a better quality lighting at lower cost.

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Beginning with 1998, the establishment of Energobit Schréder Lighting as a joint-venture between Energobit and Schréder Group GIE, began to work with this company. She developed important lighting projects for the public space.

All over the time, I strongly believed that the City, its Identity and the People have to beneficiate from a right lighting, which fits to the ambient, with a perfect light management, therefore I consider that urban lighting should be considered a part of a city brand.

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ASSESSMENT OF DAYLIGHT TRANSPORT CAPACITY VIA HORIZONTAL VS VERTICAL LIGHT-PIPES

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Abstract. *One of the main directions to reduce the carbon emissions consists in the use of advanced daylighting technologies capable to transmit daylight into the depth of buildings. The use of daylight throughout the day would help to significantly reduce the global energy consumption of buildings and to cut down carbon emissions. This paper assesses the capacity of daylight transport by SUNPIPE light-pipe systems installed in the Laboratory of Lighting Systems at the Faculty of Civil Engineering of Brasov. There are two light-pipes used in this study: one horizontal pipe of 300 mm diameter and 3 m length, collecting daylight on the façade of the building, and one vertical pipe of 300 mm diameter and 1.5 m length, collecting daylight on the roof of the building. The light-pipes are similar and use 98% reflectance pure silver base mirror-finish aluminium tubes. Illuminance values are measured inside the pipes and an evaluation module is proposed by the use of non-linear regressions.*

Keywords: *Daylighting, Light-pipes, Side-lighting, Top-lighting*

1 Introduction

The light-pipe is a secondary light source which transmits light from the primary (natural or artificial) source to a specific target or on specific reflective or transmitting surface within interior spaces [1]. Light transmission is achieved at the end of the light-pipe, where light is distributed and directed depending on task particularities, or by lateral transfer towards specific targets. Light-pipes transmit light radiation through total internal reflection.

The light-pipe is perhaps the most technologically exciting among the innovative daylighting systems because of the long distances over which it can operate. In principle, light-pipes collect, direct, and channel daylight into virtually any area of a building. The system consists of three main components: collecting and concentrating unit (heliostat or light dome), transport system (reflective conducts) and emitter (which distributes light into the targeted space). The use of light-pipes can increase energy savings, but generally system efficiency is low because of light losses within ramification or direction changing [9].

There are specific light-pipe systems for roof applications, known as sun-pipes. These systems maximize the concept of renewable energy by reflecting and intensifying sunlight and even normal daylight, down through a highly reflective silver mirror-finish aluminium tube. As compared to heliostat collecting units, the sun-pipes have the advantage of collecting sunlight and diffused skylight by means of fixed, passive collecting domes. These domes collect daylight for any sun position in the sky, without consuming energy for lens rotations.

Other systems are based on the micro-prismatic film as the element which performs the total internal reflection and have 0.98 reflectance. The internal reflection is produced within the structure of the 0.5 mm thick optic film, made of transparent acryl or polycarbonate [7].

2 SUNPIPE natural lighting system

This system developed by the British manufacturer Monodraught Ltd. is a revolutionary new way to pipe natural daylight from the rooftop into the building to brighten areas from dawn to dusk where daylight from windows cannot reach, even on overcast days [4].

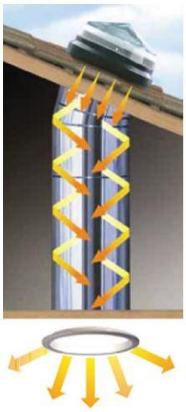

Figure 1 How the SUNPIPE works

The diamond dome specially designed to maximise the capture of sunlight collects both direct sunlight and diffused daylight. The faceted top surface catches sunlight from any angle and the vertical prisms at the base of the diamond dome capture low level light, i.e. early in the morning and late in the afternoon. Global daylight is piped down into the desired room by means of silver-coated aluminium pipes with a mirrored surface internally. At ceiling level, the diffuser has the ability to distribute the light in every direction, giving an even spread of light throughout the interior space (see Figure 1).

A SUNPIPE can be almost any length that is needed, but loses 6% of light for every meter [4]. There are different SUNPIPE diameters, from 230 mm to 1000 mm, typically lighting up areas of 6 to 70 sq. metres. SUNPIPE systems have a 98% reflectance, which means that there is 2% loss on every bounce, so the longer the light-pipe, the greater the loss is and in addition, there are losses through the roof dome or light collector and the ceiling diffuser. Nevertheless, the performance of a light-pipe is remarkable and typically, the 300mm diameter SUNPIPE can light up an area of 10 sq. metres to a normal daylight level, that is, without the need for electric lighting during normal daylight hours [5]. Larger light-pipes, of 450 mm and 530 mm diameter, are used in larger offices and buildings with higher ceilings.

Tests carried out by the BRE (Building Research Establishment) in the UK showed a 68% increase of the lighting performance on the 300 mm diameter for the new Super Silver SUNPIPE as compared to the original anodised aluminium SUNPIPE. [5]

3. Measurement of daylight transfer through SUNPIPE systems

For the purpose of this paper, one horizontal 3 m length 300 mm diameter SUNPIPE was used in order to collect daylight on the façade at the top level of the window and to pipe daylight inside the depth of the room. Two 45 degrees elbows are used to simulate a descent of the SUNPIPE at a false ceiling, as it can be seen in Figures 2 and 3.

Figure 2 Daylight dome collector of the horizontal SUNPIPE installed on the façade

Figure 3 Horizontal SUNPIPE ending with two 45 degrees elbows above imaginary false ceiling

A second vertical 1.5 m length, 300 mm diameter SUNPIPE was used to bring in daylight collected at roof level. This light-pipe is the daylighting component of a hybrid system used both for daylighting and natural ventilation, installed in the laboratory.

The measured and calculated values are shown in Table 1.

The illuminance was measured inside the two light-pipes at specific points along their axis: the vertical axial illuminance $E_{v,l}$ was taken into consideration for the horizontal light-pipe and the horizontal axial illuminance $E_{h,l}$ was taken into consideration for the vertical light-pipe.

The daylight transport factor *DTF* was introduced as the ratio between the measured values of the axial illuminance and the external horizontal illuminance E_0 for each light-pipe. These values were thereafter used as criterion of comparison between the two light-pipes and to develop modelling equations for characterizing the daylight transport capacity of the two light-pipes.

On the other hand, the most important fact about the light transfer performance of the SUNPIPE can be deducted from the fact that for a measured horizontal external illuminance of 5000 lx, the horizontal illuminance at the level of the SUNPIPE ceiling diffuser (right below it) was 1400 lx, after the two 45 degrees elbows.

Although daylight was collected on the façade of the building (which is less exposed to daylight as compared to the roof), and despite the length of 3m and the presence of two 45 degrees elbows, the illuminance measured at the end of the SUNPIPE was still as high as 28% of the external illuminance.

Equations (1) and (2) show the expressions for $DTF_{h,l}$ and $DTF_{v,l}$ which are the horizontal and vertical daylight transport factors of the horizontal light-pipe and of the vertical light-pipe respectively, relative to the vertical and horizontal illuminance respectively at distance *l* from the dome level:

$$DTF_{h,l} = \frac{E_{v,l}}{E_0} \cdot 100\% \quad (1) \qquad \text{and} \qquad DTF_{v,l} = \frac{E_{h,l}}{E_0} \cdot 100\% \quad (2)$$

Table 1 Measured values of the axial illuminance and daylight transport factors

Horizontal 300 mm diameter light-pipe / E_0 = 4800 lx		
l [cm]	$E_{v,l}$ [lx]	$DTF_{h,l}$ [%]
0	4600	95.83
60	2900	60.42
120	2600	54.17
180	2550	53.13
240	2300	47.92
Vertical 300 mm diameter light-pipe / E_0 = 13,200 lx		
l [cm]	$E_{h,l}$ [lx]	$DTF_{v,l}$ [%]
0	10500	79.55
30	8500	64.39
60	7900	59.85
90	6500	49.24
120	6000	45.45

The inner end of the SUNPIPE system with the sections where the illuminance was measured can be seen in Figure 4.


Figure 4 Internal end of the horizontal SUNPIPE

Other measurements showed that for external horizontal illuminance of 12,200 lx, the vertical illuminance within the axis of the horizontal SUNPIPE at 3 m from the dome daylight collector was 6000 lx (which is almost half of the horizontal illuminance available at the same time), while the horizontal illuminance within the axis of the vertical segment of the SUNPIPE after the two 45 degrees elbows was as high as 4600 lx [8].

These values show indeed the high performance of the SUNPIPE in terms of daylight collection and transfer by internal reflection.

For the measurements of the illuminance one Chauvin Arnoux LM 76 digital luxmeter with ±3% accuracy and incidence correction and one Konica Minolta CL-200 digital colorimeter with ±2% accuracy have been used. By the use of the colorimeter the colour temperature of the external daylight and the daylight reaching the end of the horizontal SUNPIPE has been measured. Thus it has been noticed that the SUNPIPE introduces a "warming" effect to the transferred light, given the values of 5900 K for the daylight SUNPIPE at the outside and of 4300 K for the daylight transferred at the internal end of the horizontal SUNPIPE.

Based on the measured values, modelling equations were created using the Levenberg-Marquardt method to solve non-linear regressions in order to model the daylight transport capacity of the two light-pipes.

4 The Levenberg-Marquardt method

This method combines the steepest-descent method and a Taylor series based method to obtain a fast, reliable technique for non-linear optimization [2].

Neither of the above optimization methods are ideal all of the time; the steepest descent method works best far away from the minimum, and the Taylor series method works best close to the minimum.

The Levenberg-Marquardt (LM) algorithm allows for a smooth transition between these two methods as the iteration proceeds.

In general, the data modelling equation (with one independent variable) can be written as follows:

$$y = y(x;\vec{a}) \qquad (3)$$

The above expression simply states that the dependent variable *y* can be expressed as a function of the independent variable *x* and vector of parameters *a* of arbitrary length.

Note that using the LM method, any nonlinear equation with an arbitrary number of parameters can be used as the data modelling equation.

Then, the "merit function" we are trying to minimize is

$$\chi^2(\vec{a}) = \sum_{i=1}^{N}\left(\frac{y_i - y(x_i;\vec{a})}{\sigma_i}\right)^2 \qquad (4)$$

where *N* is the number of data points, x_i denotes the *x* data points, y_i denotes the *y* data points, σ_i is the standard deviation (uncertainty) at point *i*, and $y(x_i,a)$ is an arbitrary nonlinear model evaluated at the i^{th} data point.

This merit function simply measures the agreement between the data points and the parametric model; a smaller value for the merit function denotes better agreement. Commonly, this merit function is called the chi-square.

From the area of pure optimization, two basic ways of finding a function minimum are a Taylor series based method and the steepest-descent method. The Taylor series method states that sufficiently close to the minimum, the function can be approximated as a quadratic. A step from the current parameters *a* to the best parameters a_{min} can be written as

$$\vec{a}_{min} = \vec{a}_{cur} + H^{-1}\cdot\left[-\nabla\chi^2(\vec{a}_{cur})\right] \qquad (5)$$

where *H* is the Hessian matrix (a matrix of second derivatives). If the approximation of the function as a quadratic is a poor one, then we might instead use the steepest-descent method, where a step to the best parameters from the current parameters is

$$\vec{a}_{min} = \vec{a}_{cur} - c\nabla\chi^2(\vec{a}_{cur}) \qquad (6)$$

This equation simply states that the next guess for the parameters is a step down the gradient of the merit function. The constant c is forced to be small enough that a small step is taken and the gradient is accurate in the region that the step is taken. Since we know the chi-square function, we can directly differentiate to obtain the gradient vector and the Hessian matrix. Taking the partial derivatives of the merit function with respect to a gives

$$\frac{\partial\chi^2}{\partial a_k} = -2\sum_{i=1}^{N} \frac{y_i - y(x_i;\vec{a})}{\sigma_i^2} \frac{\partial y(x_i;\vec{a})}{\partial a_k} \qquad (7)$$

To obtain the Hessian matrix, take the gradient of the gradient above (so that we have a matrix of partial second derivatives):

$$\frac{\partial^2\chi^2}{\partial a_k \partial a_l} = -2\sum_{i=1}^{N}\left[\frac{1}{\sigma_i^2}\frac{\partial y(x_i;\vec{a})}{\partial a_k}\frac{\partial y(x_i;\vec{a})}{\partial a_l} - \frac{y_i - y(x_i;\vec{a})}{\sigma_i^2}\frac{\partial^2 y(x_i;\vec{a})}{\partial a_l \partial a_k}\right] \qquad (8)$$

Now, for convenience, define the gradient vector and the curvature matrix as

$$G_k = -\frac{1}{2}\frac{\partial\chi^2}{\partial a_k} = \sum_{i=1}^{N}\frac{y_i - y(x_i;\vec{a})}{\sigma_i^2}\frac{\partial y(x_i;\vec{a})}{\partial a_k} \qquad (9)$$

$$C_{kl} = \frac{\partial^2\chi^2}{\partial a_k \partial a_l} = \sum_{i=1}^{N}\left[\frac{1}{\sigma_i^2}\frac{\partial y(x_i;\vec{a})}{\partial a_k}\frac{\partial y(x_i;\vec{a})}{\partial a_l}\right] \qquad (10)$$

Note that the second derivative term in C will be ignored because of two reasons: it tends to be small because it is multiplied by $(y\text{-}y_i)$, and it tends to destabilize the algorithm for badly fitting models or data sets contaminated with outliers. This action in no way affects the minimum found by the algorithm; it only affects the route in getting there. So, the Taylor series method (inverse Hessian method) can be written as the following set of linear equations:

$$\sum_{k=1}^{NP} C_{kl}\delta a_l = G_k \qquad (11)$$

where NP is the number of parameters in the model that is being optimized.

This linear matrix will be the workhorse for this method after some modification; it can be solved for the increments δa that, when added to the current approximation for the parameters, gives the next approximation. Likewise, the convenient definitions can be substituted into the steepest descent formula to obtain

$$\delta a_l = cG_l \qquad (12)$$

Neither of the aforementioned optimization methods are ideal all of the time; the steepest descent method works best far away from the minimum, and the Taylor series method works best close to the minimum.

The Levenberg-Marquardt (LM) algorithm allows for a smooth transition between these two methods as the iteration proceeds.

The first issue in deriving the LM method is to attach some sort of scale to the constant c in the steepest-gradient method - equation (12).

Typically, there is no obvious way to determine this number, even within an order of magnitude. However, in this case, we have access to the Hessian matrix; examining its members, we see that the scale on this constant must be $1/C_{ll}$. But, that still may be too large, so let's divide that scale by a non-dimensional factor (λ) and plan on setting this much larger than one so that the step will be reduced (for safety and stability).

The second issue to formulate the LM method is noting that the steepest-descent and Taylor series methods may be combined if we define a new matrix M_{ij} by the following:

$$\begin{cases} M_{ii} = C_{ii}(1+\lambda) \\ M_{ij} = C_{ij},\ i \neq j \end{cases} \quad (13)$$

This matrix combines equations (11) and (12) into a convenient and compact form. So finally, we have a means of calculating the step δa in the parameters by the following system of linear equations:

$$\sum_{k=1}^{NP} M_{kl}\delta a_l = G_k \quad (14)$$

When λ is large, the matrix M is forced to be diagonally dominant; consequently, the above equation is equivalent to the steepest descent method - equation (12). Conversely, when the parameter λ goes to zero, the above equation is equivalent to the Taylor series method - equation (11). Therefore, we vary λ to switch between the two methods, continually calculating a parameter correction δa that we apply to the most recent guess for the parameter vector.

The steps that are taken in the LM algorithm are as follows:

1. Compute $\chi^2(a)$
2. Pick a conservative value for λ
3. Solve the linear equations for δa
4. Evaluate $\chi^2(a+\delta a)$
5. If $\chi^2(a+\delta a) >= \chi^2(a)$, increase λ by a factor and go back to step 3
6. If $\chi^2(a+\delta a) < \chi^2(a)$, decrease λ by a factor, correct the parameter vector by $a=a+\delta a$, and go back to step 3.

Iteration is stopped when

$$\left|\chi^2(a+\delta a) - \chi^2(a)\right| < tolerance$$

5 The modelling equations

The goal was to find a recurrence law for the light transmission. Therefore, the horizontal illuminance within the axis of the vertical light-pipe and the vertical illuminance within the axis of the horizontal light-pipe were measured at certain distances from the diamond domes.

Based on the values of *DTF* factors determined previously, recurrence laws were determined to predict the axial illuminance at the end of a light-pipe of specific length for a certain value of the external horizontal illuminance at roof level.

If E_0 is the external horizontal illuminance at roof level, then the horizontal illuminance $E_{h,l}$ within the axis of the vertical light-pipe at distance l [cm] from the diamond dome will be

$$E_{h,l} = E_0 \cdot DTF_v(l) \quad (15)$$

where $DTF_v(l)$ is the recurrence function expressing the daylight transport capacity of a light-pipe of length l measured in cm.

It was determined using the CurveExpert v1.4 software based on the Levenberg-Marquardt method of nonlinear regression.

The same applies for the vertical illuminance $E_{v,l}$ within the axis of the horizontal light-pipe, which at distance l [cm] from the diamond dome will be

$$E_{v,l} = E_0 \cdot DTF_h(l) \quad (16)$$

where the recurrence function $DTF_h(l)$ was determined using the same method as above.

For the measured values, the CurveExpert v1.4 software generated the recurrence functions using the Levenberg-Marquardt method of nonlinear regression for 23 regression models. The most accurate form determined for the recurrence function of the daylight transport capacity of the horizontal light-pipe was:

$$DTF_h(l) = \frac{1}{a + b \cdot l^c} \qquad (17)$$

if using the Harris regression model with 1.4965 standard error and 0.9985 correlation coefficient, where:

a = 1.0436 · 10^{-2}
b = 1.4251 · 10^{-3}
c = 3.5527 · 10^{-1}

For the daylight transport capacity of the vertical light-pipe, the following recurrence function was proposed:

$$DTF_v(l) = \frac{1}{a \cdot l + b} \qquad (18)$$

if using the reciprocal model with 2.0356 standard error and 0.9914 correlation coefficient, where:

a = 7.9140 · 10^{-5}
b = 1.2668 · 10^{-2}

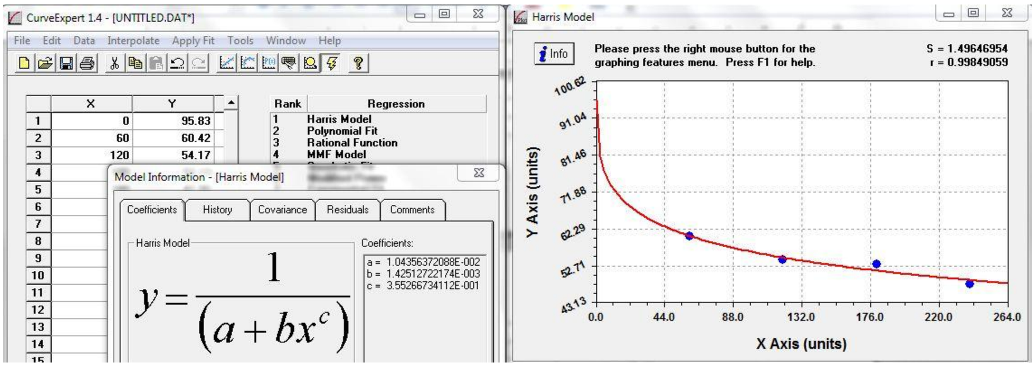

Figure 5 Modelling equation for the daylight transport capacity of the horizontal light-pipe

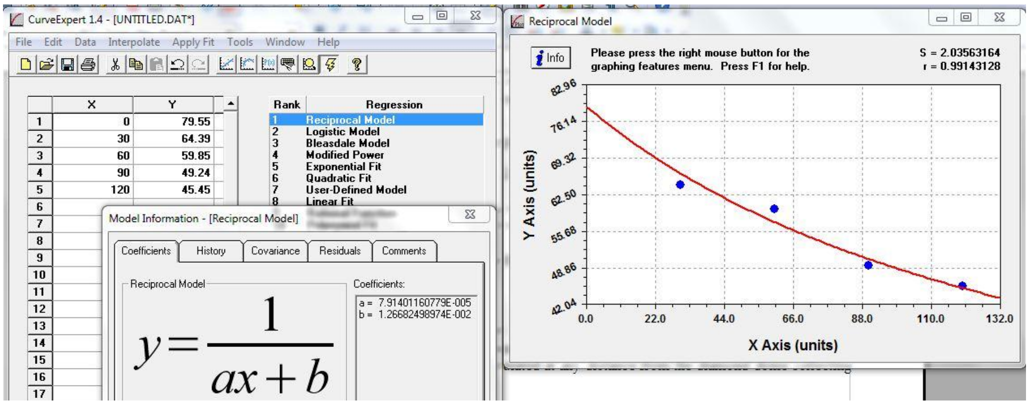

Figure 6 Modelling equation for the daylight transport capacity of the vertical light-pipe

Figures 5 and 6 show the curves which correspond to the functions $DTF_h(l)$ and $DTF_v(l)$ determined above and expressed by equations (17) and (18). On the other hand, the daylight transport capacities of the two light-pipes can be compared by means of the daylight transport factors measured and modelled as above and shown in Table 2.

Considering the equations determined above, *DTF* values can be calculated at any distance from the diamond dome collecting unit of the light-pipes both for the horizontal and the vertical light-pipe.

Table 2 Daylight transport factors for the horizontal and vertical light-pipes

l [cm]	DTF_h [%]			DTF_v [%]			Difference [%]	
	Measured	Calculated	Error	Measured	Calculated	Error	Measured	Calculated
0	95.83	95.82	0.01	79.55	78.94	0.61	16.28	16.88
30	n/a	65.76	n/a	64.39	66.48	2.09	n/a	-0.72
60	60.42	60.46	0.04	59.45	57.42	2.03	0.97	3.04
90	n/a	57.19	n/a	49.24	50.53	1.29	n/a	6.66
120	54.17	54.81	0.64	45.45	45.12	0.33	8.72	9.69
150	n/a	52.94	n/a	n/a	40.75	n/a	n/a	12.19
180	53.13	51.41	1.72	n/a	37.16	n/a	n/a	14.25
210	n/a	50.10	n/a	n/a	34.14	n/a	n/a	15.96
240	47.92	48.96	1.04	n/a	31.58	n/a	n/a	17.38

Figure 7 shows the difference between the daylight transport factors of the two light-pipes, which proves that a vertical light-pipe has indeed a higher transport capacity as compared to a horizontal light-pipe of similar length and diameter.

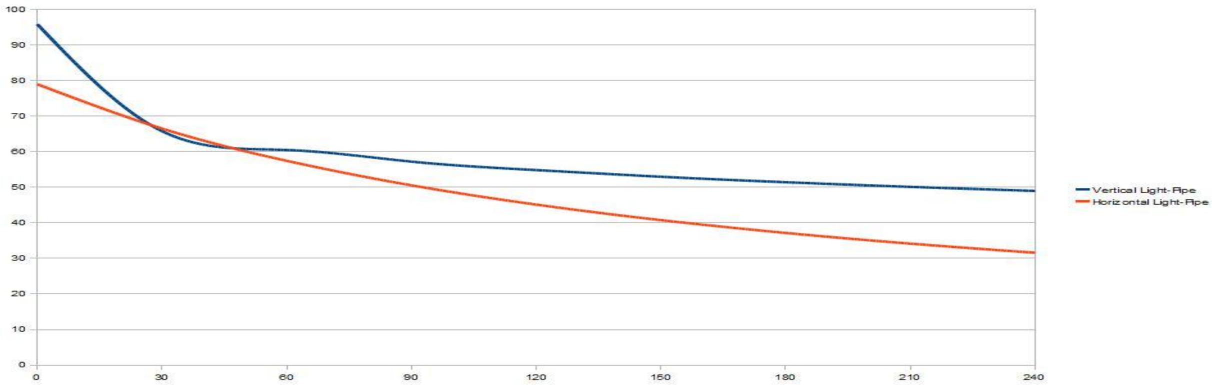

Figure 7 Comparison of the daylight transport capacities of the vertical and horizontal light-pipes

6 Conclusions

The experimental research undertaken by the authors shows an important potential of light transmission towards interior spaces by means of light-pipes. It is essential to emphasize that the 300 mm diameter of the SUNPIPE systems used for this research is only the second one from the range of SUNPIPE diameters. The 450 mm diameter would double the light transmission potential, while the 530 mm diameter would triple it. Therefore, the quantity of light which may be transported by such light-pipes would grow significantly.

Although the vertical light-pipe proved to be more efficient in terms of daylight transport as compared to the horizontal light-pipes, it can be concluded that the difference of 10.59% is not so high. This may entitle us to suggest that horizontal light-pipes can be a relatively efficient solution of side daylighting, in order to collect daylight on the façade of buildings and to transport it towards blind interior spaces. It seems however that the daylight transport capacity of a horizontal light-pipe decreases faster with its length as compared to a vertical light-pipe. This fact would make it acceptable for relatively short distances of less than 3 m from the façade to the blind interior space. Future work will be carried out by the author to improve the modelling equations so that accurate estimates can be made for any length and diameter of the SUNPIPE light-pipes.

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LIGHT SYMPOSIUM 2010 - NATURAL LIGHT – DAYLIGHT AND ARTIFICIAL LIGHT FOR MANKIND

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Lighting Engineering Laboratory, Technical University of Cluj-Napoca, Romania

The LIGT SYMPOSIUM 2010 was held in Stockholm between 28 and 30 October 2010 (www.lightsymposium2010.com).
This event was organized by the Lighting Laboratory from the School of Technology and Health, KTH The Royal Institute of Technology, director professor Jan EJHED. The Symposium was, also, the celebration of the 10th anniversary of the Lighting Laboratory, and the start of the Architectural Lighting master. A book was launched with this occasion, discussing the future of Architectural Lighting Design profession.

The speakers were selected by the organizers and they were:

Ferdinando PATAT,
European Southern Observatory
Fundamental aspects: Natural Light and mankind. An excellent pro dark-sky speech about preservation of the night sky natural darkness and an efficient and cost effective illumination.

Abraham HAIM,
University of Haifa
Biological Aspects of light. About the risk of light at night (LAN) on increased number of breast and prostate cancer on night shifts.
Tessa POCOK,
Heliospectra
Light, Plants and the Human Landscape - the interaction of light, plants and man at the holistic and sub-cellular levels.

Linnaea TILLETT,
Tillett Lighting Design
Environmental Psychology and Lighting Design. Concepts found in Environmental Psychology can be incorporated into a lighting design approach uniting the perceptual, emotive and contextual aspects of light.

Louis CLAIR,
Light Cibles
Cultural Aspects and Lighting Design. Natural daylight in architecture and cultural differences between Western and Asian countries. How can survive the cultural differences in this universal new civilization?

M.J. PINTO-COELHO,
lightmotif arquitectura
Shadows: more content with less information. Modeling natural light is the architect's ambition in any culture since ages. Electric lighting provides an opportunity by subtracting the obvious and adding the meaningful.

Federico FAVERO,
Lighting Laboratory KTH
Social and natural rhythms defining architectural experience. The difference

between electric and natural light is increasingly fuzzy today. Natural light could be the combination of artificial and natural resources that best serve man's basic needs.

Tor NØRRETRANDERS
Philosophical Perspective: Natural Light and Mankind. Daylight offers itself as the new, fundamental value for environmental strategies. But more daylight also means more unpredictability. Are we ready for that?

Luke LOWINGS,
Carpenter Lowings Arch@Design
Architectural Design and Natural Light. The work of Luke Lowings and James Carpenter has tried to connect the city dwellers and the natural world through the experience of daylight, to try to heighten and make manifest the specific qualities of local light.

Kaoru MENDE,
Light Planning Associates
Lighting Masterplan for the tropical Cosmopolis Singapore The results of the Lighting Masterplan of the tropical Cosmopolis at one-north of equator, Singapore which is very unique compare to previous European cities.

I. ALDAY and M. JOVER,
aldayjover arquitectos
Physical Environment and its relation to Natural Light. The work of architecture or landscape aspire to produce small specific paradises, manipulating, smoothing or emphasizing, catching or rejecting the light; using it for valuing volumes, creating spaces or showing textures.

Lars GEMZOE,
Gehl Architects
Social aspects of Architecture and Natural Light. The scale of the spaces and their edges are of major importance but also the climate, sun exposure and temperature, as well as culture play important roles. The way people inhabit spaces is fairly universal and both the role of culture and the perception of climate can change.

Ann WEBB,
University of Manchester
Lighting: Brightening Lives or Dimming the Future? As population have grown and technology improved the world has become lighter and brighter. The 24-hour day of light is no longer restricted to the Polar circles, yet such a lit environment is both unsustainable and has detrimental effects on the environment, while our bodies still strive to follow a circadian rhythm. Can technology reduce the burden of lighting and dim the world with more intelligent systems of illumination?

Bjorn KARLSSON,
Malardalens Hogskola,
Development of windows with high solar and light transmittance. Present the advanced windows which combine high visible transmittance and low U-values.

Peder NORDEBACK,
Ljuskontroll
Developments in Lighting Technology. The latest LED technology uses more electronics and high sophisticated phosphor technology which enable LED module not only dimming but also to change correlated color temperature.

Rogier van DER HEIDE,
Philips Lighting
"Available Light" An exploration of the design of natural light in architecture. A deliberate vision on natural light and how it relates to humans as well as the architectural environment makes daylight a true building element, with a potential much beyond visibility and functional illumination. And when backed with research, computer technology and a strong artistic view, the design of natural light is perhaps the most powerful contribution to live ability, sustainability and attractiveness of contemporary architecture.

In a separate session there were presented 6 papers with speakers not older than 30, for PLDA Vox Juventa Award. The winner was Vellachi GANESAN with "The Light Within" followed by Laura BERNADET with "Leonardo da Vinci, Edward Hopper and their homologues knew something about light. How Art History can influenced our work?"

The Symposium was a success and around 240 lighting designers, architects, professors were attending this event.

Light Symposium 2010 is the inspiration source for the Romanian Lighting Convention 2011 (www.rlc.org.ro), and we hope that some of the speakers that were in Stockholm will come to Bucharest too.

Next Light Symposium 2012 will be held in Wismar, Germany.

Dr. Dorin BEU, Lighting Engineering Laboratory, Technical University of Cluj-Napoca, participated from Romania.

Day 1 - Panel discussion - speakers
Federico FAVERO, Ferdinando PATAT, M.J. PINTO-COELHO, Tessa POCOCK, Linnaea TILLETT, Abraham HAIM, Tor NØRRETRANDERS; panelist Jan EJHED, Diana JOELS.

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 http://www2.brno.cz/index.php?lan=en.

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, Deputy Minister, Director of the Directorate of Economics and Environmental Policies, Ministry of Environment of the Czech Republic
Prof. Brian NORTON, President of Dublin Institute of Technology, Ireland

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

MANAGEMENT OF INFORMATION FOR EVALUATING THE MAINTENANCE OF PUBLIC LIGHTING

Fernando DECO
Municipalidad de Rosario, Argentina

Thesis of *Magister in Luminotecnia*.

On Friday November 19, 2010 the Esp. Eng. Fernando DECO publicly defended his Lighting Master's thesis on "Management of information for evaluating the maintenance of public lighting" in the Department of Luminotecnia, Light and Vision of the National University Tucumán, Argentina. The thesis was directed by Dr. Eng. Eduardo MANZANO, was evaluated by a foreign court, earning the highest rating. During his work, he presented papers in national and international conferences as Lux America 2006, 2008, 2010 and the Congress of the CIE Beijing 2007, as well as publications in professional journals. Remarkable is the effort made by the Master now Fernando DECO in conducting his thesis since it works as Head of the Public Lighting Maintenance of the Municipality of Rosario, as a teacher of the UTN and is also the father of a proud family.

Also remarkable is the support received by the Lighting Division of the Municipality of Rosario in his thesis. Be taken into consideration, the public lighting system has its own structure strongly interrelated components. The public lighting system is not only an electrical installation, but is established as a service to the public. Since it is a service, not only the operation must be controlled, but the continuity across the life cycle must be carefully planned, as well, along an estimated period of 20-30 years. Without the defined basic criteria and policies, the management of urban lighting will conduct the service to an imbalance in various aspects. So, a management focusing its attention only to the commissioning, forgetting its temporal continuity, will quickly lead to the obsolescence of high-cost facilities. By contrast, an information management program will:

- provide adequate service to the needs of citizens;
- ensure that those responsible for public lighting shall not depart from the minimum basic premises;
- encourage citizen participation;
- reduce the environmental impact;
- improve the image of the city;
- ensure coordination and coexistence with other public services as urban trees;

- take advantage of available human resources.

The thesis of Mr. Deco develops basic measures to achieve the goal of management information to assess the maintenance of street lighting, with the premise of achieving efficient public lighting service. To do this, it is not enough to emphasis the technical quality, but also must be obtained quality provision that addresses the requirements of citizenship.

To accomplish the above, it is necessary to have an adequate structure to monitor the progress of the service and to obtain characteristic indices, which will achieve efficiency and take corrective action, when necessary, in order to consolidate a system of continuous improvement. This states the set of tools, methods, strategies and policies which, combined in harmony within a philosophy of management, will facilitate access, consistent, new and higher standards in quality, service and satisfaction allowing guiding the management of public lighting to who should be addressed: the public.

Fernando DECO
Director de Fiscalización del Mantenimiento del Alumbrado Público de la Municipalidad de Rosario
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Electrician Engineer, specialist in ambient environment and efficient lighting, Master in luminotechnics, Postgraduate in management of urban lighting and efficient energy solutions. Graduate of Universidad Tecnológica Nacional, Facultad Regional Rosario, with a degree in Exterior Architectural Ligting

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LIGHTING IN THE NEW WORLD

Cristian ŞUVĂGĂU
BC Hydro, Vancouver

LED's – Are we there yet?

Writing or discussing about LEDs can give you mixed feelings: while you can look at achieved technology milestones and significant advancements the future is more of less a crystal-ball predicative. This editorial is somehow a continuation of a LED fairy tale started in INGINERIA ILUMINATULUI 6 years ago.

Before getting into the present North American Sold State Lighting (SSL) stage let's look at what the little light diodes status was in 2004:

- Traffic Lights
- Commercial and Industrial Signaling
- Exit Signs
- Retail Food and Beverage Displays
- Retail Lighting

And the big talk was about the white light LEDs. I believe there is no further need for comments: when it comes to products and applications we came a long way since then.

However, when it comes to the barriers encountered towards inducing market transformation things have slowly evolved. While technological conditions have been continuously improved, the standards, market education and distribution infrastructure have lagged the technological transformation.

This editorial will not insist on the technological update but rather explore how these issues have been resolved while estimating the risk management of adopting SSL technologies for various applications.

Intensive Collaboration

It was mentioned in the 2004 article that "research, education, and industry collaboration are key activities to accelerate market acceptance".

For example, since its inception in 2002, the Lighting Research Center's Alliance for Solid-State Illumination Systems and Technologies (ASSIST) has been active in a number of research projects and other activities to advance and promote SSL technology. Seen in the beginning as a need for collaboration between researchers and manufacturers it quickly came evident that this needed to be extended to government organizations too.

For several decades now the US Department of Energy (DOE) has worked towards all possible ways in conserving energy and in preventing an energy crisis. The invention of LED, obviously, caught their focus and have been in steady progress

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ever since. Some of the most remarkable alliances have been formed up to this date between DOE and several notable lighting organizations:

- 2005, the first to commit is the Next Generation Lighting Industry Alliance
- 2006, the Illuminating Engineering Society of North America (IESNA) also joined the force
- 2008, the International Association of Lighting Designers (IALD) has also decided to take part.

The group since then has organized a number of activities – hosting seminars, demonstrations, competitions, and much more.

The goal of federal (DOE in US – the main dragging force - and NRCan in Canada) lighting R&D is to increase end-use efficiency in buildings by aggressively researching new and evolving lighting technologies. Working in close collaboration with partners, government agencies aim to develop technologies that have the potential to significantly reduce energy consumption for lighting.

To effectively lead the manufacturing of LED chipsets, lamps and luminaires DOE has engaged researchers, manufacturers and testing agencies in a vast orchestrated effort.

Core Technology Research & Product Development. As part of DOE's on-going initiative in promoting and developing the use of SSL, a Multi-year Program Plan (MYPP) towards SSL/LED is devised. The general content of this plan includes data corresponding to the present status of the technology (i.e. power draw, efficiency), and from such data a forecast can thence be extrapolated. The MYPP is updated regularly, and the most recent edition of update was in March 2010. Two major types of LED have been the key focus in LED development – general white light LED and another more advanced type of LED known as Organic LED (OLED); both of which have great potentials in one day dominating the lighting industry.

For example, the LED chip efficacy in 2010 was about 70 lm/W (warm white)/113 lm/W (cold white) and is expected to increase by 2015 towards 184 lm/W and respectively 215 lm/W; for a LED luminaire the efficiency is forecasted to grow from 69 lm/W to 172 lm/W (2015). The chip costs are set to decline by a factor of ten from about $25/klm (2010) to $2/klm (2015).

For OLEDs the panels are presently at an efficiency of about 45 lm/W and targeted to reach 105 lm/W by 2010, while for OLED luminaires presently at about 26 lm/W the 2015 target is set for about 85 lm/W. The OLED panel costs are forecasted to drop even more dramatically (than LED) from $450/klm to about $9/klm (2015) making then a viable alternative to LED luminaires.

Manufacturing. The creation of an LED chip often involves series of intricate and complicated steps. Manufacturers commonly experience a difficult time in finding a fair balance between purchasing expensive precision tools as to lowering production costs.

Every year, a workshop tailored specifically towards manufacturing R&D is held by DOE. Topics discussed include the current state and forecast of the LED market (discussed in later section), and also any technical difficulties encountered during the manufacturing process.

Beside the chipsets, for SSL luminaire manufacturers a continuous effort is dedicated to competitive and appropriate drivers and controls, items that can make or break not just the reliability of a product but the manufacturers' reputation.

Standards development. As appealing as the SSL technology may appear, many of the features have yet to be perfected. Meanwhile, manufacturers and marketing professionals are eager to promote their LED products, and sometimes incomplete or inaccurate test results may be released unto the public, which could result in adverse financial commitment by misinformed consumers.

The most effective way in engaging the issue of false claims regarding SSL is to establish concrete standards for this rising technology. Beginning 2006, the US Department of Energy (DOE) has held various workshops with the intent to facilitate opportunities for different standards organizations from across the world to get together and work towards producing universally recognized standards for SSL. Renowned standards institutions, in response, have taken up the responsibility in developing new codes and regulations, as well as updating existing ones, to better accommodate for the new technology.

Among various ANSI, CIE and IESNA testing procedures, the most revealing are:

- IESNA LM-79-08 - for Efficacy, Light Output, Input Power, CRI, CCT, Color Spatial Uniformity and Color Maintenance
- IESNA LM-80-08 – Life/Lumen Maintenance (L70 - end of life is when source reaches 70% of initial output).

However, all these standards are in fact just test procedures and not a seal of product approval. Also, due to the incredible rate the current SSL industry is advancing, much work still needs to be done in order to attain a sufficient coverage of all SSL aspects. Certain aspects, such as the color rendering index (CRI) deem unsuitable for SSL evaluation due to the interesting nature of LED's, and a new system is currently pursued by the CIE as replacement alternative, known as the Color Quality Scale (CQS).

Commercial Support and Recognized Testing

Having testing standards and procedure satisfies only one part of the equation for product verification. Customers want to know how the SSL products compare with more conventional technologies for their required application. Therefore a need for Performance Criteria is more acute with SSL technologies.

***Energy Star* -** since 2008, the ENERGY STAR Solid-State Lighting Program has taken the initiative to run thorough tests on commercially available SSL products according to the industry standards.

Products that pass the examination will be rewarded with an ENERGY STARapproved label. These labels serve as a symbol of confidence to consumers.

***DesignLights Consortium* -** much like ENERGY STAR, DesignLights Consortium (DLC) conducts regular tests on SSL products. Upon adequate test results, each individual product will thus be placed on their Qualified Products List (QPL).

DLC works closely with ENERGY STAR, and their primary role is to cover products which fall in a category where the corresponding standards have yet to be completed by ENERGY STAR (i.e. streetlights).

***Lighting Facts* -** this DOE sponsored program issues special Lighting Facts labels for SSL products all across North America. On these labels are convenient performance data (not a performance metric, just provides) for each corresponding SSL product, thus provide information for consumers, a quick glance of how well products compare to LM-79 criteria.

CALiPER Program - for in-depth test results and reports on specific SSL products, DOE has a unique program titled the Commercially Available LED Product Evaluation and Reporting (CALiPER) program. CALiPER regularly tests commercially available SSL products much like ENERGY STAR, except for the fact that their in-depth test results are accessible to the general public (non-commercial purposes).

NVLAP Testing - instated by the National Institute of Standards & Technology (NIST) in 1976, the National Voluntary Laboratory Accreditation Program (NVLAP) is dedicated in ensuring that testing laboratories are in good shape and have the appropriate testing equipment and environment at all times. Laboratories are evaluated according to the US Code of Federal Regulations which include all that are specified in ISO/IEC 17025.

Only NVLAP-approved institutions can provide recognized test results, regardless of whether it is ENERGY STAR or CALiPER.

As mentioned previously in the report, based on the test results retrieved from recent DOE publications, this section will thus analyze the feasibility for SSL products to replace older technology in each lighting application.

Codes and Regulations

Regulations under US and Canadian Energy Efficiency Acts, in effect since 1995, set minimum energy-performance levels for a number of energy-using products such as appliances, lighting, and heating and air-conditioning products. Broadening and strengthening the Acts means that 80% of the energy used in homes and businesses will soon be regulated. It is obvious that SSL can lead to significant energy savings.

A continent-wide move toward SSL for general illumination could save a total of approximately 1500 terawatt-hours, representing $120 billion at today's energy prices. These savings would reduce greenhouse gas emissions by 246 million metric tons of carbon.

At the forefront of the legislative attack is the replacement lamp regulation designed to eliminate inefficient (incandescent) lamps from the market (and mainly in the residential sectors) in three stages:

- 2011/ 2012 – min. 20 lm/W, targeting omni-directional lamps, between 25 and 100 W
- 2013 – min. 25 lm/W, targeting reflector lamps between 40 and 200 W
- 2015 – min. 40 lm/W, targeting all general service lamps.

Additional regulation, such as the one targeted to remove the T12 lamps from the market (the fluorescent magnetic ballasts have been finally removed in 2010) in 2012 could also push the SSL adoption even further to the general commercial illumination.

Product Analysis

Based on the test results retrieved from recent DOE publications, this section will summarize the feasibility for current white light SSL products to replace older technology in various lighting applications.

Low Risk SSL – products performs much in the same way as conventional technology. Risk involve is limited to lower-than-anticipated energy savings life expectancy:

- recessed downlights
- task and desk lights
- street and area lights
- bollards and step lights
- parking/parkade lights

Medium Risk SSL **-** not all aspects are met. Hence, the associated lamp/fixture must be used in a specific way in order to meet the minimum requirements. If used incorrectly, it may lead to discomfort, but poses no immediate danger:

- 2 x 2 troffers
- directional replacement lamps (MR, R, PAR)

High Risk SSL **-** products not meet the minimum requirements of intended use, and could lead to discomfort and/or danger depending on the application. Cannot achieve the same level of output as existing technology:

- 4 ft linear fluorescent replacement lamps
- omni-directional replacement lamps
- high-bay luminaires

SSL Market Forecast

As LED and OLED research progresses, competing energy efficient lighting technologies are also steadily improving in efficacy and cost through the efforts of the major manufacturers, further raising the bar for market penetration of SSL.

SSL products have only recently become a viable alternative to conventional lighting technologies in many main stream applications. The products are not economically competitive the price, but the cost are dropping rapidly both in LED chip production but also in aggregation and luminaire assembly and manufacturing. In the OLED case this is even more dramatic, with recent forecasts showing an exponential development curve set to catch up with LEDs by 2020.

Overall, the SSL presence is posed to significantly increase in the next years. As a near term forecast, DOE estimates the SSL penetration (of luminaire market) jumping for a meager 7% in 2010 to 14% by 2013 and up to 25% by 2015.

A continuous cost reduction paralleled by an increased life time could mean that the conventional model of lighting industry (majorly based on replacement lamps) could become less profitable past 2020. It is anticipated that the most of the competition will be for aggregated SSL products, rather than replaceable lamps.

To further reduce the cost of LED luminaires, further automation of the process will be needed. That in turn will likely favour larger players due to economics of scale and access for capital for process improvement.

All above considered, lighting companies may need to find new markets and applications for lighting to sustain growth such as:

- lighting areas where previously it was not practical/ economical (i.e. off-grid exterior applications, battery-operated remote mounted SSL)
- adding new features to already lit areas (i.e. accent/ façade lighting, battery-operated SSL luminaires for night illumination in stairwells/ corridors).

Nevertheless, other emerging lighting technologies (plasma, induction, etc) will compete with SSL to benefit the end-users but one thing is sure: the future (in lighting) has started yesterday.

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He holds a Ph.D. from the Technical University of Construction in Bucharest, Romania for his thesis on improved calculations methods for indoor lighting systems. He has been practicing and teaching architectural lighting design and energy efficiency in Europe and North America for over 20 years. A senior lighting and energy management engineer with BC Hydro since 1998, he focuses on lighting efficiency and DSM programs and research in British Columbia. He is also a member of the Canadian National Committee of the CIE and President of the BC chapter of IESNA.

LIGHTING ENGINEERING CENTER – LEC UTC-N
2000 - 2010

Florin POP, Dorin BEU
Lighting Engineering Laboratory, Technical University of Cluj-Napoca, Romania

Lighting Engineering Center - LEC - was created following the Tempus-Phare programme CME-03551-97 [15.12.1998 - 14.03.2000]- see http://users.utcluj.ro/~lec, by the Decision of the Technical University Senate Council to establish the Centrul de Ingineria Iluminatului – UTC-N – Lighting Engineering Center (LEC), under the frame of the Continuing Education and Distance Learning Department - 25 April 2000.

Professors Florin POP and Ramon SAN MARTIN

Co-ordinated by Professor Florin POP, the CMEs project entitled **Lighting Engineering Centre - LEC** involved the university Lighting Laboratories from Barcelona - Professor Ramon SAN MARTIN, contractor, Helsinki - Professor Liisa HALONEN and Naples – Professor Luciano DI FRAIA, and specific units from Babeş-Bolyai University, Department of Computer Science - Professor Horia F. POP, Universitat Politecnica de Catalunya, Department of Student Guidance, Theresa BOFILL GORINA, Electric Suply Branch of Electrica - General manager Gabriel RUGA, and Energobit Schréder Lighting - Vice-president Pál PETER.

Its milestone was the creation of an excellence centre for consultancy and continuing education in lighting field in direct link with the needs of the labour market, in the North-Western Romania, to support the process of university reform at management level with a view to develop managerial and administrative skills, taking into consideration: - the undergraduates' problems concerned with their further placement on the job market; - the employees' problems concerned with a possible redistribution of the work force caused by the current economy restructure; - the necessity to refurbish almost entirely old lighting installations; - the achieving a permanent co-operation between university and a specific economic sector, one of the

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ways that increase the reform process in Romanian education and economy system in one of their aspect, the lighting field.

A leading path of our activity for the development of lighting education at the Technical University of Cluj-Napoca constituted the promotion of cooperation relationships with strong international academic and research centers. Study visits supported through research grants or programs were followed by the establishment of Bilateral Agreements of cooperation between the Technical University of Cluj-Napoca (Dr. Florin POP, Professor, Dr. Dorin BEU, Reader) and Universitat Politecnica de Catalunia, 1998 (Professor Ramon SAN MARTIN, Estudios Luminotecnicos), University of Stutgart, Department of Buildings Physics, 1994 (Professor Karl GERTIS) and University of Liverpool, 1993 (Dr. David CARTER, Reader, Lighting Research Unit).

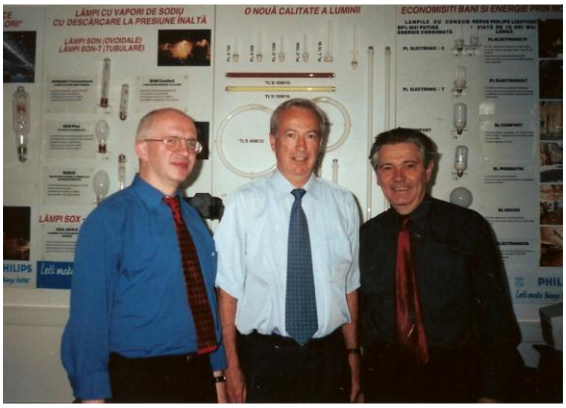
The university cooperation continuously developed under the frame of the EU institutional university programs SOCRATES-ERASMUS 1999-2001 - Helsinki University of Technology (Professor Liisa HALONEN, Lighting Laboratory), and University of Liverpool (Dr. David CARTER, Reader, Lighting Research Unit).

Professors Inhan KIM (chairman, major in Architecture), Jeong Tai KIM (director of LAEL), Florin POP, Byung Ik SOH, Dean, Hee-Cheul KIM, Sun Kuk KIM (chairman, major in Architecture)

Dr. Florin POP was invited to participate at the International Seminar “Advanced Daylighting and Electric Lighting Systems in Architecture”, October 2003. The Seminar was organized by the Light & Architectural Environment Laboratory – LAEL, Kyung Hee University, Seoul, Korea, director Prof. dr. Jeong Tai KIM. Two agreements for university cooperation were signed: The Memorandum of Understanding between the College of Architecture and Civil Engineering, Kyung Hee University, Korea, and the Universitatea Tehnică din Cluj-Napoca, Romania and (signed by Prof. Florin POP on behalf of the Rector of UTC-N) and The Memorandum of Understanding between Light & Architectural Environment Laboratory, Kyung Hee University and Lighting Engineering Center, Universitatea Tehnică din Cluj-Napoca. The activity of Professor Florin POP was recognized with a diploma - Award of Appreciation.

There are two highlights: the INGINERIA ILUMINATULUI (Lighting Engineering) journal, and the ILUMINAT Conferences (started in 2001 and held every two years in Cluj-Napoca). The journal was started in 2000, and arrived at the 12th volume - http://users.utcluj.ro/~lec/journal) The ILUMINAT 2001-2009 conferences managed to bring worldwide specialists in Cluj, and this fact increased the lighting knowledge in our area.

At the first conference ILUMINAT 2001, Wout van BOMMEL and Axel STOCKMAR visited the Electric Installations and Lighting Laboratory of the LEC UTC-N.



Professors Axel STOCKMAR, Wout van BOMMEL, Florin POP

The Lighting Engineering Center of the Technical University of Cluj-Napoca, Romania was recently involved in three programs for promoting lighting energy efficiency and energy saving measures in residential buildings.

NAS-EnerBuild RTD "Newly Associated States for Proposal to Extend EnerBuild RTD, the Thematic Network for Energy Research in the Built Environment" – FP4-FP5. Contract ERK6-CT-1999-2001 Coordinator National University of Ireland, Dublin, Energy Research Group.

EnERLIn "European Efficient Residential Lighting Initiative"-2006-2008, Grant EIE/05/I76/SI2.419666, coordinated by Profesor George ZISSIS, LAPLACE Laboratory, University Paul Sabatier, Toulouse, France, an EIE-SAVE program to promote Compact Fluorescent Lamps in the residential sector.

CREFEN – Integrated software system for energy efficiency and saving in the residential sector, a Romanian CEEX (Excellency in Research) program - 2005-2008.

Since the first postgraduate course in lighting in 1998, it has been started a cooperation with architects (lighting designers need to understand architects and vice-versa). Starting then, Dorin Beu has been in charge with relations with architects from and abroad. A special relation was recently developed with the Lighting Laboratory from KTH Sweden, Professor Jan Ejhed. In December 2008, Dr. Beu visited KTH Handen for teaching a course on Romanian Lighting Design, and in 2010 he participated to Light Symposium 2010. In 2011 Jan Ejhed will participate at the Romanian Lighting Convention.

In 2010 the Technical University of Cluj-Napoca restructured its research centers. On this occasion, we set the Lighting Engineering Laboratory (starting November 25, 2010) as one of the new 65 research centers and laboratories of our university.

One of the first activities of the Lighting Engineering Laboratory was to propose a joint research project with National Technical University of Athens, School of Electrical and Computer Engineering, Lighting Laboratory – Professor Frangiskos Topalis – "Development of control system with digital optical CCD sensor for monitoring of artificial interior lighting aiming to utilization of daylighting and energy saving".

By far, the largest project is the involvement in Romanian Lighting Convention 2011 (http://www.rlc.org.ro), where we would like to get together lighting professionals with architects, city councils, designers. It is a joint project with CIE, PLDA and Romanian Architects Chamber. Personalities like Ann Webb, Wout van Bommel, Jan Ejhed, Martin Lupton, Roger Narbonni, and others, participants at our previous ILUMINAT conferences, announced their intention to participate at this event.

Also in 2011, the Lighting Engineering Laboratory will organize the first Architectural Lighting course for students from the School of Architecture, UTC-N.


UNIVERSITATEA TEHNICĂ
DIN CLUJ-NAPOCA

CERTIFICAT
DE ACREDITARE INTERNĂ

În baza aprobării Senatului Universității Tehnice din Cluj-Napoca din 22 iulie 2010, ca urmare a îndeplinirii standardelor de performanță științifică ale universității, se acreditează pentru funcționare:

Laboratorul de Cercetare pentru Ingineria Iluminatului

Director laborator de cercetare:

Conf.univ.dr.ing. Dorin Beu

Perioada de valabilitate a certificatului: 25.11.2010 – 24.11.2015

Rector,
Prof.univ.dr.ing. Radu Munteanu

Prorector Cercetare și Relații Internaționale,
Prof.univ.dr.ing. Aurel Vlaicu

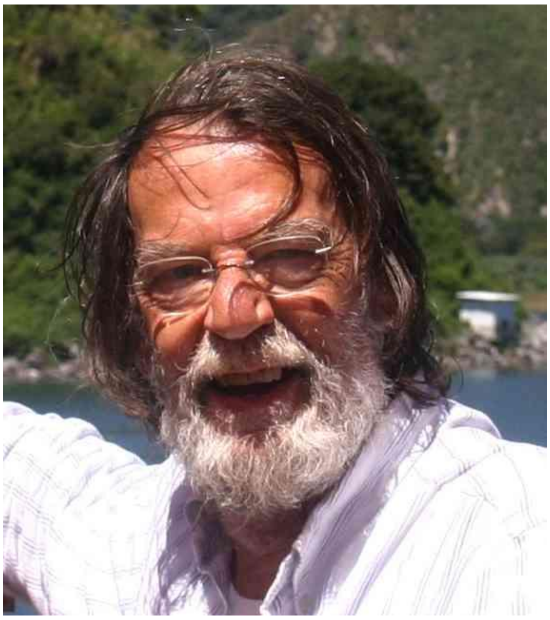
Director DMCDI,
Prof.univ.dr.ing. Stelian Brad

25.11.2010
Cluj-Napoca

Florin POP and Dorin BEU

Professor Ramon SAN MARTIN - a life for lighting

Professor SAN MARTIN at the retirement time. Ramon joins the elite of professors leaving didactical activity after a life in service of Light & Lighting.



Ramon SAN MARTIN is a discrete personality, performing his research activity in the silence of his office from the Departamento de Proyectos de Ingeniería of the UPC - Universitat Politécnica de Cataluña.

During years 1990 I have met his name in a few volumes of lighting conferences and I have personally met Ramon at the Right Light Conference - Arnhem 1993. With its savage beard, he seemed more like an experienced sea wolf wandering on land. I was there at my third participation at a lighting conference organized in the Western world, after the political changes in my country. I approached him and asked for copies of a few of his papers. I discovered a warm person, an open character.

I had the honour and happiness to be accepted among his friends and to cooperate at more specific activities, as scientific papers and research programs.

Ramon supported me with a research mobility (1.12.1995 - 1.03.1996) at his Department, granted by the Spanish Ministry of Science and Education, and we cooperated at the development of the Energy and Costs Management of the Lighting Installations - MECOSIL 2000 - Research and Development project under the frame of an international cooperation program Romania - Spain, Romanian Ministry of Research and Technology, 1998-2000.

We also cooperated at the accomplishment of a very important project for the lighting education in the Technical University of Cluj-Napoca: *"Lighting Engineering Centre - LEC - an excellence centre for consultancy and continuous formation in the lighting field in direct link with the needs of the labour market"*, Tempus-Phare CMS - Compact Measures Project - CME-03551-97, EU (14.12.1998 - 14.03.2000). The LEC web page http://users.utcluj.ro/~lec has more information on this project.

The LEC program - contractor Professor Ramon SAN MARTIN, coordinator Professor Florin POP - concentrated the efforts of university professors from Cluj-Napoca, Barcelona, Helsinki and Naples.

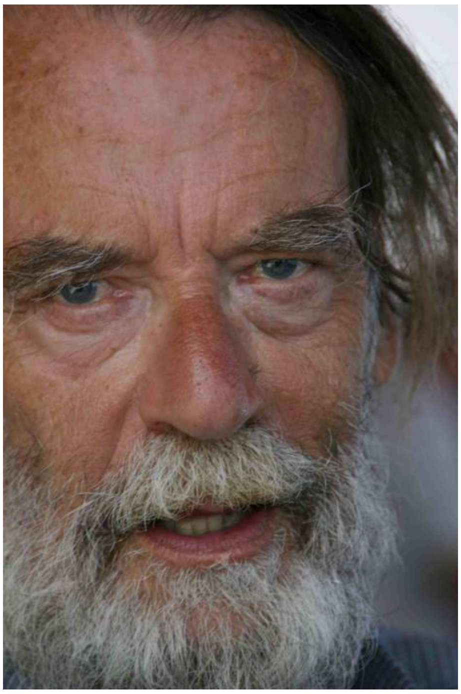
Professor Ramon SAN MARTIN graduated as an industrial engineer. He worked as an engineer of the Services of Illumination of the City Council of Barcelona - 1965-1989.

His university teaching activity started in 1969 as an Associated Professor with the UPC - Polytechnic University of Catalonia. From 1989 he activated as Regular Professor of the Department of Projects of Engineering of the UPC, and Director of the Postgraduate Lighting Courses of the UPC.

Author of books, journal articles, communications and presentations at conferences, research reports, Prof. SAN MARTIN coordinated also PhD theses. His main field of interest is urban lighting - see http://eprints.upc.edu.

Ramon SAN MARTIN was a member of several Committees of Normalisation and Certification AENOR, president of the 1st International Symposium on Light Pollution, the Spanish representative of the Division "Exterior Lighting" of the CIE, and the representative in the European Committee of Normalisation TC 169-WG 2, "Illumination Applications.".

He was granted with Gold Medals of the Lighting Merit and Electrotechnical Merit, First Award of Technology Transfer UPC-1997, Ecomed Polutec Award 2004 of the Sustainable City.



Ramon is changing his life these days. So, one of his today's questions is "My dear dog, Duck: where are we?"

Ramon SAN MARTIN is a warm and kind friend, closed to the Romanian Lighting community.

Ramon will remain forever in my memory as one of my best friends, as one of the foreign professors understanding well our needs and offering his strong support for our development in the international lighting field.

Happy many returns to you and a long and fruitful retirement life!

Florin POP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