ISSN 0236-2945

LIGHT & ENGINEERING

Volume 19, Number 3, 2011

Znack Publishing House, Moscow

Volume 19, Number 3, 2011

LIGHT & ENGINEERING

LIGHT & ENGINEERING
(Svetotekhnika)

СВЕТО ТЕХНИКА

Moscow, 2010

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VOLUME 19 **NUMBER 3** **2011**

LIGHT & ENGINEERING
(SVETOTEKHNIKA)

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Light & Engineering
Vol. 19, No. 3, pp. 5-14, 2011

Svetotekhnika
No. 1, 2011, pp. 6-11

LIGHTING QUALITY AND ENERGY EFFICIENCY, A CRITICAL REVIEW *

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ABSTRACT

The review is structured around four questions:

Question 1: Do we have the right focus in product development? From a society point of view sustainability and in its context energy friendly, long life product and application design will remain important. The lighting industry has to focus more on total waste free products as defined in cradle to cradle design. Futuristic daylight products like transparent OLED windows, transparent solar windows and translucent concrete, can increase the daylight use in interiors.

Question 2: Do we use the right basic information? Good glare restriction in solid state lighting requires innovative optical design. Here a totally new glare evaluation system is needed as the present systems were developed for circumstances totally different from solid state lighting. In fixed road lighting, especially for motorway lighting, we base our concepts on visibility of objects but that concept is losing importance because of developments in car systems.

Neurological research is needed to find out if fixed road lighting can contribute to minimize micro sleeps in night drivers. For lighting in built-up areas, instead of the luminance concept of road lighting a more three-dimensional concept is needed

Question 3: Do we provide the users with the right information? The changeover to solid state lighting may be slowed down because it is precisely for solid state lighting that wrong data are often supplied, thus disappointing new users in their expectations. Statements that for domestic home lighting the changeover from incandescent lamps into LED-lamps poses a health risk are shown to be incorrect.

Question 4: Are we addressing the right public? Most recommendations and standards on lighting quality are based on people of around 30 years old. With age eyesight deteriorates. It is therefore essential that in lighting recommendations and standards special sections are incorporated on the special needs of the elderly. It is shown that the effectiveness of LED-lamps is negatively affected by the blue light loss of the aging eye. 1,6 Billion people in developing countries have no access to electricity. It is good to see that where so far only non-profit organizations were offering low-cost solar home lighting units, larger lighting manufacturers are now developing off-grid concepts for remote rural areas.

1. INTRODUCTION

With regard of lighting quality and energy efficiency, the situation of today and possibilities in the future are very much dependent upon our quality as lighting professionals. This review is therefore structured around the following four questions: Do we have the right focus in product development? Do we provide the users with the right information? Are we addressing the right public? The subject will be treated more illustratively than exhaustively.

* Report at the "CIE 2010 Lighting Quality & Energy Efficiency", March 2010, Vienna

2. DO WE HAVE THE RIGHT FOCUS IN PRODUCT DEVELOPMENT?

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 took some time before the lighting world reacted appropriately, for example, by reconsidering our lighting standards and developing more energy efficient lighting products. Of course since then, we have learned to react quicker, especially also since in the 1990s next to shortage of availability of resources, also the negative consequences of CO_2 emissions on climate change became apparent. Today sustainability is the key word.

2.1. Energy and lifetime

In the professional lighting world sustainability has been approached from an energy efficiency and lifetime point of view. And indeed we have seen very important developments in this respect in gas discharge lamps and more recently in solid state lighting. Also the design of the total installation (lamps, luminaires, gear and layout of luminaires) is today geared towards energy friendly installations that live long. Intelligent installations that optimize the actual use of lighting, further decrease the energy use.

2.2. Cradle to Cradle

In some other industries impressive recycling steps have already been taken. The ultimate goal here is "Cradle to Cradle" design or in practical words to create systems that are not just efficient but essentially waste free. As the inventors of this term, McDonough and Braungart [1], say: "remaking the way we make things" is needed for this. In the lighting industry this theme is still underdeveloped. Recycling of glass, mercury and phosphors can only be seen as an important but first step, especially if we take all components of a lighting installation into account.

2.3. Daylight use

Intelligent daylight linking systems have been available for a long time. They can contribute considerably to energy efficiency and have a positive influence on the final lighting effect.

Emphasis should be placed on making these systems reliable under all circumstances in order to increase the speed of market penetration. More knowledge of daylight behaviour and its influence on the comfort and wellbeing of office and factory workers is required, especially with those normally working with artificial light. This becomes even more important because of envisaged developments in windows. Complete transparent OLED windows are principally possible so that we can have daylight and artificial light from one single product. Small sized prototypes have been produced [2]. Studies are being carried out to develop transparent solar windows of normal flat glass. The glass gets a low cost luminescent coating which captures radiation of a certain wavelength over the whole area of the window. That captured radiation is redirected efficiently to the small edge areas of the window where it is captured by solar cells attached to the edges. Prototypes have been shown in [3]. Another interesting future possibility to use daylight in buildings is translucent concrete [4]. Glass fibers are being mixed with the concrete substance. It may be used for example for subway stations and other underground buildings. The city of Stockholm has a demonstration project with translucent concrete in a sidewalk.

3. DO WE USE THE RIGHT BASIC INFORMATION?

3.1. Glare concepts

The very small size of an individual LED is one of the very interesting properties of LEDs. It opens many new possibilities to create light distributions that were never possible with the larger conventional light sources. However, the same property in many applications gives the risk of glare. New innovative (luminaire) optical designs are urgently needed. Here it is important to realise that evaluation of a design as far as glare restriction is concerned is difficult because most, if not all, of today's glare evaluation systems are not suitable or valid for LED light sources. For indoor lighting the UGR system is used for glare evaluation. The empirical research from both USA and Europe, on which the UGR system is based, dates mainly back to the late fifties and early sixties of last century (e.g.Luckiesh, Hopkinson, Guth, Sollner, Bodmann, Fischer). Small light sources and mirror optics were not or hardly taken into account in the research of those days. The TI concept as we use it today for glare restriction in road lighting has been developed based on research dating back to the 1930s (e.g. Holladay, Stiles). The concept has been refined for road lighting in the sixties and early seventies based on assessments of installations using long tubular low pressure sodium lamps and ovoid high pressure mercury lamps (e.g. de Boer, Schreuder, Adrian, Fisher, Sörensen). With smaller tubular high pressure sodium lamps it has already been noticed that sometimes the TI system leads to somewhat unexpected results as far as actual glare sensation is concerned. Finally outdoor sports lighting also has got its own glare evaluation system: the GR system. It is based on appraisal tests carried out in the eighties on training fields and in stadiums with high power metal halide lamps (van Bommel, Tekelenburg). With conventional light sources these three separate systems worked moderately well. Given the specific properties of LEDs and LED clusters, it is urgently needed that all three glare systems are evaluated on their validity for installations using LEDs. Probably the development of a whole new glare evaluation system is needed. This would also give the chance to try to develop one generic system for all fields of application.

3.2. LUMINANCE CONCEPT OF ROAD LIGHTING

3.2.1. Visibility of objects

In the early years of last century Waldram defined on the basis of visibility of small objects the "silhouette principle": most objects on roads with road lighting are seen as dark silhouettes against the bright background of the lit road surface. This, in turn, has been the key to the development of the luminance concept of road lighting as still used today. Early on it was realised that the combined effect of road- and car lighting is a negative combination because the vertical component of car lights reduces the silhouette effect. However, in order to limit glare from oncoming cars, car beams could not reach far ahead and thus the negative "combination effect" was limited and could be neglected. With the introduction of Advanced Front lighting Systems (AFS) this now has been changed. These intelligent and automatic car lighting systems have specific urban-, highway- and "curve" beams that reach far and even "around the corner". They increase visibility of objects to such an extent that often sufficient visibility can be guaranteed by the advanced car lighting system alone. IR night vision systems that display on the dashboard an image recorded with the aid of IR radiators have also been introduced.

They will further increase the importance of individual car systems as far as visibility is concerned. Clearly, as far as fixed road lighting is concerned visibility of objects on the road, especially on motorways is not the first requirement any more. The role of fixed road lighting will move much more in the direction of providing traffic guidance, facilitating traffic flow, and probably towards an aspect that so far has received little attention, reducing micro sleeps.

3.2.2. Micro sleeps

Drivers falling asleep are the cause of many night time accidents. In field tests, brain activity (EEG) of test drivers is measured while they drive a long stretch of road. The purpose of this type of research is to examine if road lighting can reduce the number of micro sleeps of night time drivers. If so, the next question to answer of course is which type of road lighting does this most effectively. To illustrate the importance of this type of research: a test where the EEG of drivers was analyzed during a night time drive of 415 km motorway without fixed road lighting revealed that the cumulative duration of these micro sleeps adds up to more than 6 minutes [5]. Here we thus have a whole new approach to defining the need and quality of road lighting, totally different from the conventional visual performance and visual comfort requirements.

3.2.3. Personal security

For roads in built-up areas probably the most important requirement is providing personal security. It is doubtful, to say the least, whether the luminance concept of road lighting is the right concept in this respect. Probably a three dimensional lighting concept is more suitable. It seems that there is an urgent need for more research in this direction in order to be able to design road lighting for built-up areas on a more appropriate basis. Here also the colour contribution to identification of human faces with different lamp spectra should be evaluated.

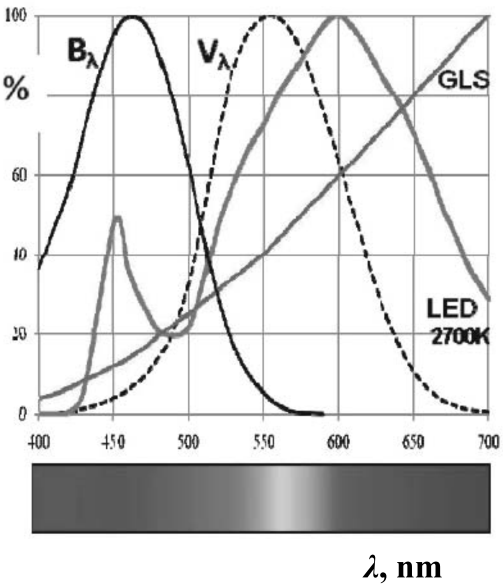

Fig. 1. Relative spectral energy distribution of an incandescent lamp (GLS) and a LED-lamp of 2700K (Ra 80) together with the relative spectral sensitivity of the eye for vision V_λ and the biological action spectrum B_λ

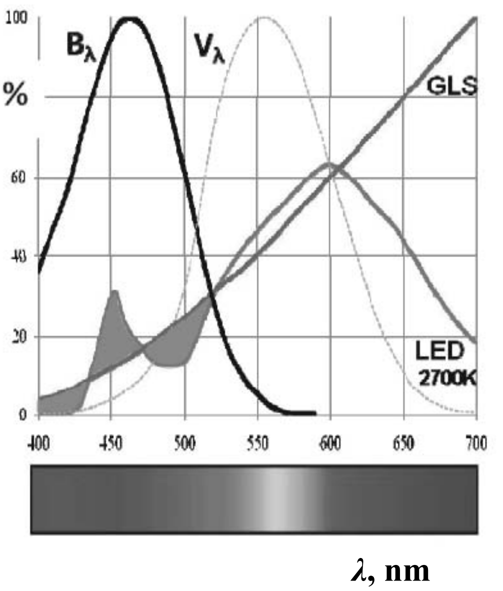

Fig. 2. V_λ weighted spectral energy distribution of an incandescent lamp (GLS) and a LED-lamp of 2700K (Ra 80) together with the relative spectral sensitivity of the eye for vision V_λ and the biological action spectrum B_λ

4. DO WE PROVIDE THE USERS WITH THE RIGHT INFORMATION?

4.1. Data of LED products and designs

In conventional lighting the vast majority of suppliers of both products and lighting designs provide correct data about their products or designs. It is disturbing to see that this is too often not the standard procedure when it comes to solid state lighting. The reason probably being that still too often products and designs do not (yet) fulfill the needs of the end-user. As an illustration: the Dutch Metrology Institute VSL in February of 2009 tested 5 different brands of LED-lamps. The incandescent lamp wattage equivalence claimed was 25 to 40 W whereas the measured reality was less than 15 W [6]. Also in designs, “equivalence” with conventional installations is sometimes claimed while in reality the LED installation is not equivalent in terms of lighting level or uniformity or glare restriction.

This behaviour of both suppliers and lighting designers leads to new users of solid state lighting being disappointed in their expectations and as such it hampers a quick and successful introduction of good quality solid state lighting products and installations in both the consumer and professional market.

Table 1. Total visual dose (light output) and biological dose of LED and CFL lamps relative to that of an incandescent lamp (GLS) [7]

	Visual dose basis V_λ (%)	Biological dose basis B_λ (%)
GLS	100	100
LED 2700K Ra80	100	99.0
LED 4000K Ra65	100	133.8
CFL 2700K Ra80	100	99.1

4.2. LED-lamps and health

Especially in the popular press we have seen quotes of laymen but sometimes also of authorities from the lighting or medical profession, claiming that domestic use of LED- lamps instead of incandescent lamps can disturb the biological clock and therefore also the natural body rhythm. The reasoning is that LED-lamps have a peak in the blue part of the spectrum for which the biological action spectrum peaks as well. In order to verify such statements we made detailed calculations for many different LED-lamps, a CFL lamp and a normal incandescent lamp (GLS) [7]. First thing we did was scaling all relative spectra according to V_λ in order

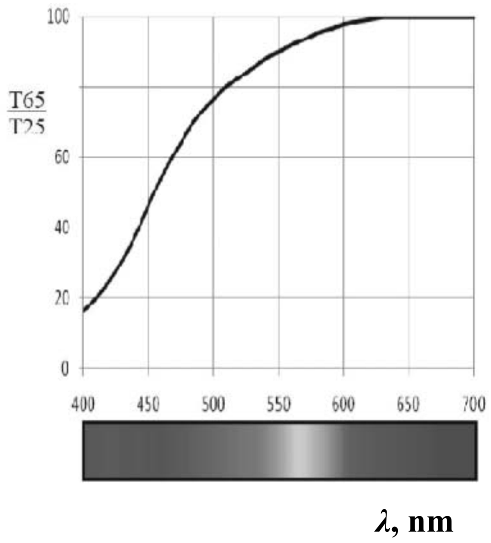

Fig. 3. Transmission of the human crystalline lens of 65 year old persons relative to that of 25 year old persons, calculated on basis of [10]

to compare the effect of the different spectra based on a same visual dose (light output). Fig. 1, as an example, shows the unweighted, relative spectra of the incandescent lamp and a 2700 K LED-lamp (Ra 80) together with V_λ and the biological action spectrum B_λ as defined by Brainard [8]. Indeed the LED-lamp has a peak in the blue part where also the biological action spectrum has high values. LED-lamps of higher colour temperature have even higher peaks in this part. Fig. 2 shows the V_λ weighted incandescent and LED-lamp spectra ensuring comparison of equal visual dose. It can be seen now that some parts of the LED spectrum in the "biological action spectrum area" have higher values than the incandescent lamp spectrum but that there are also parts where the values are lower. For all lamps taken into account we calculated, based on the V_λ weighted spectra, the total biological dose based on B_λ. The results for some of these lamps are given in Table 1. The total biological dose of LED-lamps of 2700 K and Ra 80 is not higher but in fact slightly lower than that of a normal incandescent lamp (of same visual dose viz. same light output). Our calculations show that this is true for all LED-lamps in the range of 2700–3000 K and a colour rendering index of at least 80. LED-lamps with a colour temperature of 4000 K (and poorer colour rendering) do have a 34 % higher biological dose. The conclusion is thus that there is no objection seen from a health point of view to use LED-lamps of 2700–3000 K and good color rendering (Ra > 80) instead of incandescent lamps.

Table 2: Total visual dose (effective light output) in % of 65 year old persons relative to 25 year old persons for different lamps [7].

	Visual dose	
	25yr.	65 yr.
GLS	100	92,9
LED 2700K, Ra 80	100	64,6
LED 4000K, Ra 65	100	52.2
CFL 2700K, Ra 80	100	55,3

5. ARE WE ADDRESSING THE RIGHT PUBLIC

5.1. The elderly

Most recommendations and standards on lighting quality are based on people of around 30 years old. With age eyesight deteriorates in terms of contrast sensitivity, visual acuity, depth of field, glare sensitivity and colour vision. It is therefore essential that in lighting recommendations and standards special sections are incorporated to address the special needs of the elderly. As an illustration we will sketch the consequences of the effectiveness of LED-lamps for the aging eye.

Short wavelength loss and LED-lamps

The human crystalline lens in the eye turns yellowish with age. One of the consequences is blue and green (short wavelength) vision loss. Fig. 3 gives the transmission of the eye lens for the age group of 65 relative to the age group of 25 year.

A somewhat practical sad example of what it means becomes evident by comparing Claude Monets paintings before and after he developed an early severe case of cateract [9]. This spectral property of the aging eye can have an important consequence for the effectiveness of light sources with different spectra that is too often forgotten. To quantify this consequence, the visual dose has been calculated for the spectra of the LED-, CFL- and incandescent lamps also analysed in Section 4.2 [7]. For this purpose these spectra have been corrected according to the spectral losses given in Fig 3. The results are summarised in Table 2.

Where the incandescent lamp results in a loss because of this spectral age effect of 7 %, the loss with

LEDs and CFLs is much larger, up to 48 %. Of the latter category the LED with 2700 K and good colour rendering is giving the lowest loss (35 %). Again a reason to encourage home lighting LEDs with colour temperatures of 2700–3000 K and good colour rendering and not use the higher colour temperature range.

For some time discussions have been taking place about certain lamp spectra having advantages for vision at low lighting levels (mesopic vision). For this reason it is sometimesproposed to use lamps with high colour temeratures for low level road lighting. Since we have many ageing drivers we must also here take the spectral age effect into account and not use lamps (LEDs) with too high a colour temperature [11].

5.2. Developing countries

More than twenty years ago CIE started to involve lighting professionals from developing countries in the work of CIE. This has resulted in, amongst others, a publication on road transport lighting for developing countries (free download from CIE website). So far these important activities have been restricted to situations where there is electricity available.

However 1,6 billion people in developing countries have no access to electricity. For lighting after sunset, wood and kerosene is used. This is costly, poses harmful smoke and fire risks and is polluting. Renewable energy sources based on low cost small units of a battery and a solar cell can offer a solution for domestic use. However, conventional lamps for domestic use are not efficient enough to be operated on such units. LEDs are efficient enough for this purpose and the long life and robustness makes them very suitable. More and more simple and low cost solutions are made available to the rural population in many different developing countries by non-profit organisations. The “Light Up The World (LUTW)” organisation is an example and one of the pioneer organizations since 1997. They have been active in 51 countries and impacted directly 200 000 people with their approach [12, 13]. The LUTW basic home lighting unit has two 1,8 Watt LED-lamps of 75 lm each, a 10 W solar panel, a sealed lead acid battery and a charging unit. The two lamps can be placed in separate rooms. Based on 4,8 sun hours the two LEDs can be used for 7,5 h on full power. Via donations prices are kept as low as possible [12].

It is good to see that some large lighting companies started pilots to fulfill other specific needs in off-grid remote areas. OSRAM is addressing the need for energy in small portions not only for CFL or LED lighting but also for charging small domestic appliances like a small radio or mobile [14]. Philips is addressing the need for bringing communities together and introduced a solar powered LED flood lighting system that can be used for evening social community gatherings and/or to enjoy a game of evening football on an area of some 40 x 20 m [2].

6. CONCLUSIONS

The lighting industry has to focus more on total waste free product development as defined by cradle to cradle design. Futuristic daylight products can increase the daylight use in interiors. For this to happen lighting professionals should increase their knowledge on daylight behaviour.

A totally new, generic glare evaluation system is needed as the present systems have been developed for circumstances totally different from solid state lighting. The luminance concept of road lighting is as a sole concept no longer relevant enough. For lighting in built-up areas, instead of or as an addition to the luminance concept of road lighting, a more three-dimensional concept is needed. The changeover to solid state lighting may be slowed down because often wrong data are supplied, thus disappointing new users in their expectations. Statements that for domestic home lighting the changeover from incandescent lamps to LED-lamps poses a health risk, are shown to be incorrect. It is essential that in lighting standards and recommendations special sections are going to be incorporated on the special needs of the elderly. It is shown that the effectiveness of CFL and LED-lamps is negatively affected by the blue light loss of the aging eye. 1,6 Billion people in developing countries have no access to electricity. It is good to see that where so far only non-profit organisations were offering low-cost solar home lighting units, larger lighting manufacturers are now developing off-grid concepts for remote rural areas.

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Prof. M.Sc. worked for more than 35 years with Philips Lighting in different lighting application functions. He has carried out research into many different lighting subjects. Some concepts based on his research work now used in international standards for lighting. He became responsible for the company's international lighting application knowhow centre.

For the period 2003 - 2007 he has been President of the International Lighting Commission, CIE. From 1988 up to 2008, he was the Dutch representative of the European Lighting Normalisation Committee CEN TC 169. He is a board member of the Dutch "Light & Health Research Foundation", SOLG.

Wout van Bommel was in 2004 appointed Consulting Professor at the Fudan University of Shanghai and in 2008 External Examiner of the Master Course "Light and Lighting" at the University College of London (UCL- Bartlett Institute). He has published more than 150 papers in national and international lighting journals in different languages. He is the author of the book "Road Lighting". All over the world, he has presented papers, has taught at universities and schools and has given invited lectures at Conferences.

After his retirement from Philips Lighting, he advices, as an independent Lighting Consultant, lighting designers, researchers, companies municipalities and governmental bodies

Light & Engineering
Vol. 19, No. 3, pp. 12-15, 2011

Svetotekhnika
No. 4, 2010, pp. 48-57

HIGH POWER WHITE LIGHT EMITTING DIODES WITH LIGHT EFFICACY UP TO 120 lm/W AND PRODUCTS ON THEIR BASE

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ABSTRACT

The article presents high values (120 lm/W at the current 350 mA) of luminous efficacy reached by the authors for white light emitting diodes (WLED). WLEDs of 1.1; 3.2 and 6.6 W are developed with luminous flux up to 500 lm containing a printed-circuit board with aluminum or copper base. Based on these WLEDs, light-emitting diode modules of linear and square configurations with luminous flux up to 1200 lm and luminous efficacy 85 lm/W are manufactured.

Keywords: white light emitting diode, spectrum, light-emitting diode module, correlated colour temperature, colour coordinates, radiation angle, luminous flux, luminous efficacy, luminous intensity, luminaire with light emitting diodes

1. INTRODUCTION

With WLEDs luminous efficacy increase, possibilities of their application in illumination (industry, office, street, architectural, household, etc.) is expanding.

Previously, WLEDs have been widely used in light-signal devices and local illumination [1–6]. In the present work (as a development of previous works [1, 3]), for lighting purposes WLEDs of 1.1; 3.2 and 6.6 W power (P_e) are developed. They have a new structure with printed-circuit board on aluminum or copper base.

2. EMITTING CRYSTAL AND LIGHT EMITTING DIODE STRUCTURE

Blue crystals of SEMILEDs and GREE companies (USA) manufactured on the basis of *p-n* heterostructures in *InGaAlN* system, were used. The crystals size were equal to 1.2×1.2 mm (at P_e = 1.1 and 3.2 W) and 1.52×1.52 mm (at P_e = 6.6 W). Flux of the crystals made 300–550 mW at a current of 350 mA (according to the supplier's data), and their peak wave length (λ_{max}) was within the interval of 455–460 nm. The crystals were mounted on a printed-circuit board. A special reflector containing a transparent polymer with relative refractive index of 1.53–1.54 covered with a phosphor, was located round the crystal, and the phosphor did not contact with the crystal. The reflector structure was optimized according to a minimum of radiation losses. Appearance of the WLED is presented in Fig. 1a.

3. PHOSPHOR

Phosphor versions were synthesized based on gallium aluminum garnets when replacing by mass up to 20 % of aluminum with gallium. To manufacture a WLED with correlated colour temperature T_{cc} ≈ 4500–6000 K, yttrium oxide was added in the phosphor, and to manufacture a WLED with T_{cc} ≈ 3000–3700 K, gadolinium oxide was added. Phosphor activation in the first case was carried out by cerium and dysprosium additions, and in the sec-

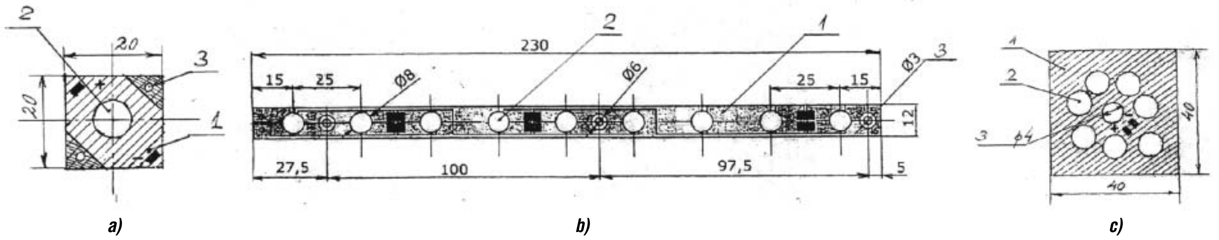

Fig. 1. Light emitting diode (a) and light-emitting diode modules of linear (b) and square (c) configuration: 1 – printed-circuit board, 2 – light-converting unit containing crystal/s, reflector and phosphor, 3 – openings for fixing on the radiator. (Products height is no more than 4 mm)

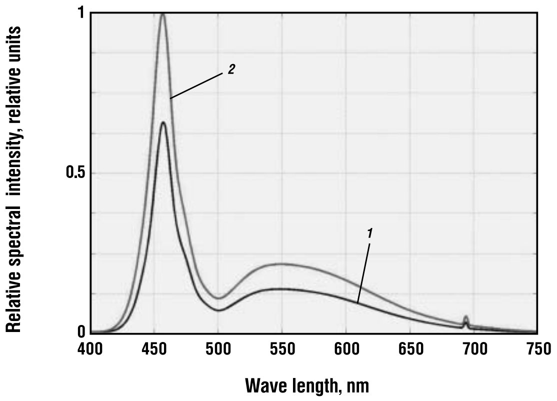

Fig. 2. Typical spectrum of light emitting diodes with correlated colour temperature of 4500 –6000 K at a forward current of 200 (1) and 350 (2) mA

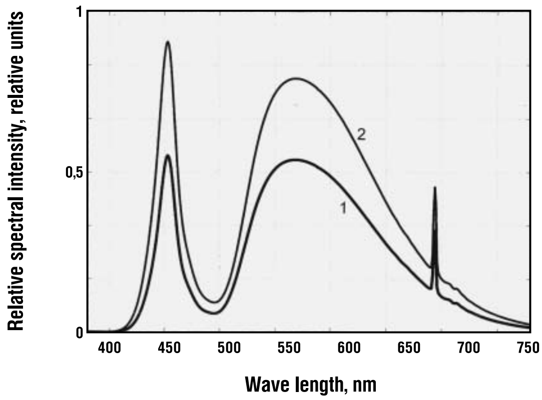

Fig. 3. Typical spectrum of light emitting diodes with correlated colour temperature of 3000–3700 K at a forward current of 200 (1) and 350 (2) mA

ond case – by cerium and praseodymium. Besides, a part of oxygen ions in the anion sublattice, was replaced with fluorine and nitrogen ions. Introduction of these activators raises the quantum efficiency of phosphor by 5 % – 7 %. These phosphors were named multi-ligand garnet phosphors [7].

Synthesis of the phosphors was made by the solid-phase sintering method in a controlled gas atmosphere (hydrogen, nitrogen, fluorides) during 10 hours at a temperature of more than 1500 º C. On the grains' surface, a thin phosphate film interfering agglomeration was formed. Average dispersity of the phosphor grains was 4–6 μ.

4. LIGHTING CHARACTERISTICS OF THE LIGHT EMITTING DIODES

A typical spectrum of the WLED with $T_{cc} \approx$ 4500–6000 K is given in Fig. 2. As can be seen from Fig. 2, λ_{max} is 550 nm and emission band half-width $\Delta\lambda$ is 130 nm. Such a wide emission band of the phosphor reduces the depth of the gap between the blue emission band of the crystal and emission band of the phosphor that promotes an increase of light efficacy and of colour rendition quality of the WLED.

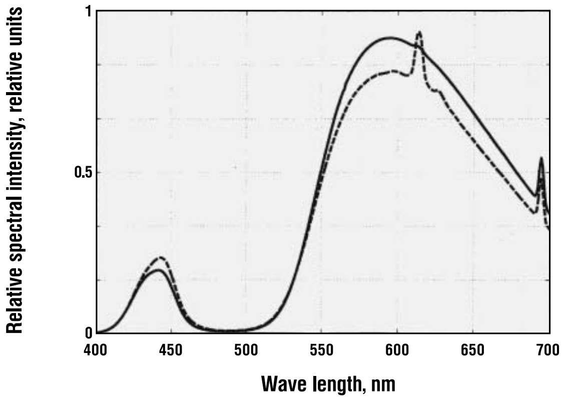

Fig. 4. Spectrum of a "hyperwarm" light emitting diode (with correlated colour temperature 2100 K). Continuous line and dotted line concern different phosphors

Colour coordinates of the WLED are as follows: x = 0.33–0.36, y = 0.34–0.38.

A typical spectrum of the WLED with $T_{cc} \approx$ 3000–3700 K (Fig. 3), is characterised by $\lambda_{max} \approx$ 570 nm and $\Delta\lambda \approx 130$ nm. Chromaticity coordinates of this WLED are: x = 0.43–0.45, y = 0.41–0.43.

We also obtained WLED samples with $T_{cc} \approx$ 2100, which $\lambda_{max} \approx 595$ nm, $\Delta\lambda \approx 139$ nm (Fig. 4) and light efficacy of 47 lm/W. Their chromaticity coordinates are: $x \approx 0.507$ and $y \approx 0.401$.

Table 1. Some lighting parameters of the developed white light emitting diodes

Type	Forward current I_f, mA	Power *Pe*, W	Luminous flux, Φ_v, lm	Axial luminous intensity, I_v, cd	Correlated colour temperature T_{cc}, K	Luminous efficacy, η_v, lm/W
У-130 Бл	350	1.1	100–125	35–40		100–120
У-133 Бл	350	3.2	280–320	80–100	4500–6000	80–100
У-137 Бл	700	6.6	450–510	140–160		68–77
У-130 Бл-Т	350	1.1	75–82	20–25	3000–3700	70

Note: Radiation angle of the light emitting diodes $2\ \theta_{0.5} \approx 120\ ^{o}$.

Table 2. Some lighting parameters of the developed light-emitting diode modules

Type	Forward current I_f, A	Forward voltage U_f, V, maximum	Power P_e, W	Luminous flux, Φ_v, lm	Correlated colour temperature T_{cc}, K	Luminous efficacy, η_v, lm/W .
СЛН-Бл3	1.0	12,0	12.0	800 ± 50	4500–6000	70
МСО-18 Бл	0,35	24.0	8.0	675 ± 25	4500–6000	85
МСО-18 Бл-Т	0.35	24.0	8.0	500 ± 25	3000–3700	60
МСО-21 Бл	0.7	24.0	16.0	1200 ± 100	4500–6000	75
МСО-21 Бл-Т	0,7	24.0	16.0	900 ± 50	3000–3700	60

Note: Radiation angle $2\ \theta_{0.5} = (120 \pm 10)^{o}$.

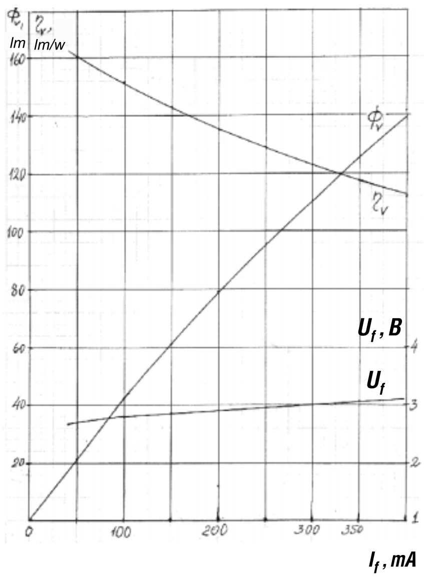

Fig. 5. Luminous flux Φ_v, light efficacy η_v and direct voltage U_f of У-130 Бл type light emitting diode dependences on the light emitting diode forward current I_f

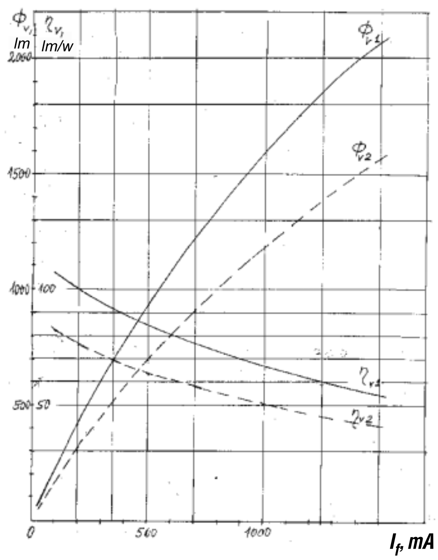

Fig. 6. Luminous flux Φ_v, light efficacy η_v and direct voltage U_f of light-emitting diode modules (LEDM) on the LEDM forward current I_f. 1 – LEDM of МСО-21 Бл type; 2 – LEDM of МСО-21 Бл-Т type

Flux measurements of the WLEDs were performed by means of an integrating sphere of 30 cm sphere diameter, a radiometric head of the All-Russian Scientific Research Institute of optical-and-physical measurements (VNIIOFI FSUE) production and by means of a standard WLED (calibration test certificate of the VNIIOFI FSUE).

As can be seen from Table 1, luminous flux and light efficacy of the developed WLEDs of У-130 Бл, У-133 Бл ($T_{cc} \approx$ 4500–6000) K and У-130 Бл-Т ($T_{cc} \approx$ 3000–3700 K) types are at an up-to-date technological level.

Luminous efficacy of the У-130 Бл and У-133 Бл WLED types at small currents (50–100 mA), reaches 150–160 (Fig. 5) and 125–135 lm/W accordingly.

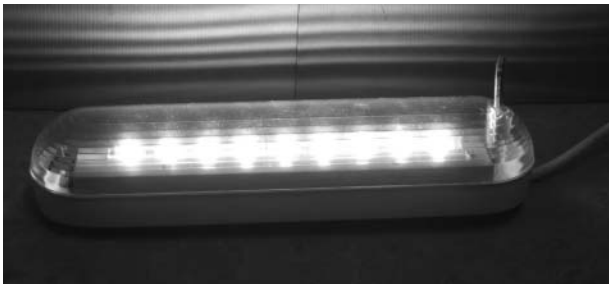

Fig. 7. OPTEL-05 luminaire

5. LIGHTING PRODUCTS WITH LIGHT EMITTING DIODES

We have developed light-emitting diode modules (LEDM) of linear, СЛН-Бл3 type (Fig. 1 b) and square, МСО-18 Бл and МСО-21 Бл types (Fig. 1 c) configurations (Table 2).

A linear LEDM contains 9 WLEDs being close to the У-130 Бл type WLED connected in series-parallel, and current-limiting resistors.

A square LEDM is manufactured using a printed-circuit board with aluminum base and contain 7 WLEDs being close to the У-130 Бл type WLED connected in series. WLEDs used in the МСО-21 type LEDMs (Fig. 6), contain a crystal of increased size (1,52×1,52 mm).

An example of the specified above LEDMs use, can be the OPTEL-0.5 luminaire with linear LEDM of СЛН-Бл3 type containing radiator, secondary power supply unit (ballast), case, diffuser, etc. (Fig. 7). At a power of 10 W and mains voltage of 220 V, the luminaire luminous flux makes 750 lm.

CONCLUSION

High levels of WLEDs luminous flux reached by the authors at a high luminous efficacy, as well as high values of luminous flux for the LEDMs (“linears” and “squares”) constructed based on these WLEDs, allow expecting their wide applicability in lighting devices.

The authors thank Mr. I.T. Rassokhin for his creative participation and big help in the work.

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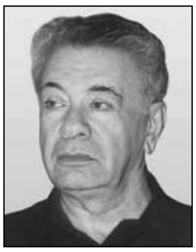

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Light & Engineering
Vol. 19, No. 3, pp. 16-17, 2011

Svetotekhnika
No. 3, 2011, pp. 48-57

ON THE INABILITY OF OPTICAL RADIATION RECEPTION BY RETINAL GANGLIONIC CELLS

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ABSTRACT

Arguments are given on the inability of retinal ganglionic cells to act as receivers of optical radiation. It is shown that control of circadian recurrence of an organism only occurs with the participation of cones and rods; the "traditional" photoreceptors.

Keywords: ganglionic cells, melanopsin, rods, cones, depolarization of cellular membranes.

When considering results of some experiments connected with the discovery of previously unknown photoreceptors in the eye's retina, the photosensitive retinal ganglionic cells (J. Brainard etc.), some questions arise which prevent the author from agreeing with the statement that these cells have an ability to receive optical radiation and accomplish the role of photoreceptors in the control path of the circadian rhythms of an organism.

At the same time, some important propositions should be mentioned which were not taken into consideration by the authors of the "discovery" but have the potential radically impact the interpretation of the possible role of separate retinal elements in the hypothalamus and epiphysis control during a day.

Control of the neuroendocrinal system and its synchronisation by optical radiation are only possible at big radiances of the visual field. In this case a statistical averaging of radiation characteristics and use of integral energy and luminous values for its description is possible. And spatial-temporal flux distribution in this case completely corresponds to the spatial configuration, time mode and radiation spectral composition of the objects located in the visual field.

From this point of view, function configuration representing the envelope of spatial and other radiation characteristics, at the macroscopic level comprises all information on spatial characteristics, time mode, radiation spectral composition and its energy characteristics. This envelope is some kind of analogous representation of the characteristics of emitting objects and can be presented as a scalar continual function of spatial coordinates and time. Accordingly, such an envelope is an analogue to the signal containing full information on radiation characteristics of the objects in the visual field. (Forthwith "analog signals", "analog signal processing" etc. are exclusively considered in this sense.)

An organism cells can be conditionally divided into two categories by principle of their functioning and, in particular, by nature of cellular membranes depolarisation. The cells, in which functioning at analog nature of external effect, a reversible analog depolarisation of their membranes occurs, fall into the first category. In respect to photosensitive cells, reversible variations of depolarization degree of their membranes occur in response to variations of spatial-temporal and energy radiation characteristics. As it is known, this response type is provided in receptor cells of all sensory systems, including retinal "traditional" photodetectors (cones and rods), as well as horizontal and bipolar cells.

The functional purpose of the second category of cells consists in the reception, processing and generation of binary signals as packs of electro-chemical pulse signals. In cells of this type, a response to input action being electrochemical pulses, is the step-wise depolarisation of their membranes and generation of pulse electrochemical signal packs of a constant amplitude and variable on-off time ratio resembling pulse-frequency modulation (binary type of cell functioning).

Overwhelmingly most of the brain cells and retinal ganglionic cells (this fact is especially important here), fall into the binary type functioning cells.

In a retina, code conversion of analog signals to binary ones occurs in cells triads being a part of bipolar, amacrinal and ganglionic cells. Input elements of these triads being some kind of analog-digital converters, are bipolar cells with analog type of signal processing, and output elements are ganglionic cells with input and output signals of binary type. Axons of ganglionic cells forming visual nerves, transmit binary signals into visual cortical areas and into areas responsible for control of vegetative functions, including circadian rhythmics of an organism.

The most important thing is that a cell is able to receive optical radiation, if two following indispensable conditions are accomplished:

• Obvious availability in the cell of a substance sensitive to optical radiation. It is known from general biology that proteins act as such a substances in cells. When exposing optical radiation on proteins containing in cell cytoplasm, the proteins are subject to reversible denaturation at the levels of their secondary and/or tertiary structure. The specified condition comes true for any proteins of any cell cytoplasm (as a rule, this takes place at radiation in 250–350 nm spectral interval approximately). Rhodopsin and iodopsin being sensitive to visible spectrum area, are the only exceptions.

• Possibility of direct photodetection of analog signals and selection of their envelope containing information on analog characteristics of the influencing radiation. Cells with cytoplasm containing photosensitive proteins are able to give an analog response as a reversible analog depolarisation of cellular membranes on spatial-temporal and energy characterisics of external exposures. The degree of analog depolarisation of cellular membranes is connected with the energy of exposing optical radiation by means of a continuous function with upwards convex. Due to specifics of functional purpose of cells and intercellular interaction in a retina, cells performing analog conversion of signals, that is rods, cones, horizontal and bipolar cells, can only give such a reaction to external exposures.

Thus the statement[1] only corresponds to the first of these indispensable conditions. Obvious non-compliance with the second condition doesn't allow for considering reception of optical radiation by ganglionic cells to be possible – because of their functional features connected with reception, processing and generation of binary type signals. This type of functioning ganglionic cells in essence cannot ensure ananalog type of reception, processing and generation of signals even if there are photosensitive proteins in the cytoplasm of the cells.

As to melanopsin, firstly, in the experimental research on the basis of which the statement about existence of photosensitive ganglionic cells is formulated, there is no direct evidence of melanopsin sensitivity in short-wave area of visible interval with a maximum near 440–460 nm, and secondly, availability of melanopsin in some ganglionic and other retinal cells, which are a part of the control path of circadian rhythmics of an organism, is natural, because this type of protein is produced by epiphysis and can be considered to be some kind of a marker confirming that the cells belong to the path controlling epiphysis activity.

The reasons described above allow us to assuming the participation of groups of the well-known ("traditional") photoreceptors sensitive in blue-green spectrum area and localised in the retinal peripheral part as an initial link of the neuroendocrinal system control path.

According to the above, conclusions can be drawn as follows:

1. There are not currently sufficient reasons for agreeing with the concept presented by J. Brainard about the reception of analog optical radiation by retinal ganglionic cells, only processing binary signals and being associative transmitting links in the regulation path of neuroendocrinal system activity and of circadian rhythms of an organism.

2. One should search optical radiation primary receivers controlling neuroendocrinal processes of a human body, in a group of retinal cells being sensitive in blue-green spectrum area, performing exclusively signal analog conversion and localised in a retinal peripheral part.

3. The question about morpho-functional structure of the photoreception link of neural path controlling circadian rhythms of an organism, remains open and needs further research.

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[1] «Melanopsin is the molecule that transduces light signals in intrinsically photoreceptive retinal ganglion cells »

Light & Engineering
Vol. 19, No. 3, pp. 18-33, 2011

Svetotekhnika
No. 3, 2011, pp. 48-57

IMPACT OF LIGHTING RENOVATION ON ENERGY CONSUMPTION AND VISUAL COMFORT: A CASE STUDY IN SOCIAL DWELLINGS

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ABSTRACT

The use of energy efficient lighting in dwellings in combination with the preservation, or the improvement of visual comfort is a huge challenge.

This paper presents a lighting renovation project in eight social apartments, in Belgium. The lighting system was renovated at four levels of quality, in order to evaluate the light saving potential, the lighting comfort and the influence of the human behaviour on the lighting consumption.

The methodology dealt with the criteria and targets of the lighting renovation, the way to record monitoring data and the concept of the extrapolation of consumption. This extrapolation presented a way to obtain more case studies without knowing the occupancy schedule of the occupants.

Illuminance, power, luminance, UGR values reached for the different lighting solutions were determined. The measurements showed that if the occupant selected his lighting installation, the comfort is seldom reached. Replacing initial lamps (incandescent) by high efficient compact fluorescent lamps induced high energy savings and comfort level was reached more often. The visual comfort (higher illuminance level) could even be improved by the use of efficient luminaires.

Finally, the paper concludes that, the human behaviour has a large influence on the lighting installation and consumption. Moreover, occupants tended to install the worst lighting equipment (high power level, low visual comfort). However efficient luminaires are not widespread on the domestic lighting market. On the other hand, the extrapolation allowed concluding that for some behaviour profiles there were no economic gains from the use of economic lamps and efficient luminaires. With this study, we point to the importance of evaluating correctly the needs of the occupants in terms of visual comfort and to install adequate energy saving lamps and luminaires.

Keywords: lighting, dwelling, visual comfort, extrapolation

1. INTRODUCTION

The residential sector represents about 40 % of total energy consumption in Belgium. Strong policies based on the tightening of energy performance legislation and on incentive, combined with a collective awareness of climatic issues and rising energy costs, have pushed Belgian owners to renovate their buildings in order to decrease their energy demand or to newly build low-energy buildings.

However, while important technological progress in the development of lamps, luminaires and control systems has been realised, the share of lighting in the total energy consumption of a building remains high (6 to 18 % in Europe [1]).

Due to the improvement of thermal insulation in dwellings, the proportion of lighting energy consumption in the total energy consumption of dwellings is even increasing.

It seems that the technological progress realised especially for lighting in the tertiary sector has been poorly (or not at all) exported to the residential sector.


Fig. 1. View of the apartment buildings before (left) and after (right) renovation

In this context, the government decided to fund a project with the objective to study which developed technologies could be appropriate for the residential sector and which were the barriers to use these technologies.

The objectives of the ECLOS projects were the reduction of lighting consumption in dwellings, while maintaining or improving the visual comfort. The work consisted of laboratory measurements combined with monitoring activities in a lighting renovation project. The deliverables of the project were the establishment of energy efficiency criteria for residential lighting, the evaluation of possible energy savings in dwellings, according to the renovation process, and the editing of three guides.

2. MATERIALS AND METHODS

2.1. Lighting renovation

2.1.1. Selection of the dwellings

The different lighting solutions were applied in the apartments of a large social housing complex, simultaneously to a complete renovation programme; the buildings were thermally insulated, single pane windows were replaced by double glass windows and the interior and exterior finishes were renewed. Inhabitants moved from their old apartment to another, renovated apartment located in the same complex but in another building.

The Fig. 1 shows a view of the apartment building before and after the renovation.

8 apartments were selected in order to renovate the lighting system at four levels of quality. We coupled the apartment by two. The lighting renovation quality levels were the following:

Type 1: Reference case – lighting installation chosen by the inhabitants (apartment 1 A and 1 B).

Type 2: Luminaires freely chosen by the inhabitants. Once installed, the lamps were replaced by energy efficient lamps (CFL) (apartment 2 A and 2 B).

Type 3: Installation of an efficient lighting installation, at the lighting points positions fixed by the social housing agency (apartment 3 A and 3 B).

Type 4: Installation of an efficient lighting installation, choosing the best position for each lighting point and trying to create specific lighting ambiences (apartment 4 A and 4 B).

2.1.2. Criteria for the choice of lamps and luminaires

Step 1 – Selection of appropriate lamps and luminaires

The first step of the project was an extensive study of available lamps and luminaires.

For the lamps, the studied characteristics were the start-up time, the colour and colour rendering, the shape and the bases.

For luminaires, the priority was to find aesthetic luminaires for fluorescent or compact fluorescent lamps, equipped with separate, (if possible) electronic, ballasts. Cost aspects were considered in type 3 and 4 solutions. In one case, the lighting retrofitting was executed with low-cost residential luminaries (case A) and in the other case, industrial lighting systems having some aesthetic qualities were used (case B).

Step 2 – Target illuminance values

As there is no European standard for visual comfort with residential lighting installations, minimal average illuminance values were fixed at, in general, 50 % of the values recommended for rooms similar

Fig. 2 a. Map and lighting installation in apartments 1 a and 1 b

use in the European EN 12464–1 standard dedicated to interior working places [2]. These values also match the values recommended for dwellings by the IESNA [3].

The goal values were: 500 lx for the working plane in the kitchen and 300 lx for the rest of the room, 150 lx in the living room and 100 lx in bedrooms.

Step 3 – Simulations

DIALux simulations were then realised in order to determine the suitable lamp powers and the locations of the luminaires. For luminaires developed for application in the residential sector, photometric data are often not available. In that case, photometric data were based on similar industrial luminaires.

Step 4 – Choice of lamps and luminaires with the inhabitants

For apartments of the type 1, the traditional lighting system provided by the social housing agency in the renovated apartments consists of one light point in the middle of the ceiling in the bedrooms, two light points in the living rooms (with separate supplies) and three light points in the kitchen (two light points on the ceiling and one 36 W T8 lamp above the cooking plane). In the bathrooms, one central ceiling light point (20 W CFL downlight) and one lamp above the mirror (14 W TL) are installed. One light point is placed in the entrance hall and two light points in the corridors. All lighting points were equipped by a nude 40 W incandescent lamp, except for the bathroom and the TL above the sink in the kitchen.

For the type 2, we changed the traditional bulbs by efficiency bulbs in the luminaires, installed by the inhabitants.

For the type 3 and 4 apartments, based on the results of the above simulations, several luminaires were proposed to the inhabitants for each room. The chosen luminaires were then installed before their moving to their apartment.

2.1.3. Installed lighting systems.

The following paragraphs describe the different lighting systems chosen by the inhabitants and/or the researchers, for kitchen and living rooms.

Type 1 apartments

The type 1 apartments were reference cases; the lighting systems were freely chosen and installed by the inhabitants.

In apartment 1 A (Fig. 2 a), the living room is lit by seven halogen spotlamps and the kitchen is lit by an incandescent lamp alone (no luminaire) combined with the fluorescent lamp above the sink.

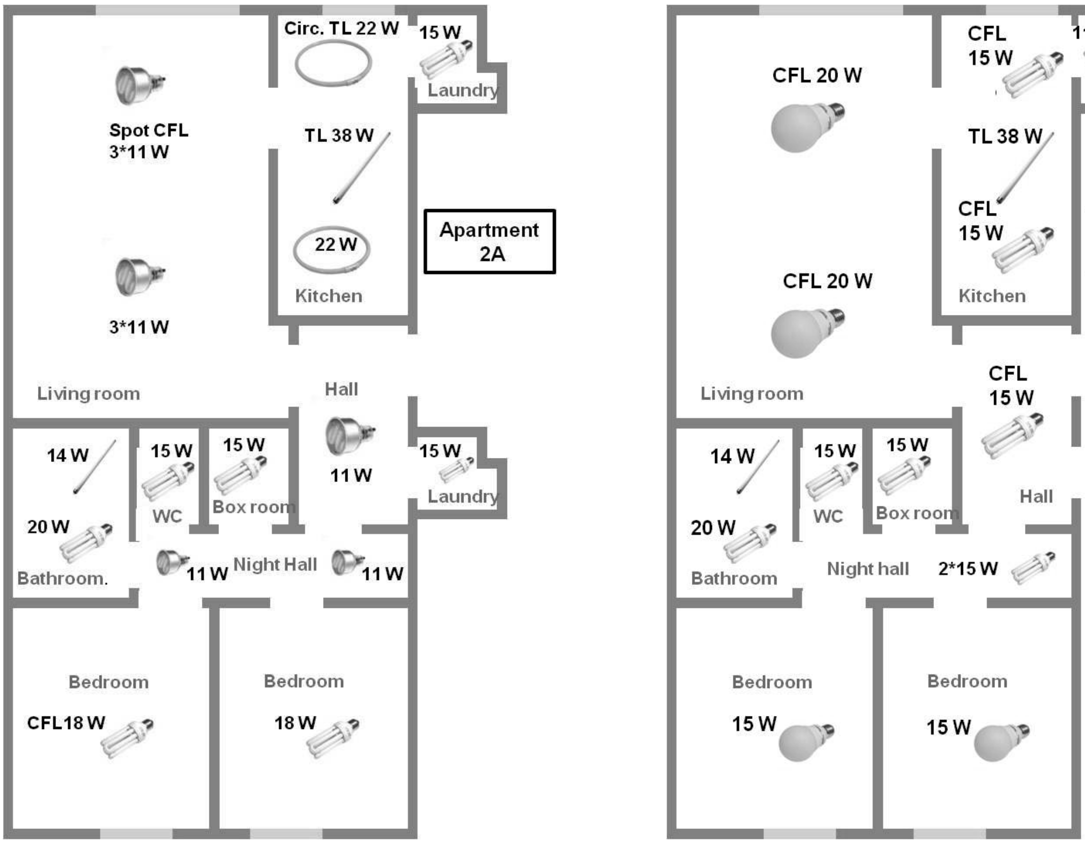

Fig. 2 b. Map and lighting installation in apartments 2 a and 2 b

In apartment 1 B, the living room is lit by two chandeliers equipped with incandescent lamps, seldom used, and two portable indirect halogen torchieres of 500 W and 300 W usually used as general lighting. The total installed lighting power is very high, mainly due to these two halogen lamps. The kitchen is lit by two incandescent spotlight combined with a fluorescent linear tube above the sink.

Type 2 apartments

In type 2 apartments, the easiest relighting solution was applied; the lamps chosen by the inhabitants were replaced by low energy lamps, placed in the same luminaires.

In apartment 2 A (Fig. 2 b), the initial installed lighting power was about 300 W in the living room and 120 W in the kitchen. After replacement, the power was reduced to 66 W and 82 W, respectively, without loss of light flux. In the living room, the six halogen spots were replaced by six compact fluorescent lamps of 11 W each. These lamps were the most powerful compact fluorescent spots available at that time. In the kitchen, luminaries were equipped with circline T5 fluoresecnt lamps.

In apartment 2 B, lamps initially chosen by the inhabitant were compact fluorescent lamps (CFL), except for the hood lamps. However, some of the lamps were old generation CFL, with a long warm-up time and important colour shift during the warm-up time. All the lamps were replaced by new CFL lamps [4]. The total installed power did not decrease in the living room but well in the kitchen; initial value of 114 W decreased to 68 W. The total lighting installed power is comparable in both dwellings (311 W and 258 W) and very low.

Type 3 Apartments

In type 3 apartments, low energy luminaires were installed at the position fixed by the social housing agency.

Apartment 3 A (Fig. 2 c) was equipped with low-cost domestic luminaires, except in the living room, for which all the low-cost luminaires where rejected by the inhabitant for aesthetic reasons. The living room was lit by two ceiling surface mounted luminaires of 40 W each, equipped with circline fluorescent tubes. The general kitchen lighting consisted of two luminaires each equipped with two

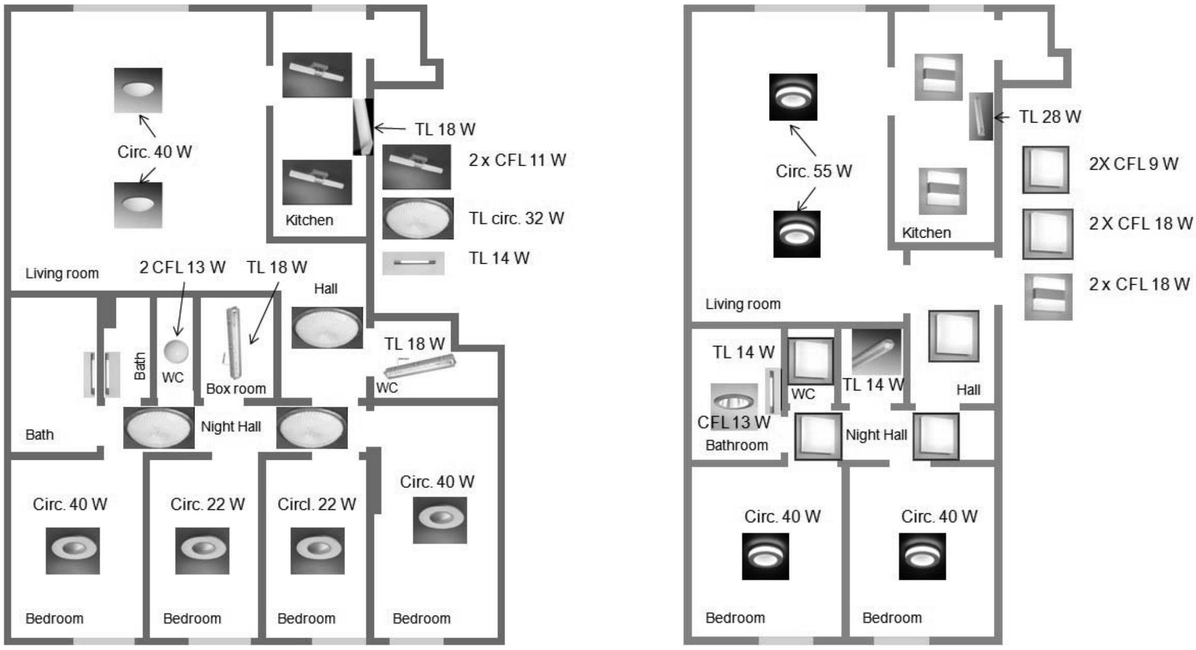

Fig. 2 c. Map and lighting installation in apartments 3 a (left) and 3 b (right)

compact fluorescent lamps of 11 W. The working plane was lit by an 18 W TL wall surface mounted luminaire.

Apartment 3 B is equipped with industrial and more expensive luminaires. The living room was lit by two ceiling surface mounted luminaires equipped with a 55 W circline fluorescent tube each. The kitchen lighting system consisted of two 36 W ceiling surface mounted luminaires combined with a 28 W TL luminaire placed above the sink.

Type 4 Apartments

In type 4 apartments, the lighting and management systems were totally renovated, in order to show that it is possible to create an attractive luminous ambience without deteriorating the energy efficiency or the comfort.

In apartment 4 A (Fig. 2 d), the living room was equipped with five recessed CFL downlight luminaires of 18 W each, combined with two 16 W wall mounted luminaires. The two systems could be switched on and off separately. In the kitchen the lighting system consisted of a combination of indirect fluorescent lighting located above the kitchen cupboard and fluorescent direct lighting above the sink (under the cupboard).

In apartment 4 B, the living room was lit by a combination of an indirect fluorescent lighting band and two CFL recessed downlight luminaires of 13 W each, having an asymmetric light distribution (wall washer). In the kitchen, the working plane was lit by four flat CFL luminaires of 7 W each, mounted below the cupboard, combined with a fluorescent ceiling mounted luminaire of 35 W.

2.2. Illuminance, luminance and UGR measurements

Once the lighting renovation programme was complete, illuminance and luminance were measured in type 3 and 4 apartments, at night and without furniture in the rooms. Luminance and illuminance values obtained in apartments 1 and 2 were measured after about 10 months of occupancy, at night but with furniture in the rooms.

Luminance values were measured by the High Dynamic Range (HDR) imaging method [6].

Views were taken at night with a calibrated CANON EOS 40 D digital camera equipped with a Sigma 4.5 mm F2.8 EX DC Circular Fisheye and combined with the PHOTOLUX software [5]. The fisheye center position was fixed at 1.2 m height, according to the EN 12464–1 Standard 2. The obtained UGR values are compared to a maximal acceptable value of 25 as imposed in EN 12464–1 for corridors in hotels and restaurants [2]. Pictures were taken perpendicularly to the window façade, in both directions, in living rooms. Two values of average luminance are thus given as well as the two UGR values related to these two directions. In kitchens, luminance views were taken from the entrance door.

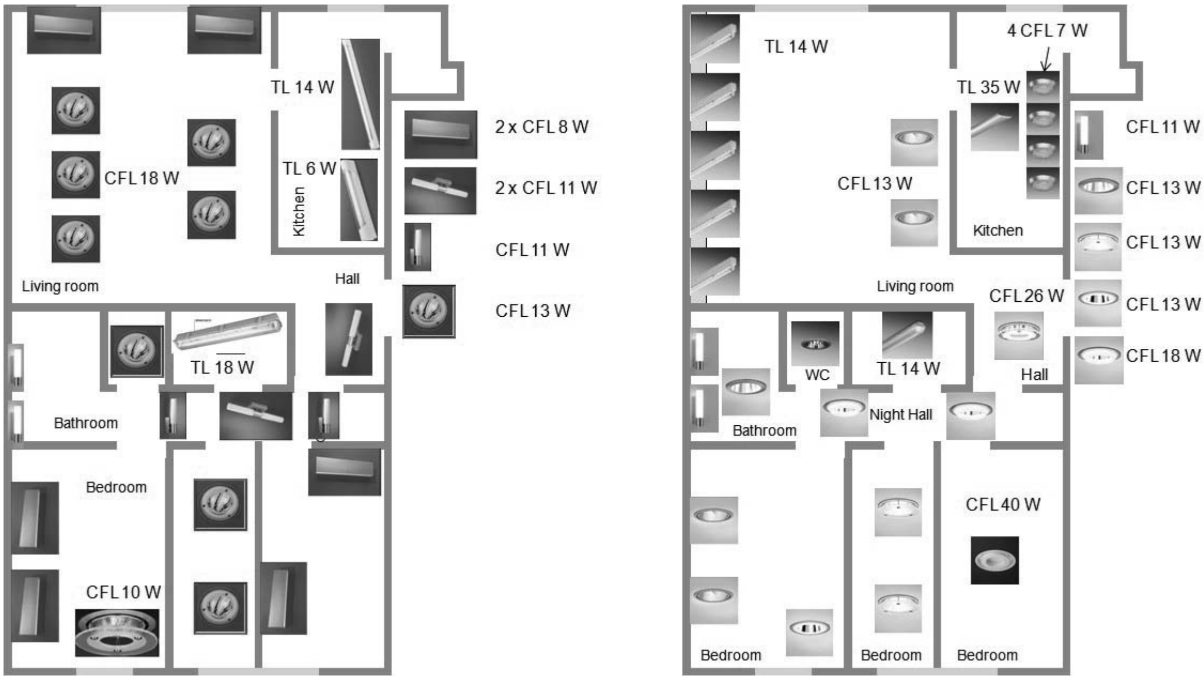

Fig. 2 d. Map and lighting installation in apartments 4 a (left) and 4 b (right)

2.3. Satisfaction study

At the beginning and the end of the project a meeting with the participant was organised. During these visits, the economic impact of the project on their economies was shown and the lighting comfort and quality were discussed.

2.4. Monitoring and extrapolation

In order to get information on the user behaviour and precise values of energy use, an advanced acquisition system was installed providing detailed data via a peer-to-peer communication network. The on/off status of each luminaire, as well as the apartment lighting consumption and the total electricity consumption were recorded with a time step of 1 minute during more than one year.

2.4.1. The concept of the extrapolation

By the monitoring, we got the opportunity to determine consumption profiles to analyse more different cases. For this goal, we used the information about the behaviour of the occupants (from the monitoring data) to predict others consumptions profiles. In this way, we could analyse how the behaviour impacts on the choice of the different renovated lighting solution and detect which lighting was the most beneficial.

First, using the monitoring data, a user profile for the occupants of each apartment (α, β, …) was determined. By combining the user profile and the different lighting solutions (characterised by the power installed in each flat) we could simulate fictitious lighting consumption patterns for a certain occupant using a certain lighting installation. For example, if we combine user behaviour α (of apartment A) with the lighting solution installed in apartment B, we get a new, "fictitious", consumption.

User profile : $\alpha, \beta, \chi, \delta, \ldots\times$
× Lighting solution : A, B, C, D, …=
= Fictitious consumption

Before starting this extrapolation between each user profile and each lighting solution, we needed to make some assumptions.

2.4.2. First assumption

Some apartments have more rooms than others. This means that, a user in his initial apartment may have more rooms than rooms available in another solution (which corresponds to another apartment and another user). So, we do not know the installed power of some rooms in the substituted solution when there are fewer rooms than in the initial one.

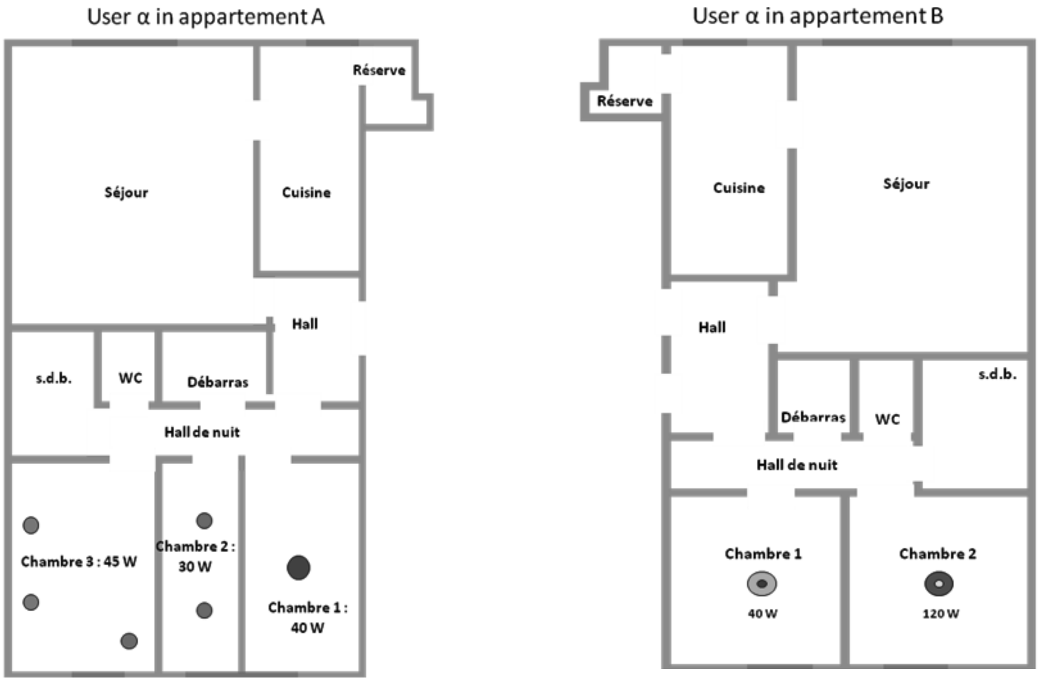

Fig. 3. Power installed in the bedrooms of the apartment A and B

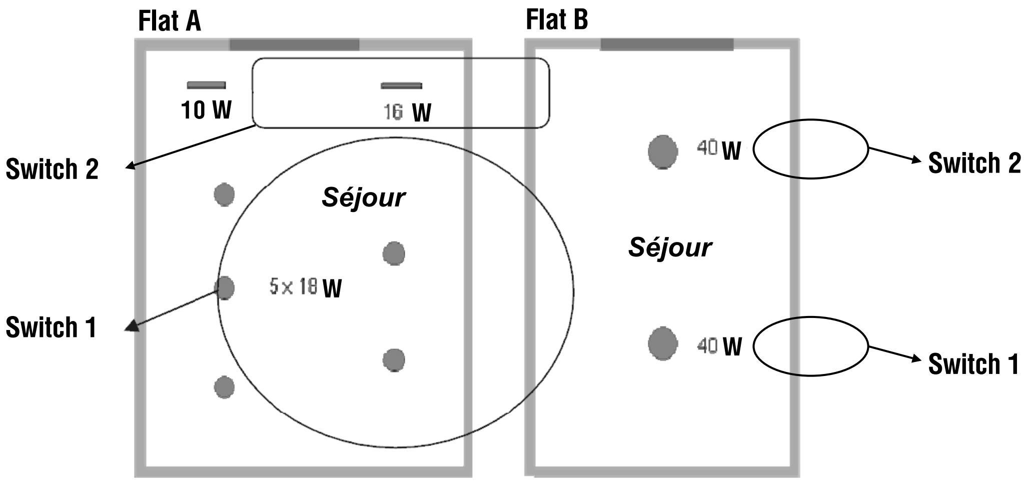

Fig. 4. Illustration of the luminaries connected to the both swith control in the apartment A and B

For example, in Fig. 3 we observe the user α in the apartment A and the same user α in the apartment B. The user α in the apartment A has 3 bedrooms, but if we want to apply the lighting solution of apartment B, we only have the installed power of two rooms. To resolve this problem, we imagine a third "fictitious" room in the apartment B.

In order to determine the power installed in this fictive room of apartment B, we compared the installed power in the bedrooms of the apartment A and then we applied the same relation between the rooms in the fictitious solution.

In the example, for the user profile α in the apartment A, the third room (45 W) does not exist in the solution corresponding to apartment B.

We see that in apartment A the installed power of bedroom 3 is the closest to the installed power of bedroom 1 (40 W). Therefore, when we apply the solution of apartment B to the user a, we consider the lighting power in the fictitious bedroom 3 to be the same of the power in bedroom 1. The user α in the flat B has an installed power of the third fictitious bedroom of 40 W.

In order to do the extrapolation, we applied this relation for each user profile in each configuration.

2.4.3. SECOND ASSUMPTION

There were two switches in the living room, each controlling a different luminaire with different functionality. However, the behaviour of the occupants was strongly dependent on the functionality and the placement of each luminaire.

For example, as illustrated in the Fig. 4, in apartment A there are 5 direct luminaries connected to the first switch and two indirect luminaries connected to a second switch. In apartment B, two direct luminaries are installed, each one connected to a separate switch.

The question was: how to predict the behaviour of the user a of apartment A when he is confronted with the lighting solution of apartment B?

To model this, we analysed the results of the monitoring in order to know which switch (and thus which type of lighting) was used as primary lighting, and which one as a supplementary solution. The user's choice for one or another could depend on many things, for example: does the user like direct or indirect lighting, are most of the user's activities under one lamp rather than another (for example, a dining table). We attempted to understand the behaviour of the user and extrapolated this behaviour to the other lighting solutions.

On a side note, it should also be mentioned that the chandeliers (indirect halogen torchieres) of user f were considered to be part of the user behaviour and not of the lighting solution. This means that the power (and the consumption) of the chandeliers, move with the user along the different lighting solutions.

In the example, user α of apartment A rarely used the indirect lighting, which could therefore be considered as being used for aesthetic reasons. When confronted by the solution of apartment B, this user will probably like the total installed power of direct lighting and might be happy to take his aesthetic and seldom used indirect luminaries with him, to create a certain atmosphere at certain times. We considered therefore the total power of the direct luminaries (80 W) to be connected to switch 1 and the indirect lighting (32 W, corresponding to his own flat), to be connected to switch 2. When user b of apartment B would be confronted to the solution of apartment A, we did not know how he would react to the indirect lighting as he only had direct lighting in his own apartment. Therefore we split the total installed power of the direct luminaries over the two switches and considered the indirect lighting not to be installed. The following Tables 1 and 2 presents the installed power in the living room for user α and β in the flat A and B.

Table 1. Consumption of user α

	Time of use switch 1	Time of use switch 2	Consumption
User α in flat A	x hours	y hours	x*90 W + y *32 W
User α in flat B	x hours	y hours	x*80 W + y *32 W

Table 2. Consumption of user β

	Time of use switch 1	Time of use switch 2	Consumption
User β in flat B	e hours	f hours	e*40 W + f *40 W
User β in flat A	e hours	f hours	e*45 W + f *45 W

2.4.4. Extension

Two extra lighting solutions were added to the simulation sample. The first two lighting solutions (1 A and 1 B) were not energy-efficient (lighting system chosen by the inhabitants). Therefore, to determine how much energy people really could save, starting from a realistic basic situation, two extra solutions could be the corresponding re-lamping (meaning that for each lamp in solution 1 A or 1 B an energy efficient alternative is applied) of these apartments. We also added a 'starting' case, where every lighting point is provided with a 60 W lamp.

The different lighting configurations used in the extrapolation are summarised in Table 3.

3. RESULTS

3.1. The lighting installation

The illuminance value

Once the lighting renovation programme was complete, illuminance values were measured in the apartments.

The average illuminances for the different local in the eight apartments are drawn in Fig. 5.

For apartments 1 A and 1 B, in the living room, we do not have the correct value of the illuminance

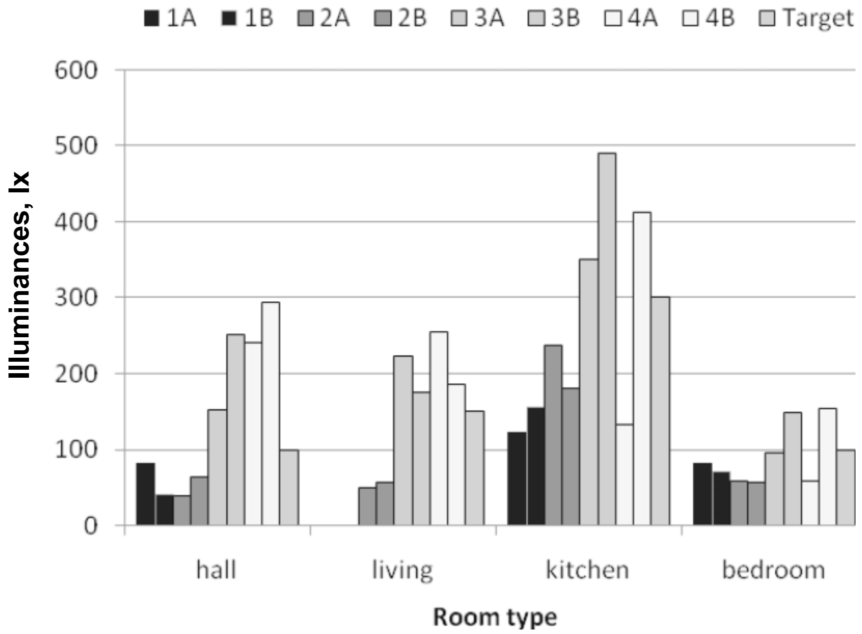

Fig. 5. Measured average illuminance values in the living rooms and in the kitchens

Table 3. The different lighting configurations

	Solution type
0 A	Every lighting point is provided with a 60 W lamp
1 A	Lighting system chosen by the inhabitants
1 B	
2 A	Luminaires freely chosen by the inhabitants. Once installed, the lamps were replaced by energy efficient lamps (CFL).
2 B	
2 C	Relamping of 1 A
2 D	Relamping of 1 B
3 A	Installation of efficient lighting systems, at the position fixed by the social housing agency
3 B	
4 A	Installation of high efficient lighting systems, choosing the best position for each case and trying to create specific lighting ambiences.
4 B	

level because when measurements were taken luminaires were not functional, so we do not display it on the graph above.

It was observed that in apartments 1 A and 1 B, the illuminance values are all below the goals.

In apartment 2 A, measurements show that the obtained average illuminance in the living room is very low, 49 lx, and far below the goal value of 150 lx. In the kitchen, the general illuminance, 237 lx, is slightly below the goal value of 300 lx. In apartment 2 B, the achieved illuminance, 57 lx, in the living room is far below the goal value. The illuminance values obtained in the kitchen, 181 lx, are still below the goal value but the result is better than in the living room. In apartment 3 A and 3 B, mainly average illuminance values are above the goal values. The illuminance goal value of 150 lx is reached in the living room (223 lx and 176 lx, respectively) and in the kitchen, measured illuminance are far above the goal value of 500 lx (351 lx and 490 lx, respectively). In apartment 4 A, illuminances are too low in the kitchen and the bedroom and above the target in the living room and the hall. In the living room, the average illuminance is high (254 lx) and inhabitants report that they seldom use the two lighting system together. In the kitchen, the illuminance obtained is too low, 133 lx and below the target value of 300 lx. In apartment 4 B, the obtained illuminance values are all above the goal value.

The obtained power installed and efficiency

The total installed power in the dwellings is given in Table 4.

Table 4. Total installed power for all apartments

1 A	1 B	2 A	2 B	3 A	3 B	4 A	4 B
1156 W	1572 W	311 W	258 W	452 W	421 W	379 W	385 W

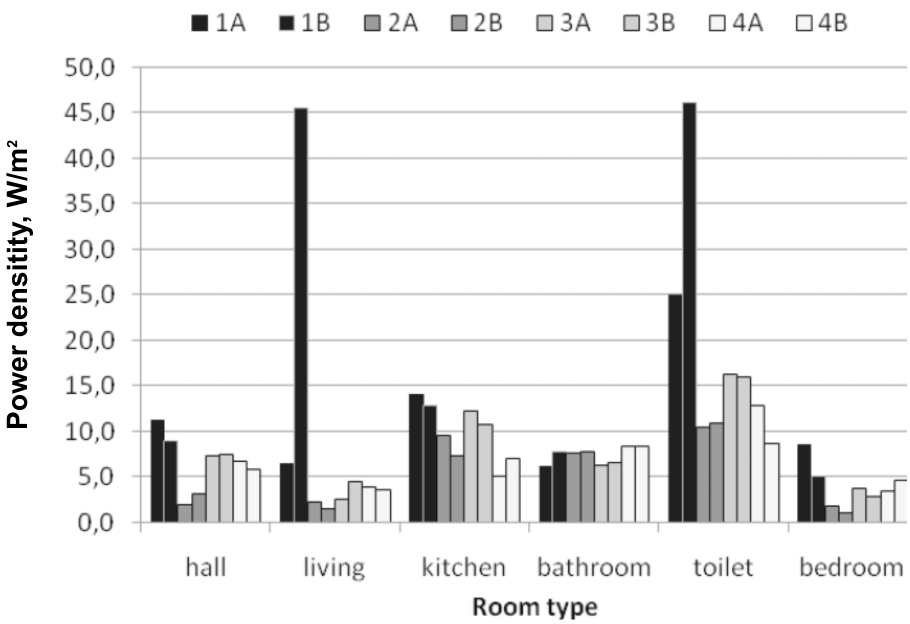

Fig. 6. Power density (W/m²) in the eight apartments

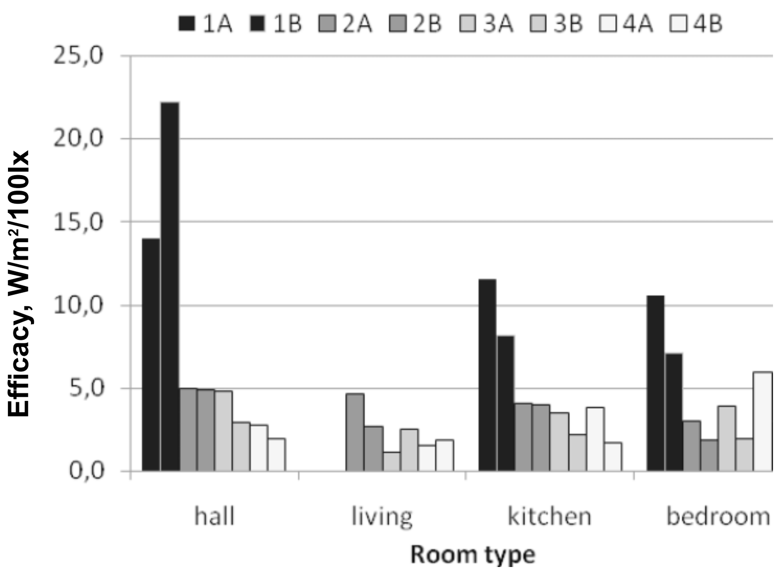

Fig. 7. Installed power/m² for 100 lx in the height apartments

The installed power of the apartments 1 A and 1 B, is 1156 W and 1572 W, respectively. The lighting power equipment of apartments of type 1 is generally higher than for the other solutions.

If all the installed lamps are replaced by CFL, the installed power is, on the contrary low, 311 W and 258 W for apartment 2 A and 2 B. Finally, installed lighting powers are comparable for type 3 and 4 (between 379 W and 452 W) and generally higher than in type 2 solutions.

Fig. 6 presents the specific installed power per m² for several rooms in the eight apartments.

Solution of type 1 presents higher power density levels for all locations, with in the worst case 45 W/m² in the living room and in the toilet. Solution 2 presents better results than in solution 3 and 4, especially for the hall, the living room and the bedrooms (between 1 and 3 W/m²). In general, the living room (less than 5 W/m²) has a better power density than the kitchen (less than 10 W/m²). The bathroom results are similar in the four cases (around 7.3 W/m²).

However, Table 4 and Fig. 6 only give information on the total lighting power and power density by local but not on the obtained illuminances.

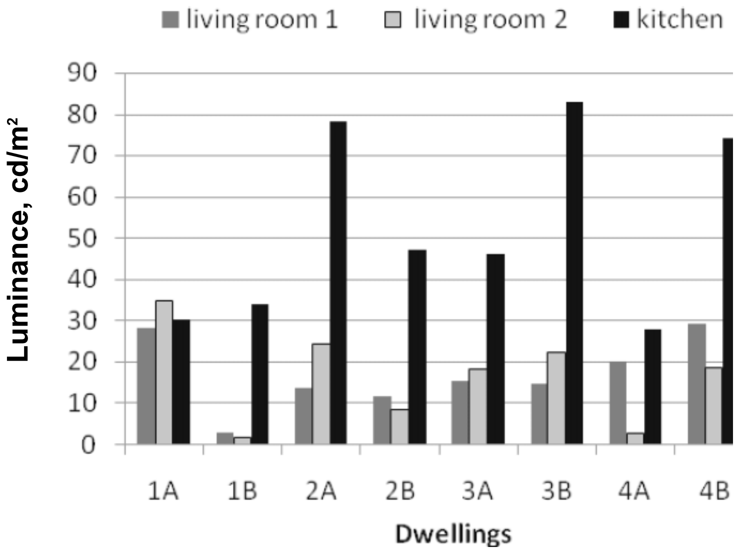

Fig. 8 a. Luminance for two view directions in the living room and one view direction in the kitchen

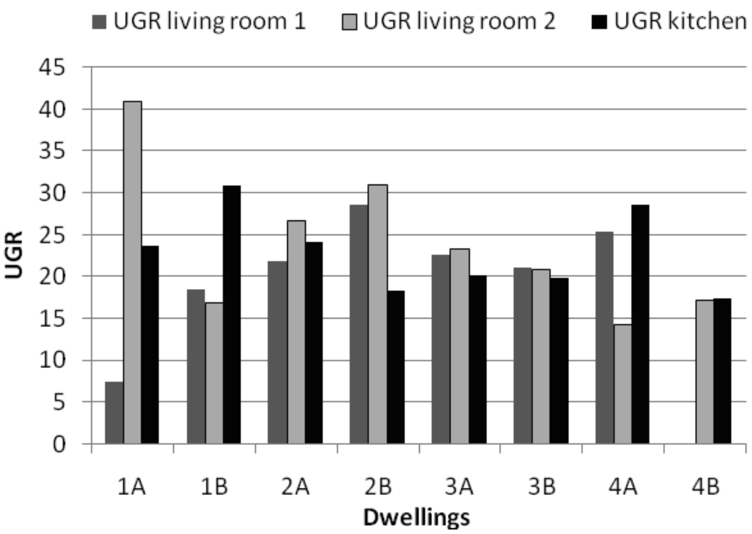

Fig. 8 b. UGR for two view directions in the living room and one view direction in the kitchen

Therefore, Fig. 7 gives the installed power per m², for an average illuminance of 100 lx. This value gives the lighting system efficacy. The higher the value, the lower the efficacy.

For apartments 1 A and 1 B, in the living room, we do not have the correct value of the illuminance level, so we do not display theses results in the graph 7.

The Fig. 7 shows that solution 2, 3 and 4 are always more efficient (≤ 5 W/m²/100 lx) than solution 1 (≥7 W/m²/100 lx). Solution 2 is always less efficient than solution 3 and 4, except for the bedrooms. So, even if the total installed power in the solution 2 is lower than in solution 3 and 4, the illuminances levels are higher in solution 3 and 4, and attempt the target value.

Luminance and UGR

Figs. 8 a and 8 b give the average luminance and the UGR values for the kitchen and living room (for 2 view points and view directions).

Fig. 8 a shows that the luminance variation is high and in general higher in the kitchen.

The UGR value of 25 (maximum level accepted in the EN 12464–1 norm) is exceeded in apartment 1 A, 1 B, 2 A and 2 B as well as in the kitchen in apartment 3 A. However, the satisfaction study showed that occupants were not disturbed by glare sources.

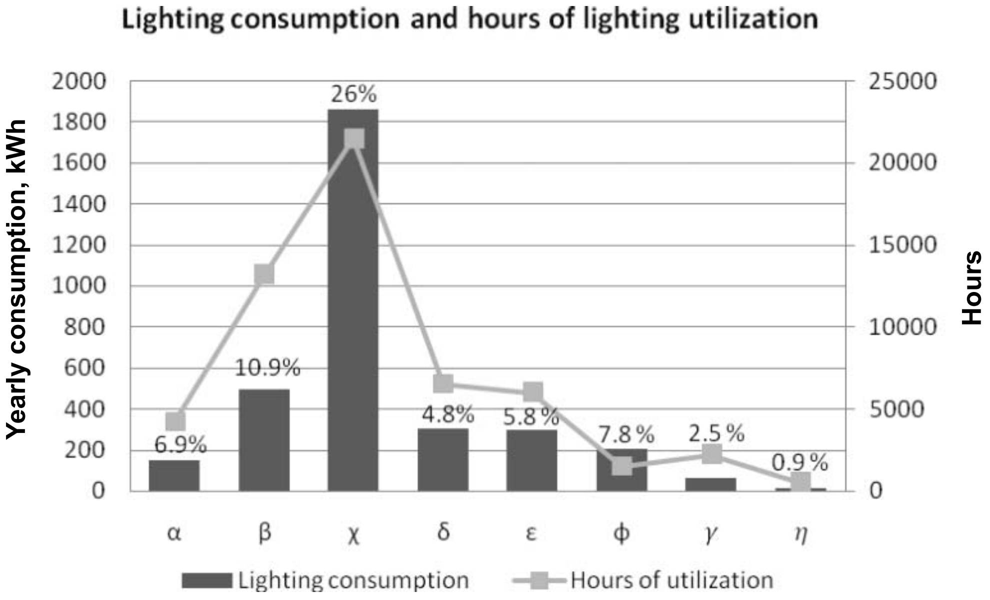

Fig. 9. Apartment lighting consumption, hours of utilization and part/percentage of the lighting in the total electricity consumption

3.2. Monitoring

Lighting consumption

The lighting consumption and the number of hours of utilization (from 12 July 2008 to 11 July 2009) are plotted in Fig. 9. The additional number (percentage values) is the proportion of the lighting energy consumption on the total apartment electricity consumption.

Fig. 9 shows that the lighting consumption is correlated with the number of hours of utilization.

Indeed, the red line follows the same trend of the histogram. We observe that the part of the lighting in the total electricity consumption vary from 1% to 26%.

The difference in behaviuor is high, η (11 kWh) consume 170 times less than χ (1865 kWh). Occupants χ have the lighting system switched on during almost the whole day (and even during night) while occupants η almost never uses the lighting system. The low consumption of occupants η and γ is due to their low use of lighting combined to the weak power of their lighting systems.

Total electricity consumption

The Fig. 10 compares the total electricity consumption in the eight apartments to the CWAPE (a Belgian energy commission) and URE (rational use of energy) reference level. We observe that, the total electricity consumption are in the same range that the predicted consumptions CWAPE and URE. These reference levels are calculated relative to the number of occupants.

3.3. Extrapolations

The combination of the user profiles consumption with the lighting solutions presented in the methodology, allows to obtain 88 (11 lighting solutions x 8 user profiles) simulations resulting in a large panel of possible energy consumptions in (renovated) dwellings.

Installed power

The Fig. 11 shows the installed power in the 11 lighting solutions for the 8 user profiles.

It was observed that in general the total installed power in solution 2 (where the lamps were replaced by energy efficient lamps (CFL) in the luminaries freely chosen by the inhabitant) is the lowest, around 400 W for a, b, c and d, 300 W for e, g and h and 1100 W for f. Solutions 3 and 4 were designed to be both comfortable and energy-efficient, so they are not the lowest power installation (between 340 W and 570 W, excepted for f +/-1200 W), with generally 4 performing a little better than 3. Of course solutions 0 and 1 are the worst because they do not use efficient bulbs (between 660 W and 1600 W).

Consumption

Annual lighting consumptions obtained from these lighting installations (Fig. 11) are presented in the Fig. 12.

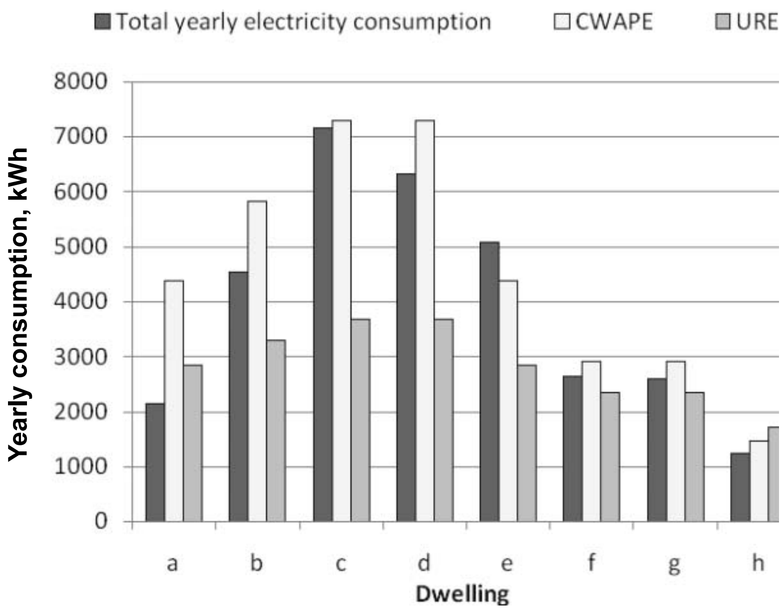

Fig. 10. Total electricity consumption, predicted CWAPE consumption, predicted URE consumption for each apartment

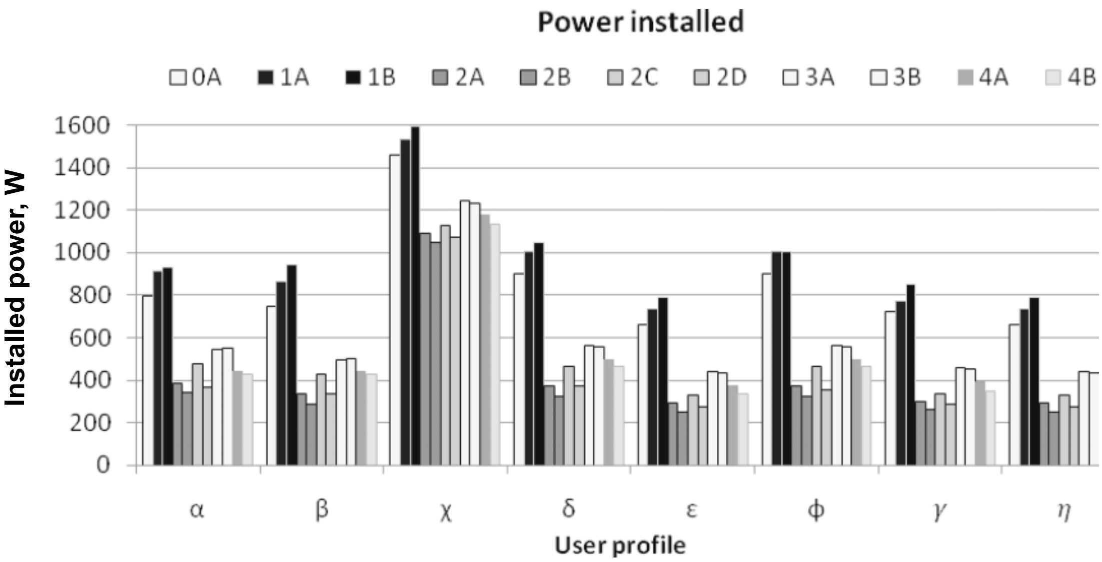

Fig. 11. Total installed power for electric lighting in function of user profile and lighting solution

It was observed that the lighting installation does not have a real impact on the consumption of the user profile η. Indeed, the η occupant has extreme energy saving behaviour. For the χ user profile, whatever his lighting solution the consumption is the largest, but they will spare energy and money by using efficiency lighting solution. For the user φ, the consumption is constant whatever the intervention type because of the consideration of the indirect lighting as an aesthetic parameter. For the others user profile, the consumption is proportional to the total installed power, with the minimum consumption for the intervention of type 2 and the maximum consumption for the intervention of type 1.

The Table 5 summarises, for each lighting solutions, the minimum and maximum energy consumption are reached for each user profile.

In conclusion, we can observe that the minimum consumption for almost each user profile is the solution 2, where a simple lamp replacement is applied. Obviously the worst are the 0 and 1 solution where incandescent lamps are mostly installed. Solutions 3 and 4 present a better visual comfort and their energy consumption is between the consumption of solution 0, 1 and 2 (and nearer to 2).

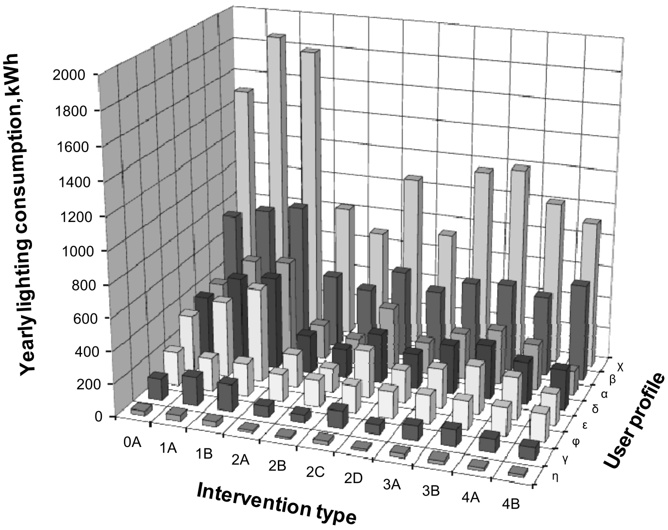

Fig. 12. Total power consumption for each combination

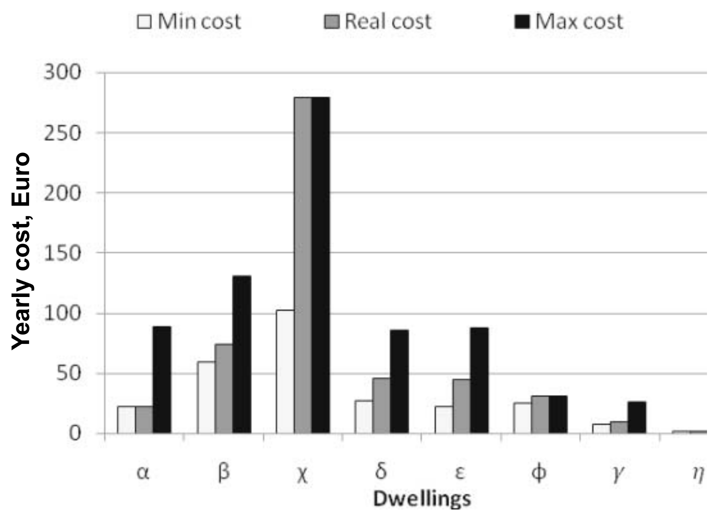

Fig. 13. Yearly cost for each user in the minimal, real, maximal and 4 B configuration

Cost

The investment of some relighting is not profitable. We can confirm that by the analysis on the yearly cost presented in the Fig. 13.

Fig. 13 shows the economic potential of the different relighting. The histogram displays the real energy cost to the occupant, the minimum and maximum cost among the different lighting solution presented in Fig. 12. These costs do not take into account the investment of the lighting installation. For the behaviour χ, the real cost is equal to the maximum cost (288 Euro). χ could save 177 Euro with a more efficient lighting solution. For the behavior χ and α, the real cost is equal to the minimal cost, 2 and 22 Euros, respectively. For these behaviour patterns, the other lighting solutions are not more economic. For the others behavior patterns, the actual lighting solution is intermediate.

Table 5. Lighting solutions corresponding to the minimum and maximum energy consumption for each user profile

User profile	Minimum solution	Maximum solution
α	4 B	1 B
β	2 B	1 B
χ	2 B	1 A
δ	2 B	1 B
ε	2 B	1 B
φ	2 D	0 A
γ	2 B	1 A
η	2 B	1 A

4. DISCUSSION

The electricity consumption for lighting in a dwelling is high. In the monitoring results from one dwelling to another, this consumption varied from 1 % to 26 % of its total electricity consumption, which is in the range of the two presented Belgian reference levels. We conclude that the consumption levels we observed were representative of the Belgian population. In our study, the lower shares of lighting consumption can be explained by an energy saving lighting configuration or by the (economic) behaviour of the occupants, or a combination of the two. The higher percentage is due to the "energy" profile of the occupant and the high power lamps installed in the apartment.

More than the quantitative impact of this study, the qualitative impact of the relighting was evaluated by the satisfaction study. What emerges from this exchange is that even if the illuminance levels are different in each apartment, all the inhabitants were satisfied by their lighting environment. The majority of them used the lighting in a usual goal and not for the aesthetic aspect. Some of them do not like economics lamps because these lamps are still considered too cold and need some time to reach their full luminous flux. The luminaries used in the third solution are judged as not aesthetic enough. At the end of the study, they were all satisfied to take part of this project. They are still using the luminaires and lamps we installed.

The measurement of the lighting renovation showed that an occupant usually tends to install high power luminaires (apartments 1 A and 1 B) with a rather poor visual comfort as a result (low illuminance level). To check this observation, we made a supplementary study in 16 homes which confirm this behaviour (which will be publishing in a future paper). We showed that it is possible to maintain this (low) illuminance level with a lower installed power and thus lesser energy cost (apartments 2 A and 2 B). We also showed that we can improve the visual comfort (higher illuminance levels) for a same or lesser energy cost (apartments 3 A, 3 B and 4 A, 4 B).

Moreover, the satisfaction study showed that occupants were not disturbed by glare sources. By the luminance and UGR analysis, we conclude that accepted glare values are higher in residential than in tertiary buildings, probably because tasks are more diversified and need less visual performance in housing.

In the extrapolation results, we observe that the occupants' behaviour impacts on the total installed power, because of the consideration of the "aesthetic" aspect on the assumption. For some occupants, whatever the lighting installation, it is their behaviour that is the predominant factor in the total installed power.

Moreover, the behaviour has an impact on the final consumption. Sometimes, the behavior is more important that the lighting installation. Indeed, in Fig. 12, for the behaviour h, occupants use electric lighting so seldom that the economic saving impact is not observable and for the occupant α, we saw that his installation, is the more economic one, and there is no reason to change it. We conclude that, in some cases, there is no economic reason to apply an energy saving relighting.

It is important to evaluate correctly the need of the occupants in terms of visual comfort and to install adequate energy saving lamps and luminaries. The efficiency luminaries are not widespread on the domestic market and some efforts in this domain might prove to be worthwhile.

As a summary of the extrapolation, it can be stated that combining user profiles with a lighting solution is not easy. Some assumptions were needed. These assumptions influence the interpretation of the results. We can guess that the behaviour does not change if the installed power does not change too much, but it remains uncertain how a user will behave in a given situation which differs from the original – measured and monitored – one: the human factor remains uncertain.

Indeed, the extrapolation allows concluding that for some behavior profiles there are no economic earnings of the use of economic lamps and efficient luminaries.

5. CONCLUSION

In conclusion, this study showed the difficulty to impact on the artificial lighting consumption for the domestic installation. Indeed, sometimes, behaviour impacts even more than an energy saving installation. However, the available aesthetic luminaires are not efficient enough. Moreover, there is no norm to guide the illuminance level objectives, and levels we observed are lesser that we expected. In a building conception, designers should work further non artificial lighting installation because of the important part of lighting in the total electricity consumption and of the importance of the visual comfort to the health of the occupants.

6. ACKNOWLEDGEMENT

Jade Deltour, Peter D'herdt and Arnaud Deneyer were supported by the "Region Wallonne" and Magali Bodart was supported by the Fonds de la Recherche Scientifique (FNRS).

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Light & Engineering
Vol. 19, No. 3, pp. 34-43, 2011

Svetotekhnika
No. 3, 2011, pp. 58-63

ANALYSIS OF SELF BALLASTED COMPACT FLUORESCENT LAMPS' ELECTRONICS CIRCUIT; DESIGNING AND OPTIMISING OF IC CIRCUIT IN AN INDIAN CONTEXT

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ABSTRACT

This paper presents an IC Based circuit design for the most commonly used 15 W and 20 W Self Ballasted Compact Fluorescent Lamps (CFL EB). A detailed study and analysis have been undertaken for various existing high power factor Compact Fluorescent Lamp Electronic Ballast circuits in which Passive power factor correction using valley fill topology was used. The results are compared with the proposed IC Based design. Experimental results and analysis demonstrate the simplicity, feasibility and reliability of the proposed idea.

KEYWORDS: CFL, electronic ballast, passive power factor correction, valley fill circuit

INTRODUCTION

The huge growth, practically a quantum jump in the usage of compact fluorescent lamps (CFL) in India occurred because of their energy saving potential, compactness, a wide variety of shape and wattages and finally their affordability and good payback period. Socio-economic conditions and governmental initiatives are further reasons for their acceptance and popularity. The production and marketing application data establish that 15 W & 20 W CFLs are most abundantly used. In India, Government initiatives includes creating strict specification standards and mandatory legislation of this standard in order to improve the quality of lamps while keeping in mind consumers' and national interests.

The CFL EB standards in India, is a unique standard which specifies safety and performance with clearly defined parameters with respect to life, lumen depreciation, colour rendering index, power factor, EMI & EMC vide IS 15111 Part-1 & Part-2 Amendment I-II.

The present work is an extension of previous work on low power factor CFL EB and high power factor CFL EB during the standardisation process [1].

The Indian lamp industry is now implementing the mandatory standards of CFL EB in terms of high power factor of greater than 0.85 and total harmonic distortion of less than 30% and EMI-EMC within the limits as per the table number and clause number of the said IS [3].

15 samples of different brand High Power Factor (HPF) CFL EB have been tested with respect to photometry and electrical parameters. The circuit designs and test result of these samples have been analysed. After careful study, in order to achieve an optimal design solution, FAN 7710 CFL Ballast IC was selected [2]. The design procedure of the purposed work is discussed below. Finally, test results of the IC Based circuit and the results are compared with the discrete version. At the end, the advantages and superiority of the IC Based concept design in terms of compatibility, performance factors like power factor, THD, EMI&EMC, safety and finally the reliability over the conventional discrete design has been established. Further this IC design method is found to be more beneficial because it is more

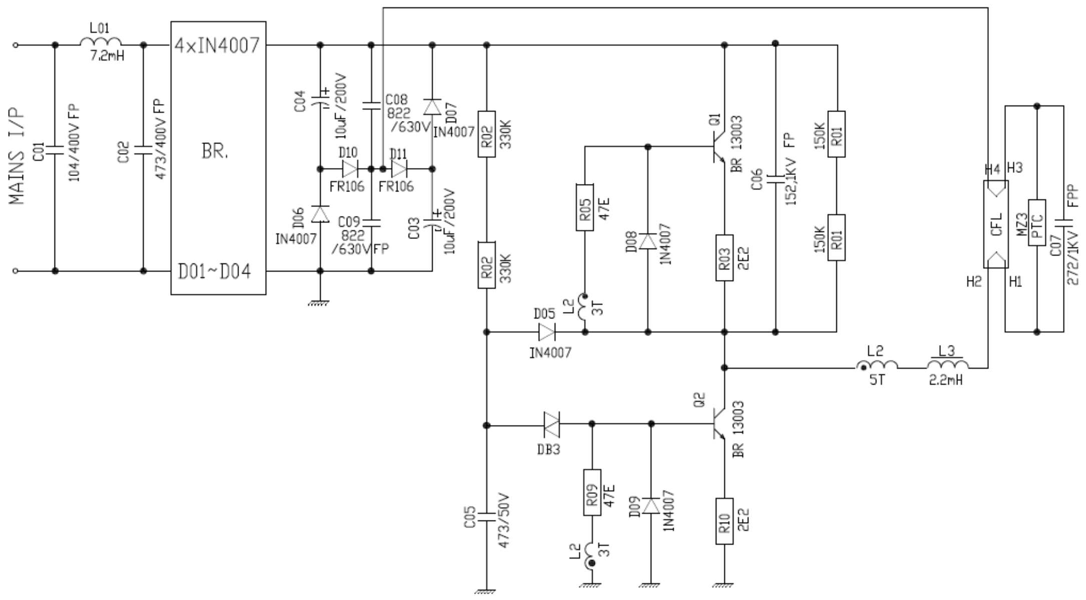

Fig. 1. Circuit diagram for Brand –A

flexible, since the designer has more exact mathematical equations which ensures designing a more reliable circuit. Finally the conclusion has been made that the IC Based circuit has a great potential to be used in mass based production process for CFLs in coming future.

ANALYSIS OF EXISTING HPF CFL EB

A survey was conducted in major markets in India to collect the samples. 15 samples of 5 popular brands were identified for sample collection. From the collected samples, 2 numbers of particular wattage of each were selected for testing. The circuit configuration and components of the existing HPF CFL EB was investigated and it was found that mainly three configurations are used.

BRAND A

In this circuit (Fig. 1) EMI/EMC Filter is in the input side that is before the bridge rectifier D01-D04 and it is basically a π-filter. The power factor is mainly done with the aid of modified valley fill circuit using two electrolytic capacitors. The switching devices are transistors Q1 and Q2 with TO-126 package and are mainly driven by a torroid core transformer, which has 3–3-5 turns. The circuit has a PTC for warm start. The PTC network has one capacitor of value 2.72 nF/1 KV parallel it. The starting is mainly done by diac and capacitor C08.

BRAND B

The analysis of the circuit (Fig. 2) reveals that the EMI/EMC filter is before the rectifier block and is an L-C Filter. The power factor correction is same and employs a modified valley fill circuit. There is use of PTC here for warm starting. The torroid core used, has 3–3-8 turns. The PTC network consists of one capacitor of value 3.32 nF/630 V parallel to the PTC. The starting circuit mainly employs a diac.

BRAND C AND BRAND D IS FOUND USE THE SAME CIRCUIT CONFIGURATION.

BRAND E

In this circuit (Fig. 3) EMI/EMC suppression is being done by an L-C filter and this is used before the rectifier block. A new concept has been used for power factor correction using only one electrolytic capacitor. The circuit is a warm starting one with the help of PTC. The number of turns in the torroid core is 4–4-6 turns.

Table 1 shows the details of components used in the circuits

TEST RESULTS

Samples of 5 brands were being tested for input and output reading. The input reading includes Pin

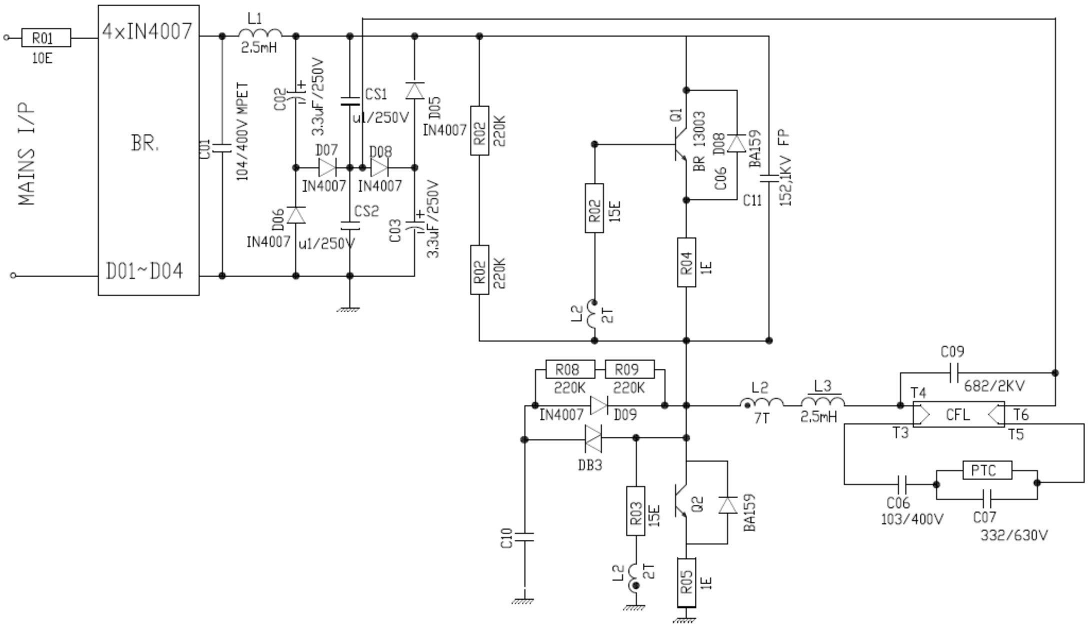

Fig. 2. Circuit diagram for Brand B

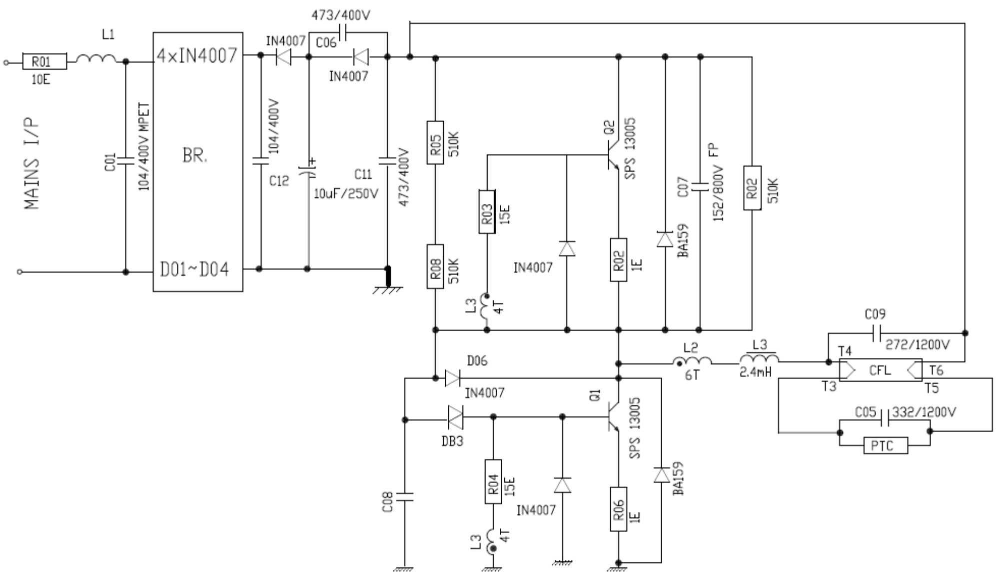

Fig. 3. Circuit diagram for Brand E

(Input power), AThd (Current Total Harmonic Distortion), P.F. (Power Factor). The output readings includes U_{lamp} (Lamp voltage), I_{lamp} (Lamp current), P_{out} (Output power) and lumen output. The test results are tabulated below.

All the electrical parameter measurements have been taken using HB-5 A high frequency ballast analyser, programmable power supply (Agilent make). The photometric readings were done by using Integrating sphere (Jadavpur University), luxmeter (Metravi manufacture).

OBSERVATIONS

It was found that all the circuits in discrete versions use three main circuit configurations of conventional types, which are summarised below as:

1. The driving transformer is a torroid core.
2. Improved Valley fill circuit has been used for power factor correction in most cases except for Brand E.
3. For EMI & EMC suppression L-C filter have been used.

Table 1. Component Table

	BRAND A	BRAND B, C, D	BRAND E
Circuit	Components used		
EMI/EMC suppression circuit	L1= 7.2 mH C01&C02=104/400 V,473/400 V	L1= 2.5 mH C01=104/400 V MPET	L1= C1=0.1 uF/400 V MPET
PFC circuit	ELCO'SC03&C04=10 uF/200 V DIODE=IN 4007, FR106	ELCO's C02&C03=3.3 uF/250 V DIODE=IN 4007	ELCO CO2=10 uF/400 V DIODE D5&D7=IN 4007 C06&C11= 47 nF/400 V
Transistor driving circuit	Base Res.R04&R06=47 ohm	Base Res R04&R05.=15 ohm	Base Res R03&R04.=15 ohm
	Emitter Res.=2.2 ohm	Emitter Res.R06&R07=1 ohm	Emitter Res. R02&R06=1 ohm
	Torroid turns = 3–3-5	Torroid turns = 2–2-7	Torroid turns = 4–4-6
Resonant tank circuit	Series L3= 2.2 mH	Series L3= 2.5 mH	Series L3= 2.4 mH
	Ig, Cap C09= 2.72 nF/1 KV	Ig, CapacitorC09= 3.3 nF/1 KV	Ig, Cap C8= 3.32 nF/1.2 KV

Table 2

PERFORMANCE PARAMETERS		15 W Samples				
		Brand A	**Brand B**	**Brand C**	**Brand D**	**Brand E**
INPUT	Pin, W	15.3	13.9	14.9	14.6	14.9
	AThd, %	22.00%	28.70%	21.90%	22.30%	30.20%
	P.F.	0.954	0.952	0.956	0.954	0.932
OUTPUT	U_{lamp}, V	78.7	**76.**6	67.4	75.4	73.9
	I_{lamp}, A	0.179	0.166	0.209	0.178	0.174
	$P_{out,}$ W	12.6	11.9	12	12.2	12.7
	Lumen output, lm	585	634	600	615	540
	Lamp C.C.F	2.10	2.01	2.00	1.96	2.20

Table 3

PERFORMANCE PARAMETERS		20 W Samples				
		Brand A	**Brand B**	**Brand C**	**Brand D**	**Brand E**
INPUT	Pin, W	20.3	20.9	20.2	20	20.1
	Athd, %	**22.00**%	28.70%	21.90%	22.30%	30.20%
	P.F.	0.954	0.952	0.956	0.954	0.932
OUTPUT	U_{lamp}, V	78.7	76.6	67.4	75.4	73.9
	I l_{amp}, A	0.179	0.166	0.209	0.178	0.174
	P_{out}, W	17.6	17.8	18	18.2	18.1
	Lumen output, lm	750	698	700	715	640
	Lamp C.C.F	1.9	1.9	1.91	1.94	1.94

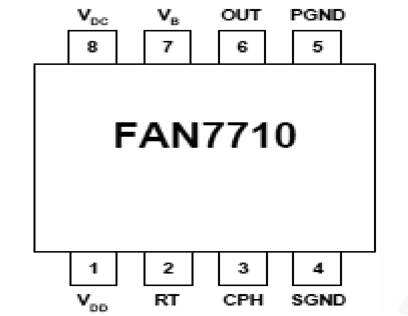

Fig. 4. FAN 7710 IC Pin Diagram

Pin Definitions

Pin #	Name	Description
1	V_{DD}	Supply voltage
2	RT	Oscillator frequency set resistor
3	CPH	Preheating time set capacitor
4	SGND	Signal ground
5	PGND	Power ground
6	OUT	High-side floating supply return
7	V_B	High-side floating supply
8	V_{DC}	High-voltage supply

Table 4. Pin Definitions

4. All the resistances used are in SMD form.
5. The light output varies with voltage variation.
6. PTC has been used for soft-start.
7. The circuit is highly populated that results in highly congested component placing connected with complications in manufacturing.

DESCRIPTION OF IC [2]

The IC used here is a Compact Fluorescent Lamp Ballast controller IC FAN7710, Fg.4. This can be used to drive a lamp of up to 20 W. One of the unique features of this IC is that it provides preheating and ignition control with the help of an external component, a capacitor which is connected to the CPH pin. The detailed pin description of the IC is given below in Table4.

The PIN 1 is a Vdd pin and its function is to bring the IC out of shutdown mode and to initiate its functioning. The electrical specification of the IC suggest that the minimum voltage of Vdd to start the functioning of the IC is 14.5 V.

Pin 2 is known as RT pin and a resistance is connected with this pin and depending on the value of this connected resistance the oscillating frequency of the circuit is determined.

The oscillating frequency is given by the following formula:

$$Fosc = 4 X 10^9/RT, RT = \text{Resistor value}$$

Pin 3 is the CPH pin and a capacitor is connected with this pin. This pin performs a very important function of determining the preheating frequency. Also depending on the voltage on this capacitor different operating modes of the IC is determined. This can be explained as follows FAN7710 has four operation modes: (A) preheating mode, (B) ignition mode, (C) active ZVS mode, and (D) shutdown mode. The modes are automatically selected by the voltage of CPH capacitor shown in Fig. 20. In modes (A) and (B), the CPH acts as a timer to determine the preheating and ignition times. After preheating and ignition modes, the role of the CPH is changed to stabilize the active ZVS control circuit. In this mode, the dead time of the inverter is selected by the voltage of CPH. Only when FAN7710 is in active Zero voltage switching (ZVS) mode, is it possible to shut off the whole system using the CPH pin. Pulling the CPH pin below 2.6 V in active ZVS mode causes the FAN7710 to enter shutdown mode. In shutdown mode, all active operation is stopped except Under voltage Lockout (UVLO) and some bias circuitry. The shutdown mode is triggered by the external CPH control or the active ZVS circuit. The active ZVS circuit automatically detects lamp removal (open-lamp condition) and decreases CPH voltage below 2.6 V to protect the inverter switches from damage.

PIN 4 and PIN 5 is signal ground and power ground respectively. PIN 6 is OUT pin and it is the output of the Half Bridge Inverter circuit. The switching components are the MOSFET'S which are integrated in the IC. PIN 7 is the VB pin, when CPH becomes higher than ~6 V, the active ZVS operation is activated. To determine the switching condition, FAN7710 detects the transition time of the output (OUT pin) of the inverter by using the VB pin. From the output-transition information, FAN7710 controls the dead time to meet the ZVS condition. If ZVS is satisfied, the FAN7710 slightly increases the CPH voltage to reduce the dead time and to find optimal dead time, which increases the efficiency and decreases the thermal dissipation and EMI of the inverter switches. If ZVS fails, the FAN7710 decreases CPH voltage to increase the dead time. CPH voltage is adjusted to meet optimal ZVS operation. The Pin 8 is the Vdc pin and the bridge rectifier output is connected with this pin.

Table 5. Function Chart of IC Design

SYMBOL	COMPONENT	FUNCTION
F1	Fusible Resistor	Overcurrent protection
MOV	Metal Oxide Variasator	Surge current protection
D1, D2, D3, D4	IN 4007 (Rectifier diodes)	Rectifies input ac to dc
D5	BA159 (Fast Recovery diodes)	mainly for bootstrap operation
D6, D7	BA159 (Fast Recovery diodes)	Freewheeling diodes
D8, D9	BA159 (Fast Recovery diodes)	Power Factor Correction
C8, C9	2.72 nF (Polypropylene Capacitor)	Power Factor Correction
C1	10 uF/450 V (Electrolytic Capacitor)	Filtering out dc ripples
R1	240 Kohm (Metal Oxide Resistor)	Initiating IC operation
C2	10 uF/50 V (Electrolytic Capacitor)	Initiating IC operation
R2	82 Kohm (Metal Oxide Resistor)	Controls Oscillating frequency
C3	0.47 uF/50 V (Film Polyester Capacitor)	Controls starting, preheating, ignition
C4	100 nF/100 V (Film Polyester Capacitor)	Bootstrap operation
C5	470 pF/1 KV (Ceramic Capacitor)	Charge pump operation
C6	33 nF/630 V (Film Polyester Capacitor)	Resonant tank component
L1	2.5 mH for 20 W 3.0 mH for 15 W	Resonant tank component
C7	2.72 nF/1 KV (Polypropylene Capacitor)	Ignition Capacitor

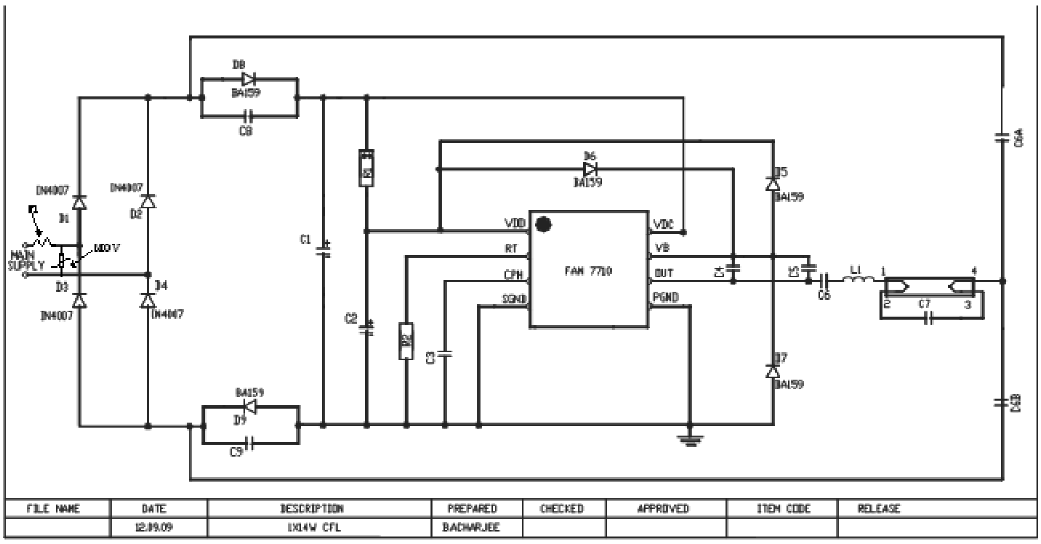

Fig. 5. FAN 7710 Circuit employing passive PFC circuit

IMPLEMENTATION OF FAN7710 CIRCUIT USING PASSIVE PFC CIRCUIT

Proposed design circuit diagram is shown in Fig. 5.

In this proposed IC design an introduction of the different power factor correction concept is used. Required power factor improvement is done by simply using two film polyester capacitor C8 & C9 and two fast recovery diodes D8 & D9. Compared with the discrete version where modified valley circuit using two ELCO's are used, this proposed PFC design definitely helps in reducing the cost and also help in eliminating to an extent the space problem, which is generally encountered in discrete CFL EB circuit.

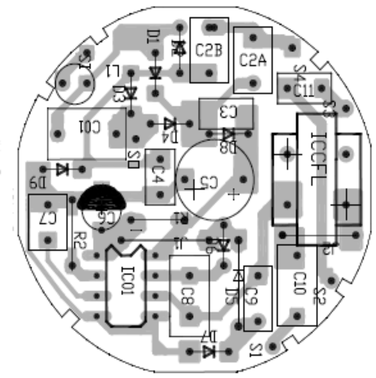

Fig. 6. PCB Layout

The functions of each and above components in our proposed circuit design are given in Table 5 where only L1 value changes for 15 W and 20 W.

The circuit PCB layout drawn in HI-WIRE SOFTWARE is shown in Fig. 6.

DESIGN CALCULATION

(a) **Series Inductor (L1) and Ignition Capacitor (C7) value**

These two components are very important as they determine the frequency at which the circuit resonates. If the series inductor value is not set correctly, this may lead to incorrect lamp current, which may harm the lamp reducing its life. In the same manner the ignition capacitor controls the filament current, if its value is not correct than the excessive filament current will cause losses in the system. Although no mathematical calculation gives a satisfactory result in finding these two values, trial and error method is found to be quite helpful in obtaining an optimal result. Below (Table 6) we have got following values for 15 W & 20 W CFL:

(b) Oscillating frequency (Fosc) [2]

$$Fosc = 4 \text{ X } 10^9/RT, \tag{1}$$

where Fosc is oscillating frequency, RT is pin resistance.

Therefore,

$$Fosc = 4 \text{ X } 10^9/82000 \text{ Ohm}$$
$$(\text{Given, RT=82000 Ohm}),\ Fosc = 48.78 \text{ kHz}$$

(c) Preheating Frequency (Fpre)

Table 6. Calculated component value

CFL, W	Series Inductor ‘L1’	Ignition Capacitor’C7’
15 W	3.0 mH	2.72 nF
20 W	2.5 mH	2.72 nF

$$\begin{gathered} Fpre = 1.6 \text{ X } Fosc, \\ Fpre= 75.2 \text{ Khz}. \end{gathered} \tag{2}$$

(d) Ignition Frequency (Fig)

$$\begin{gathered} Fig = [(0.3 \text{ X } (5\text{-}VCPH)+1] \times Fosc, \\ Fig= [(0.3 \text{ X } (5–4)+1]\text{X}75.2 \\ Fig= 96 \text{ Khz } Fpre = 1.6 \text{ X } Fosc, \\ Fpre= 75.2 \text{ Khz}. \end{gathered} \tag{3}$$

(e) Starting time (Tst)

$$Tst= \frac{Rst.Cvdd.Vddth\ (st+)}{Vdc\text{-}Rst.Ist\text{-}Vddth\ (st+)}, \tag{4}$$

where Rst= Starting resistance, Cvdd=C2 Capacitance value, Vddth (st+)= Vdd threshold starting voltage, Ist= Starting current, Vdc= Rectified dc voltage If, Rst = 270 kohm (Given Rst = 270 kohm), Cvdd= 10 uF, Vddth (st+)= 13.5 V, Ist= 120 uA, and Vdc= 311 V thus, Tst = 0.133 seconds

** (Based on IC datasheet)*

TEST RESULT OF IC VERSION

After studying the experimental result on the IC version, one conclusion drawn is that the performance parameters in terms of Power factor, THD etc are more or less the same between the IC version and the discrete version. Table 7 below gives values for 15 W and 20 W. The electrical parameter readings were taken using HB-5 A Ballast Analyser. The photometric readings were done by using integrating sphere (Jadavpur University), luxmeter (Metravi make), Table 7.

BENEFITS OF IC-CIRCUIT

The FAN 7710 has in built design to take care of the following parameters:

– Starting without sputtering;
– Automatic Open lamp detection;
– Automatic Thermal Shutdown;
– Active Zero Voltage Switching.

Table 7. Experimental Readings of IC Based ballast

IC VERSION		
	15 W	20 W
Power input, W	14.9	**20**
Total Harmonic Distortion, %	29.20%	20%
Power Factor	0.932	0.92
Lamp Voltage, V	73.9	76.6
Lamp current, A	0.174	0.207
Power output, W	12.7	15.8
Lumen output, lm	625	714
Lamp C.C.F*	1.9	1.8

* Lamp C.C.F is for Lamp current crest factor

Discrete circuits are highly congested, so adding the above features will adversely affect the manufacturing process. The IC circuit improves the lamp life by starting in a predetermined sequence, first preheating the filament, then igniting and finally stabilising the lamp operation thus avoiding sputtering. It is a well known fact that the major reason for failure found in compact fluorescent lamps is the failure of the lamp bulb. It is observed that even though the circuit is functioning normally but the filament is being damaged due to the 'sputtering' effect. This effect is prominent in Indian condition where frequent switching of power on and off is more common. In discrete version PTC is being used for warm starting across the Ignition capacitor of the CFL ballast circuit. The PTC helps avoid this 'sputtering' phenomenon by warm starting the CFL avoiding application of high voltage across CFL filament. But this too has disadvantages; that is once the lamp gets started then if its switched off and on quickly then the function of PTC is avoided because the PTC is still hot meaning its resistance is small. This is observed experimentally and shown in Figs. 7, 8.

The starting curve for discrete version CFL is given below and two conditions are noted. The experimental readings were taken on High frequency ballast data analyser (Computer Services make)

CONDITION-1

Here the CFL is switched on for the first time and has been found out that due to the effect of PTC the starting begins with preheating stage and after that

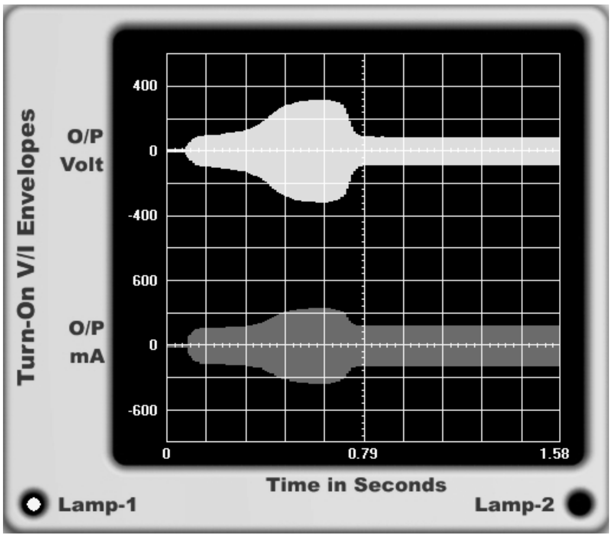

Fig. 7 a. CFL Ballast starting curve of discrete version

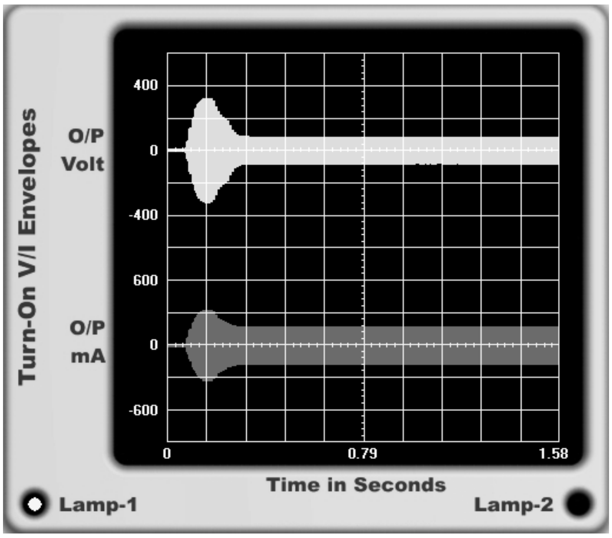

Fig. 7 b. CFL Ballast starting curve of discrete version while continuous switching

ignition takes place and finally the lamp stabilises. This not only helps its easy ignition but also avoids sputtering. Fig. 7 a shows this effect.

CONDITION-2

Effect after instantaneously switching on and off, the effect of PTC is bypassed here and the CFL is instantaneously switched on so that it cannot avoid the sputtering effect. Fig. 7 b shows effect of instantaneously switching on and these instantaneously switching predominately happen in Indian context for home lighting application. This means the increase in switching cycle deteriorate life of the lamp.

But the IC circuit is programmed start therefore whenever the CFL is switched on the starting always

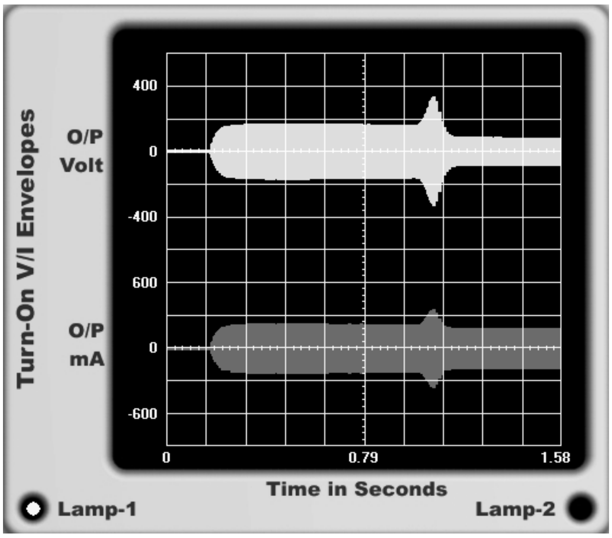

Fig. 8 a. CFL Ballast starting curve of IC version

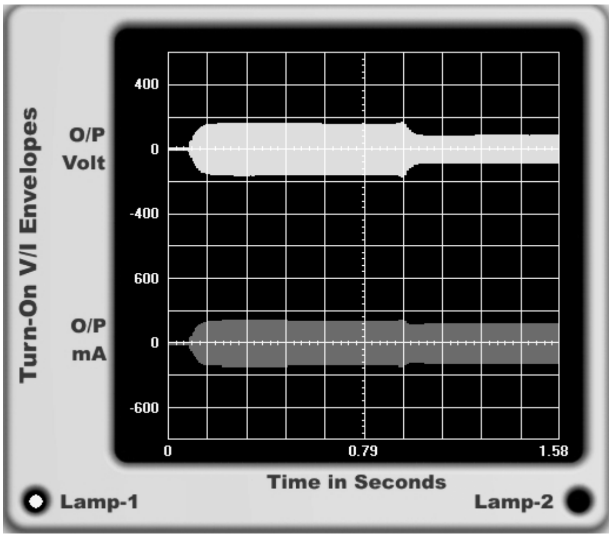

Fig. 8 b. CFL Ballast starting curve of IC version while continuous switching

takes place in a sequential manner. First it will be preheating mode in which the filament will be heated then after that the ignition voltage is applied across the filament to ignite and start the CFL and after the lamp has ignited then it enters the running mode. This is depicted with the aid of the graph below.

CONDITION-1

When the CFL is ignited for first time here the preheating of the lamp filament takes place, after that ignition voltage is being applied, Fig. 8 a.

CONDITION-2

Even after instantaneously switching on and off, the starting sequence is always maintained thus avoiding the sputtering phenomenon as shown in the Fig. 8 b.

Therefore we can see that with IC the phenomenon of sputtering is avoided to the maximum extent during the switch off and on condition and which definitely increases life of CFL EB lamp to a great extent. The IC circuit offers a complete solution in CFL EB with increased lamp life.

CONCLUSION

New proposed IC design has two distinct advantages over the existing discrete design. Firstly fewer components are required in IC version circuit manufacturing process and this makes for an easy and controlled mass production process. The second one is programmed start option instead of preheat start.

Some researchers predict that sputtering is one of the main reasons of lamp failure. Research suggests soft start as a way of avoiding sputtering. The soft starting method too has some concerns. According to the “NLPIP” [4] report it has been found in some cases CFLs with soft start have poor life compared with the instant start versions. This is because although the warm start by preheating the lamp filaments avoids sputtering but preheating has to be done for a particular period of time with correct preheating energy. Anything greater or lesser than the preheating energy required is not good for the lamp filament. In its existing discrete version PTC is used for the preheating purpose but it is not possible to accurately control the preheating energy in theses circuits.

The IC version has programmed start option, which starts the lamp in a sequential manner and the preheating is being done in a controlled manner. This has the advantage of increasing the lamp’s life.

Indeed, in the process of improvement of power factor by valley fill circuit, there is a limitation with respect to meet the Crest Factor (CF) range particularly for 15 W and lower wattage lamps. But this range is not far off to reduce lamp life drastically [5]. Over the past four years different laboratory has certified lamp life crossing 6000 burning hours and meeting all specification of Indian standards for these existing circuits.

So, it can be concluded that programmed start of IC based circuit will further enhance the lamp life as well as to a certain extent compensate for the CF limitation issues.

However integration of PF correction within the IC near future will be ideal solution and is left for future innovation.

The cost of IC circuit presently is 17–22 % higher than discrete version. The present cost of discrete circuit is around INR 28.00 to 35.00 whereas IC circuit is around INR 41.00 to 45.00 rupees. But in the IC circuit 37 % of the cost is for the IC. Presently 120 million are being made annually and a growth is expected of around 50 %. The main issue of discrete version is its cumbersome manufacturing process due to its many components. The potential of CFL market is around 400 million or more therefore within a period of time with volume expansion it is expected that the cost of IC will come down to a competitive pricings. Thus IC based design has a great potential of replacing the existing discrete version.

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Light & Engineering
Vol. 19, No. 3, pp. 44-48, 2011

Svetotekhnika
No. 2, 2011, pp. 25-28

A STUDY OF THE CHARACTERISTICS OF FLUORESCENT LAMPS WITH SMALL DIAMETER TUBES

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ABSTRACT

The paper discusses results of the studies of the discharge characteristics of experimental and commercial fluorescent lamps (FL) having discharge tubes (DT) with the outside diameters d_{dt} = 12, 19 and 25 mm at various regimes: direct current, alternating current with sinusoidal waveform at 50 Hz and 20 kHz, pulsed current with rectangular and bell-shaped form and frequency f=20 kHz with a duty cycle C= 2 ÷ 6 in the ambient air temperature range t_a equal to (20 ÷ 70)°C.

Keywords: fluorescent lamp, low-pressure (LP) mercury-argon discharge, luminous efficacy, gradient of potential, current, voltage, power, power regime, high frequency (HF), pulsed mode, discharge positive column (PC)

1. INTRODUCTION

In recent years, fluorescent light fixtures with small arc tube diameter have gained wide application. The most widely used are thin FL T5 (d_{dt} = 16 mm), which have high luminous efficacy (105 lm/W), increased lumen maintenance and low mercury content [1]. For local illumination and backlighting, even smaller diameter (less than 10 mm) FL are often used. All these new FL are intended only for use with electronic ballasts (EB).

To design a FL with reduced d_{dt} and with optimal parameters for different applications it is necessary to know the specifics of the LP discharge in a mixture of mercury vapour and inert gas in the FL with a small d_{dt}.

In spite of a lot of published experimental data on characteristics of LP discharge in FL, the results of experimental studies of the characteristics of the discharge positive column (PC) in small d_{dt} were clearly insufficient to establish the optimal regimes and temperature conditions for the respective FL.

Therefore, we present here the results of our studies of the specific characteristics of the FL positive column, and FL as a whole at various regimes: direct current, current of industrial frequency (50 Hz) and the high frequency current 20 kHz (sinusoidal, rectangular and bell-shaped with a duty cycle C = 2 ÷ 6). The main feature of the study is to provide real operating conditions of FL.

2. THE EXPERIMENTS AND THEIR ANALYSIS

The studies were conducted using specially-made FL with four electrodes spaced at certain distances from each other (which allowed us to vary the discharge length), and commercially available FL with diameters d_{dt} = 7, 12, 16, 19 and 25 mm.[1]

In the research process we obtained and analysed:

• The dependence of the potential gradient – E of the discharge PC (Fig. 1) and the FL voltage – U_l on the discharge current I_d and diameter d_{dt}. The potential gradient E was determined by measuring volt-

[1] It is worth noting that there are publications [2,3] on development of FL (compact and linear) with small d_{dt} in OAO "Lisma–VNIIIS" named after A.N. Lodygin. However, the study did not provide reliable data on the specific characteristics of such FL at various power supply regimes.

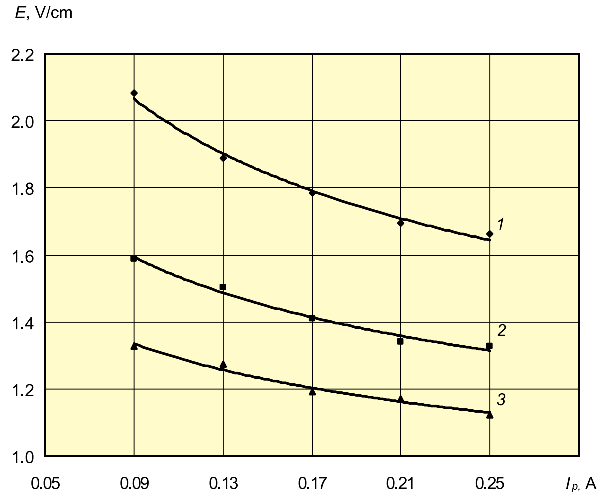

Fig. 1. Dependence of positive column potential gradient E on discharge current I_d (p_{Ar} = 533 Pa, f = 20 kHz) for d_{dt} = 12 (1), 19 (2) and 25 (3) mm

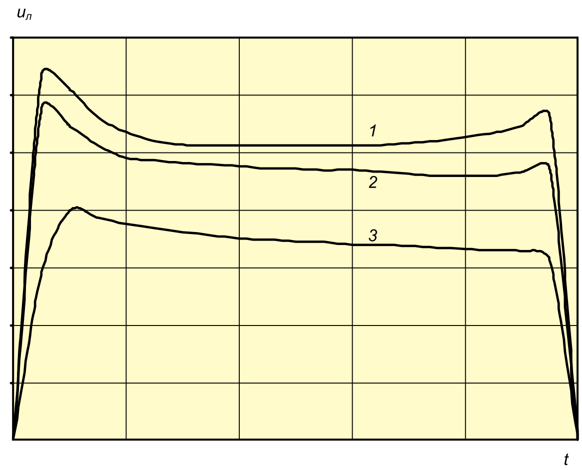

Fig. 2. Oscillograms of FL voltage for d_{dt} = 12 (1), 19 (2) and 25 (3) mm

age for two discharge lengths using special FL with four electrodes.

It is known that for the static volt–ampere characteristics of the discharge in FL is best approximation $E = a \cdot I_d^{\rho}$, where a is a constant factor; and ρ is the ratio of the differential resistance of PC to its static resistance. Analysis of the curves $E\ (I_d)$ and $U_l\ (I_d)$ shows that with a decrease in d_{dt} and all other conditions fixed, ρ increases in modulus, which agrees qualitatively with the data reported by other researchers [4]. We also found the approximate dependence of ρ on d_{dt} as:

$$\rho = 1{,}411 \cdot d_{dt}^{0{,}69}.$$

As it follows from the formula, in order to stabilise the discharge with small d_{dt} a larger ballast resistivity is needed. In addition, because of a steeper slope of the $E\ (I_d)$ for the FL with a small d_{dt}, a lower current is needed, since with increasing current the lamp power is increasing more slowly than in FL with larger d_{dt}.

• Analysis of the waveforms $u_l\ (t)$ at f = 50 Hz showed (Fig. 2) that with decreasing d_{dt} their deflection increases, which indicates a corresponding decrease in the FL power factor due to increased instability of the plasma. Therefore, to obtain the same power density as in the FL with larger d_{dt}, a higher current is required, and this leads to a decrease in the FL light output and life (due to increased current density).

• Pulsed electronic ballasts (PEB) theoretically could have lower losses compared to conventional electronic ballasts, as they lack the ballast choke – the main cause of losses. Apart from small losses,

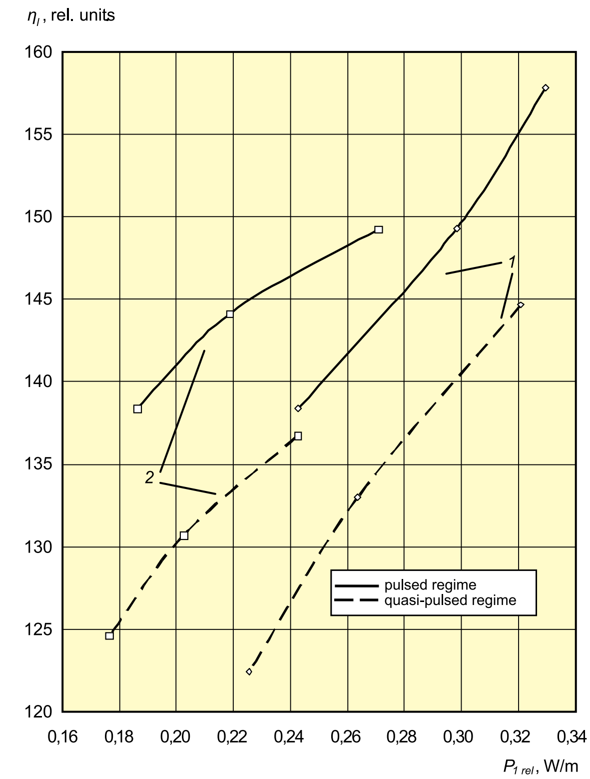

Fig. 3. Dependence of FL luminous efficiency η_l on the specific power of positive column P_1 (W/m) at I_d = 0.17 A, f = 20 kHz, and d_{dt} = 12 (1) and 19 (2) mm

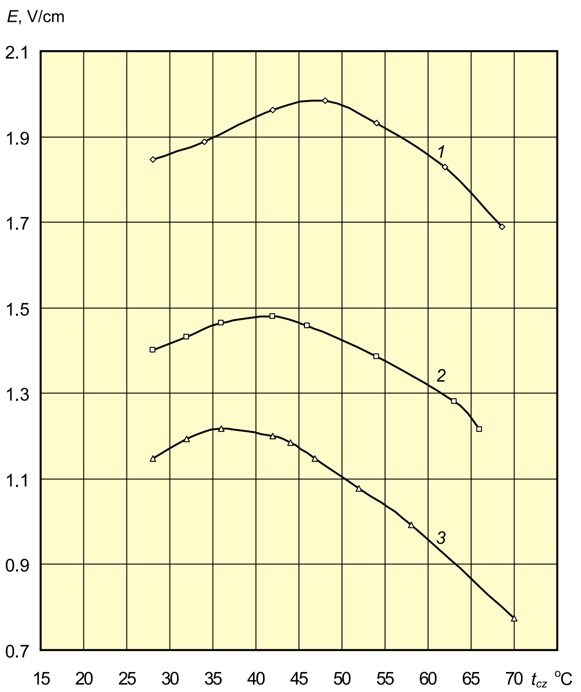

Fig. 5. Dependence of positive column potential gradient *E (V/cm)* on the cold zone temperature t_{cz} (p_{Ar} = 533 Pa, I_d= 0.17 A, *f*=20 kHz) at d_{dt} = 12 (1), 19 (2), and 25 (3) mm

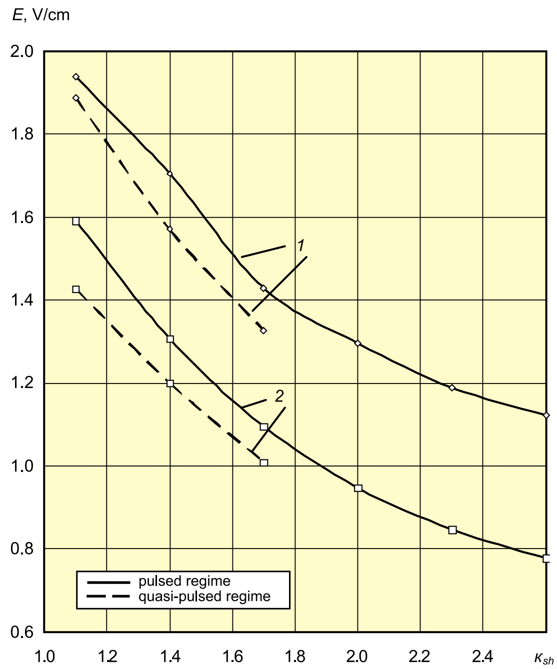

Fig. 4. Dependence of positive column potential gradient *E* on the current shape factor k_{sh} (I_d = 0.17 A, f = 20 kHz) at d_{dt} = 12 (1) and 19 (2) mm

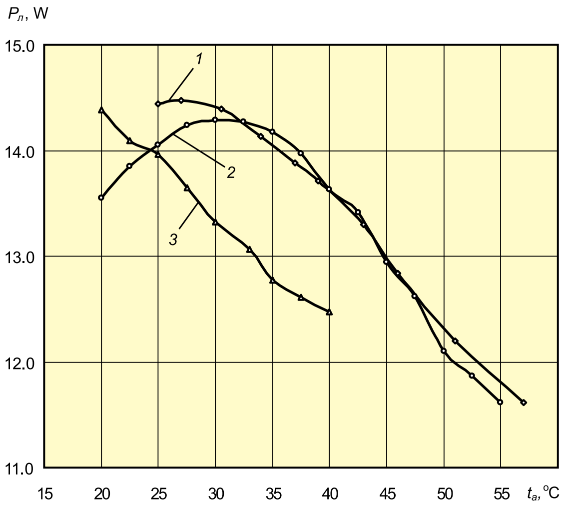

Fig. 6. Dependence of lamp power P_l on ambient temperature (I_d = 0.17 A, *f* = 20 kHz):
1 – FL production of OAO "Lisma-VNIIIS", 14 W (analog of FL TL'5' HE 14 W); 2 – FL TL'5' HE 14 W (Philips), 3 – FL LB13

PEBs can have very low weight and volume, since they might look like one small microcircuit. However, pulsed HF electronic ballasts with a rectangular current shape have not yet been used widely because of their electromagnetic incompatibility with other devices: they create a wide range of high intensity radio frequency interference. The bell-shaped (Gaussian) pulses have the narrowest spectrum of HF noise pulses [5].

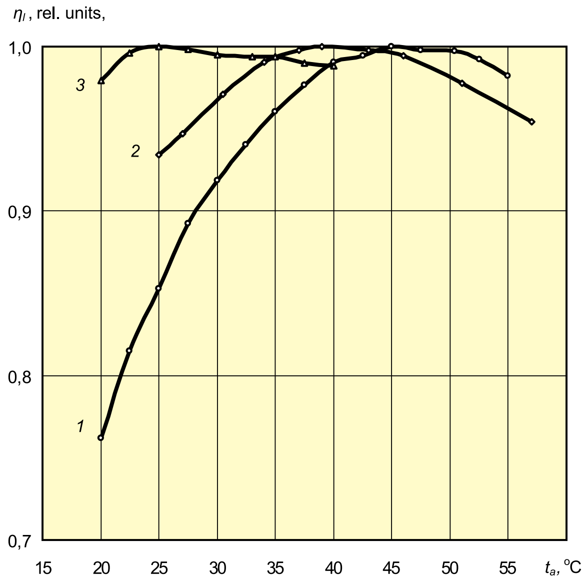

Fig. 7. Dependence of luminous efficacy η_l on ambient temperature t_a (I_d = 0.17 A, f = 20 kHz):
1 – FL production of OAO "Lisma-VNIIIS", 14 W (analog of FL TL'5 'HE 14 W);
2 – FL TL'5' HE 14 W (Philips) 3 – FL LB13

Accordingly, we investigated the possibility of using bell-shaped pulses (quasi-pulsed mode) rather than rectangular pulses (pulsed mode). Quasi-pulsed and pulsed power modes are energetically equivalent for the same PC power density. Variation of the power density in the quasi-pulsed mode was achieved by varying the current shape factor – k_{sh} and in the pulsed mode by varying the duty cycle C ($C=k_{sh}^2$). It was found that the luminous efficacy η_l of FL with small d_{dt} at pulsed regime is higher by approximately 10 % (in the range of the studied values of k_{sh}) than in the quasi-pulsed regime (Fig. 3). With the k_{sh} increase (decreasing of power density) η_l decreases in both regimes, and E also decreases (Fig. 4), always remaining larger in the pulsed regime than in the quasi pulsed one.

• It is known, that the pressure of mercury vapour p_{Hg} in FL depends on the temperature of cold zone t_{cz}. This is a serious disadvantage of FL: their characteristics are strongly dependent on ambient temperature. The temperature dependence of characteristics of new FL with a small d_{dt} differs from that of conventional FL with large d_{dt}. Studies of the effect of environmental parameters on the characteristics of the FL with small d_{dt} allow for a more sound approach to optimizing their performance.

The dependence E (t_{cz}) was obtained using experimental FL (Fig. 5). Both the experiment and calculations have shown the presence of a weak maximum. The increased p_{Hg} reduces the specific power of PC due to lower output of the resonant radiation, which leads to a decrease in E, required to maintain a given electron temperature.

• We obtained the dependence of E on the argon pressure (p_{Ar}) for small d_{dt} and various power supply regimes. They were quite sluggish: the increase of p_{Ar} by a factor of two results in only 13 % increase in E.

With decreasing d_{dt} we observed shifting of the maximum of the FL luminous flux (Φ_l) vs. t_{cz} to the right. Thus, when d_{dt} = 25 mm, the maximum of the curve Φ_l (t_{cz}) corresponds to $t_{cz} \approx 43$ °C ($p_{Hg} = 7.6 \cdot 10^{-3}$ mm Hg), and for d_{dt} =19 mm, the maximum shifts to $t_{cz} \approx 48$ °C ($p_{Hg} = 11.10^{-3}$ mm Hg), while for d_{dt} =12 mm the maximum is observed at $t_{cz} \approx 53$ °C ($p_{Hg} =15.7 \cdot 10^{-3}$ mm Hg).

The luminous efficacy of FL with d_{dt} = 25 mm has a maximum at $t_{cz} \approx 60°$, and with decreasing d_{dt} the maximum shifts to the right.

The maxima of functions E (t_{cz}) are always to the left in comparison to the maxima of Φ_l (t_{cz}) by about 5 °C.

• We also studied how the characteristics of the FL with a small d_{dt} depend on the ambient temperature t_a. We used: FL TL'5' HE 14 W (by Philips) with d_{dt} = 16 mm; FL manufactured by OAO "Lisma-VNIIIS" with d_{dt} = 16 mm, structurally similar to the FL TL'5' HE 14 W and conventional 13 W FL with d_{dt} =16 mm (LB 13).

The lamps with an artificially created cold spot behind the electrode (TL'5' HE 14 W and FL, manufactured by OAO "Lisma-VNIIIS") have a maximum $t_a = 27 \div 32$ °C (Fig. 6). The same functions for a conventional 13 W FL have the incident character. The maximum of the curve Φ_l (t_a) for the FL with an artificial cold spot is in the area $t_a = 35$ °C, and for the conventional FL at $t_a = 25$ °C. The light output of lamps TL'5' HE 14 W and FL manufactured by OAO "Lisma-VNIIIS", have a maximum $t_a = 40 \div 45$ °C; a further growth in t_a it decreases insignificantly, while with a decrease in t_a the light output decline is significant (Fig. 7).

3. CONCLUSION

As the result of this study, we obtained a wide range of data that can be used by specialists in the study of the LP mercury discharge, and in design and improvement of FL with discharge tubes of a small diameter.

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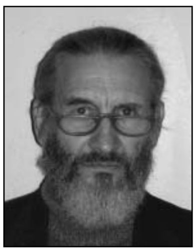

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Light & Engineering
Vol. 19, No. 3, pp. 53-59, 2011

Svetotekhnika
No. 1, 2011, pp. 43-47

CURRENT STATE OF URBAN LUMINOUS MEDIUM DESIGN

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ABSTRACT

The current state of design of the integrated illumination of cities and fragments of city medium over the last two decades both in Russia and abroad is analysed. Some representative examples are considered, and overall general statements about design methods for the urban luminous medium are made.

Keywords: luminous urban medium, designing methods, design solutions, analysis, conclusions

Work and research into city illumination, the creation of a comfortable luminous medium, have been performed for a long time. Because of a lack of a uniform approach, each company makes designs for the formation of a luminous medium building on its own experience, or even worse, based on subjective opinions of individual specialists. As a result, poor designs as night visualizations and pictures appear on the market. They do not have any basis in the cityscape, are not connected with the city, and proposals on full-value designs are not accepted in Russia neither by municipal heads, nor by customers since it is long and laborious effort. But there is one more factor: non-availability of a high-grade design concept of a city illumination. Many cities would like to have a design of luminous medium formation but they do not have a specific method and understanding of what they should obtain, and the main thing, they do not know, what is the basis against which it can be checked and measured.

A rapid pace of development of design solutions in the race for technical progress give us a multitude of illumination solutions, which are more and more integrated into architecture. Possibilities of artificial light force to look in a new way at designing and creating a uniform luminous medium of a city fragment or of a whole city.

Perception of the architectural illumination of an object is subjective. The specialists can argue for a long time, whose solution is better, which designs can be considered good and how the performance of a solution can be estimated. A luminous medium should not “turn out” casually. This is a multi-aspect and multi-stage phenomenon dependant on a considerable number of factors.

Development of a luminous medium designing method of a city, oversteps the boundaries of architecture; it is a synthesis of arts, philosophy and technology. Therefore, the theoretical basis of the analyses given here includes not only the work of architects but also of specialists in other fields.

Beginning from the 1950 s, a new approach to illumination was formed abroad: luminous decoration should not only answer to utilitarian requirements (visibility and discernibility of objects) but also meet esthetic standards. From this moment urban illumination design rested on two principles: light and architecture. This transition to a new quality demanded the introduction of new terms: “luminous architecture”, “luminous urbanism” and “luminous medium”. However, different specialists mean different things when using the terms.

To systematise all existing approaches to city illumination, the author of this article carried out an analytical and graphic study of design methods and of the implemented designs of luminous medium of a city, of a fragment and of an object. In doing so, the following representative examples were used: “General plan of Ghent city illumination” (1998–

2008), "Luminous plan of illumination of Great Channel in Hangchow" (2008), "Luminous general plan of Astana" (1999–2001), "*PESARO"* luminous plan (2006), Research report on development of recommendations and technical solutions of integrated luminous decoration of main architecture memorials, squares and streets of Novgorod (1989), "Luminous plan of Moscow" (1998), "Architectural-art illumination of Moskva river and Yauza river quays in the central part of the city" (2008), "Concept of uniform light-and-colour medium of Moscow city" (2007–2009), "Concept of Dresden illumination" (2005–2009), "Luminous plan of Boholt" (2008) and "Luminous plan of Bremen" (2009).

Thus for this analysis, designs from the last two decades implemented both in Russia and abroad were selected. Such a width of the choice allowed for identifying some universal principles of the illumination of cities.

Research on development of recommendations and technical solutions of integrated luminous decoration of main architecture memorials, squares and streets of Novgorod (1989)

The authors of the design are employees of TSNIIEP of Engineering Equipment: G.V. Kamenskaya, V.P. Zobov, L.A. Podgornykh, L.I. Petrova, and A.Yu. Kurnosov [1]. It is one of the first designs where authors have proposed a "Method of development sequence of integrated light-and-colour medium of a city". The authors took an important step in the field of luminous medium design: an achievement based on scientific and technical solutions of complexity for the design approach. They performed a pilot analysis of the main features of the city: of its cultural and historical value, of its location, natural and environmental conditions, availability of architecture and culture memorials, an analysis of general layout with studying functional areas of the city, analysis of the street network, determination of the relative importance of streets, roads, and squares, of transport and pedestrian traffic intensity. The main directions of tourist movement were also studied. Based on the above, a "concept of the city luminous architecture in town-building aspect" was developed, primary goals of luminous architecture were formulated, objects for architectural illumination and luminance dominants in luminous decoration of the city were selected. And their coordination with other objects were made. Advertising illumination according to the concept of luminous architecture was proposed, luminance (illuminance) levels for each illumination type were determined, illumination methods depending on art image and town-building value of a given ensemble were selected. Taking into consideration that architects did not participate in the development, a considerable part of the work was dedicated to the technical aspect of illumination design.

The author of this article made the method of the integrated designing proposed by G.V. Kamenskaya in 1989, the basis of her principles of forming a luminous medium of a city.

Concept of Dresden illumination (2005–2009)

The author is Karsten Vinkels, the Head of *Winkels & Partner Company* [2].

Development of the illumination design of the Saxon capital registered in the list of UNESCO cultural heritage sites, is one of the more recent high-grade designs. Karsten Vinkels was the first who compared the creation of a luminous city medium with the creation of a picturesque canvas, "where ratio of light and shade plays a paramount role. Light becomes visible and notable, becomes material in the dark only". The art of illumination and the art of painting are merged together, and the author formulates principles of a luminous image using works of art of two artists of the XX-th century: "Emptiness Obstacle" of Rene Magritt and "City" of Paul Klee. Karsten Vinkels transfers impressions arising when viewing the paintings from the canvas to "canvas of facades".

As a main idea for creation of a luminous image of the city was Bernardo Bellotto's picture "View of Dresden from the right bank of Elba downstream of August bridge".

Direct development of the illumination plan was preceded by a complex and fruitful work. In order to embody such an impression a study of the Dresden cityscape, of its cultural and historical value, location, nature and climate features, main ways of pedestrian movement, entrance areas and architectural objects was made. Complete photometric measurements of the lighting devices installed in the streets, transport highways, squares and in the pedestrian areas were performed, their chromaticity, light distribution, luminance levels were studied. A chromaticity analysis of the projected area facades and surrounding objects in a real architectural context was carried out. The choice of light sources was only made after correspondent full-scale experiments.

Fig. 1. Views of illuminated buildings of the central part of Dresden

A thorough analysis helped to make an illumination layout of the centre of Dresden and to form principles of its further development.

In the designing process, "colourimetric passports" of fifty most significant buildings in the luminous medium of the central city part were developed. The most important thing was that the authors were able to create an integral approach and to form by means of light not only architectural image of buildings but also visual luminous medium of their environment (Fig. 1).

General principles of the approach formed a basis when forming the method.

Luminous plan of Moscow (1998)

The author of the design is professor N.I. Shchepetkov [3–6]. The design was performed as a part of an integrated improvement plan under the General Plan of Moscow.

When creating a methodology for luminous medium designing, N.I. Shchepetkov provided for the following sequence of actions, based on which a luminous plan of Moscow has been developed:

1. Revealing an "urban framework" consisting of two systems: transport spaces (highways, streets, roads, squares, interchanges, parkings) and socially-pedestrian spaces (within ensembles of capital, city, regional and local centres of importance). The key parameter of this primary structural and light differentiation is the different chromaticity of light in installations of functional illumination.

2. Detailed representation under similar outline of a "natural framework" formed by systems of three types: green planting of intensive public use; landscape areas of nature systems not visited at night; quays and water areas of rivers and water bodies.

3. According to N.I. Shchepetkov, junctions of crossings or interfaces of the "frameworks" together with luminous dominants serve in this case as "basic elements of scale-and-rhythmic light modulating city spaces. They serve as well as a system of city luminous reference points needed for effective arrangement of transport traffic and pedestrian movement in evening".

N.I. Shchepetkov considers the functional areas to be the main elements of light planning structure of a city, and systems of transport highways, of public centres and green landscaping system – to be structure forming systems. "The methodology of urban lighting design" accumulates ideas of some architects and light designers on forming a modern comfortable light-and-colour medium and anexpressive image of a city using detailed representation by means of illumination of its planning basis. Resulting design layout being a "light planning city structure" is the general one. It consists of several structural patterns combined with each other reflecting "framework" and "texture" revealed by light. The "framework" is divided into "urbanised" and "natural". The "texture" is a part of the town-building system, a component field of primary localisation of people activity types, structurally dependent on the "framework". Each light layout is accompanied by tables deciphering it with regulated light-composition parameters.

When working in Svetoservis Open Company on formation of luminous medium of town Lyubertsy, the author of this article faced a situation at a stage of the pilot analysis of the town composite structure that "crossing junctions" of the "framework" do not serve as basic elements either in day time, or at night. "Centres of people attraction" are objects

Fig. 2. Views of the central part of Moscow

Fig. 3. Views of illuminated buildings and quays of Great Channel in Hangchow

of various functional purposes: for example, public gardens and playgrounds. "Large-scale light-rhythm partitionings" did not work in this case, and illumination of all "light planning texture" of the city was not a proper solution.

The method proposed by N.I. Shchepetkov is mainly based on the designing end-product and consists of detailed presentation of the "light planning texture and framework". And choice of conceptual principles remains a subjective solution of the authors. This method does not take into consideration the existing luminous medium, however most of cities, especially megapolises after all have already illuminated objects: there are about twenty designs of integrated illumination of boulevards, public gardens, squares and of central parts of cities (Fig. 2). Accordingly, the described method needs further development.

Architectural-and-art illumination of Moskva river and Jauza river quays in the central part of the city (2008)

The authors are N.V. Bystryantseva, A.S. Bukatov and N.S. Perova (Svetoservis Open Company), the advisers are G.V. Kamenskaya and A.V. Pyatigorsky [7].

Fig. 4. Views of illuminated buildings, streets and quays of the central part of Boholt

Fig. 5. Views of illuminated buildings, sculptures and squares of the central part of Bremen

Development of the concept was based on the architectural method of designing proposed in this project and approved at the Art Council in the Moskomarkhitektura. Initially a problem was set so as based on the town-building analysis, to study carefully the stages and preconditions of forming areas taking part in the project, to study a rich historical material of and the birth and development of the city, on the basis of which to develop possible conceptual aspects of the quays' luminous medium, to give proposals on general arrangement of the city illumination on these territories.

A main focus of the project was on the architectural-and-planning analysis of the quays' territory. The city medium of the central part is saturated with architectural ensembles and systems, most important perspective disclosing of which is descended from Moskva river and Jauza river quays. Formation of an architectural-and-planning structure is descended from different elements: architectural objects, city equipment, information media, landscape elements, backgrounds and panoramas. Each of them has a special importance depending on different functional saturation of the territories.

After a thorough study of a hierarchy of elements in the architectural-and-planning formation of the quays, objects having major and minor value in the city composition, were determined that later on became a basis for arrangement of integrated illumination of the quays fragments.

An important distinctive feature of this project was a special approach to the analysis of the existing luminous medium. Accordingly an analysis method of both general structure of city illumination, and of luminous composition of the quays panoramas was developed. Illumination types forming perception of city medium at night time, typology of objects perception scales and general silhouette perception of the quays were considered. As a result, problems and disadvantages of existing city illumination

Fig. 6. Views of illuminated buildings, streets, squares and quays of the central part of Ghent

in these territories emerged.

Based on this analysis, a variety of proposals and approaches to formation of a harmonious, artistically expressive luminous composition of the city quays spaces within the central part of the city were raised. A luminous plan with proposals on architectural, functional and decorative illumination was developed. Proposals on the arrangement of the city illumination on territories with different functional purpose were given.

Based on the proposed solutions, elaboration of the lighting part is needed that would form a basis for further work on the project of the quay objects illumination.

Luminous plan of illumination of Great Channel in Hangchow (2008)

The author is lighting designer Roger Narboni. The design performed within a project of Great Channel water area reconstruction [8, 9] is a "huge symphony of light". The light designer constructs a counterbalanced spectacular luminous image of the Channel by means of music and painting, revealing the local coloration and culture of the Chinese south. From the viewpoint of professional technical solutions, the project received different evaluations but from the viewpoint of principles and main idea it remains at present one of most "emotional" and "picturesque" (Fig. 3).

Luminous plan of Boholt (2008 [10], Luminous plan of Bremen (2009 [11] and General plan of Gent city illumination (1998–2008 [12]

These design solutions are focused on the creation of a clear city luminous image which underlines the uniqueness of the cities, making them more convenient and safe, raising their attractiveness for tourists and visitors, as well as promoting energy efficiency. The projects are carried out based on approaches implemented before in some other luminous plans. A distinctive feature is taking into account the factor of luminous contamination. These cities make an essential contribution to climate protection, because efficiency of electric power use became one of main aspects if the work. And this is not a question of energy saving only. Correct design solutions on creation of visual comfort and people's safety with due regard for ecological and economic requirements, are much more important (Fig. 4–6).

The performed analysis of designing methods and implemented projects of urban luminous medium allow drawing the following conclusions:

All considered design approaches to illumination of cities are developed for specific situations and cannot be recommended as a uniform designing method;

In order to ensure freedom of creative expression of the authors, a scientifically reasonable method of designing integrated city illumination is necessary.

A main factor of architectural design is pilot analysis: collection of the information and its methodological processing. Design solutions of luminous medium of a city in its fundamental principles should originate from objective information including: studying of vital dynamics of the city, its past, present and future, research of functioning all parts and their spatial arrangement, of everything that surrounds people and promotes their high-grade comfortable life.

Understanding of boundaries and importance of the concept "luminous medium" being so far new for architects, light designers and for light engineers, and determination of transition ways from intuitive use of the concept to ability of building city ensembles image, is the most essential problem, which all specialists who are engaged in designing of surrounding luminous medium should solve in the future together.

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Light & Engineering
Vol. 19, No. 3, pp. 60-67, 2011

Svetotekhnika
No. 6, 2010, pp. 23-28

SUPPLIES FOR LIGHT EMITTING DIODES WHEN CONNECTING TO AN ALTERNATING CURRENT CIRCUIT

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ABSTRACT

Features of light emitting diodes as elements of an electric circuit are dealt with in this article. Requirements for supplies of high power light emitting diodes when connecting to an alternating current circuit are systematised, their circuit solution classification and examples of electrical schematic diagrams of manufactured devices are presented.

Keywords: light emitting diodes, current-voltage characteristics, supplies, control, current sources, power supplies

1. LIGHT EMITTING DIODE AS AN ELEMENT OF AN ELECTRIC CIRCUIT

1.1. Current-voltage characteristics of light emitting diodes

Current-voltage characteristics of light emitting diodes (LED) are the same as for normal rectifier diodes, with the only difference that their direct voltage is higher, Fig. 1 (from 1 to 4.2 V).

After examining the current-voltage characteristic, one can draw the following conclusions:

- A direct current is necessary to supply an LED;
- The supply device should have the characteristics of a current source;
- In view of LED small dynamic resistance, its ripples of voltage U_n should be minimised;
- In order to avoid LED breakdown, its reverse voltage should not exceed 5–10 V.

1.2. Control

LED luminous flux control is carried out by means of changing current through the LED.

A typical control curve of an LED is given in Fig. 2. One can adjust the current in two ways: changing direct current through LED (amplitude method) and using pulse-width modulation (PWM) method. In the first case, LED luminous flux pulsation are absent, however the spectrum changes. In the second case, the spectrum does not change but there are luminous flux ripples at the modulation frequency. This frequency is selected to be equal to no less than 200–400 Hz which is imperceptible to the eye. Nevertheless, the pulsation remain, and this should be remembered.

1.3. Maximum allowable current

Maximum allowable current in the operating mode depends on the cooling conditions. As an example, in Fig. 3 a diagram is given that allows determining an admissible current value of *XP-E* series LED depending on the cooling system efficiency and on surrounding temperature [1]. The cooling system efficiency is expressed in terms of thermal resistance (R_j) between *p-n* junction of the LED crystal and environment.

Maximum allowable current in the starting mode can be exceeded by 10 % during 2 seconds [2].

In the LED pulse mode depending on relative pulse duration, 5–10 time excess of current amplitude higher than the rated one, is permissible [3].

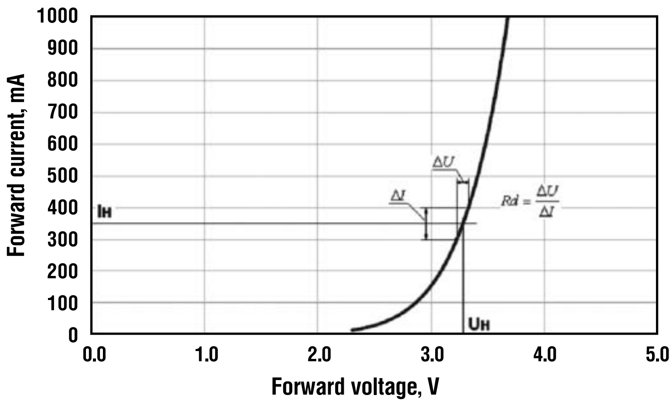

Fig. 1. A typical direct branch of a light emitting diode (LED) current-voltage characteristics, where:
– I_r is rated current (20–1200 mA depending on LED power);
U_r is rated voltage (1.5–4.2 V depending on LED color). U_r value has a technological variation of ±10 % and depends on temperature (for example, for Cree XLamp 7090, temperature coefficient is about 3 mV/°C;
R_d is dynamic resistance (it is determined by the current-voltage characteristic slope in the interval of the rated current). In view of small value of this resistance, even little ripples of voltage U_r can lead to considerable ripples of current. For a specific characteristic of the LED given in Fig. 1, R_d makes about 1 Ohm;
If voltage ripple excursion makes for example, 100 mV (3 % of U_r) current ripple excursion makes 100 mA (30 % of I_r);
Reverse breakdown voltage of LED is usually equal to 5–10 V (reverse branch of the LED in Fig. 1 is not given).

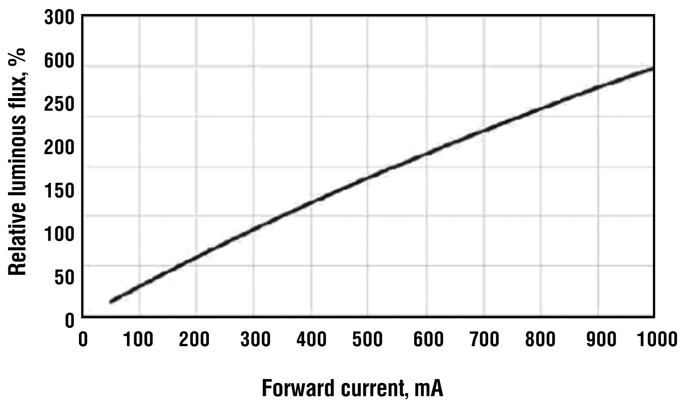

Fig. 2. Relative luminous flux of an LED dependence on its current

It follows from the above analysis that an LED represents a nonlinear electrotechnical element operating with the use of direct current. To support a set mode of such an element when connecting to an alternating current circuit, a starting controller (ballast) is required[1].

2. BALLAST PARAMETERS FOR LIGHT EMITTING DIODES

Being one of the luminaire and lighting installation elements, ballasts should not only provide optimum electric and luminous LED characteristics, but also meet a number of other requirements following their operating conditions. Therefore the ballast parameters can be divided into two groups: operational ones and those determined by the load.

Output ballast parameters determined by the load are as follows:

- I_r is rated direct current and its stability;
- U_r is rated direct voltage and its stability;
- Admissible pulsation amplitude and frequency I_r and f_r accordingly (they are set on the basis of maximum allowable level of the LED luminous flux pulsations);
- Multiplicity and control method (amplitude or pulse-width).

Operational parameters and characteristics:

- Value and frequency of the supply voltage;

[1] The term "driver" widespread for designation of LED supplies, is not absolutely appropriate here, because in electronics microcircuits of high power transistor control of voltage converters output stages are called "drivers" [4].

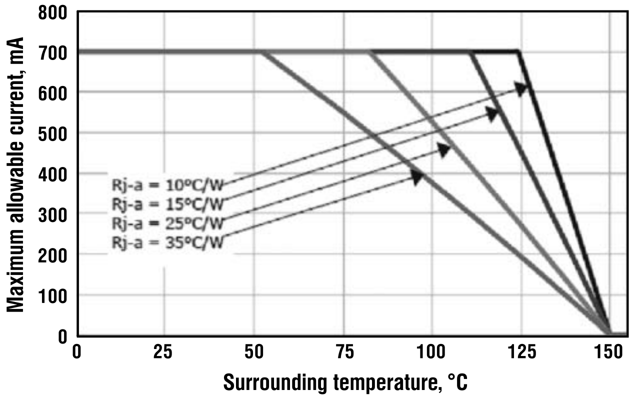

Fig. 3. Maximum allowable current of *HR-E* series LED depending on cooling system efficiency and the surrounding temperature

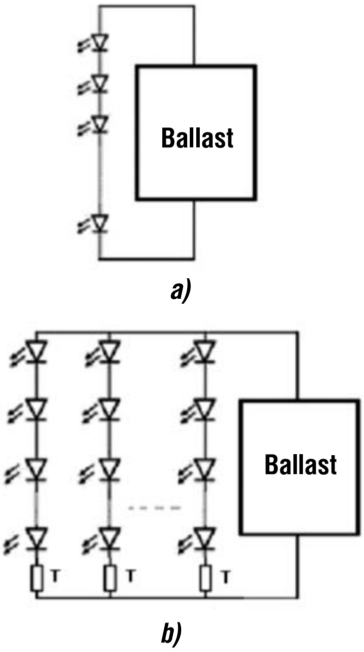

Fig. 4. Versions of LEDs' connection to ballast

• Electromagnetic compatibility with supply mains (power factor, harmonics composition of input current, level of radio noise). They are regulated by standard [5];

• Design (independent, built in the luminaire, integrated with the lamp);

• Availability or non-availability of a galvanic connection of the input with the output. This characteristic is determined by structure and protection degree of the luminaire, as well as by the LED structure. Ballast is simpler and cheaper, if galvanic decoupling is not needed, but in this case insulation between the electrodes and the LED enclosure should stand at least 1.5 kV test voltage (at 220 mains voltage);

• Mass, dimensional and mounting size, price;

• Efficiency;

• Surrounding temperature;

• Electric- and fire-safety. Test requirements and methods are regulated by standard [6];

• Indicators of reliability.

2.1. Versions of light emitting diode connection to ballast

In connections with small individual power of a LED, their group connection to ballast is used as a rule. Versions of such connection are given in Fig. 4.

In Fig. 4 a, the LEDs are connected in a united series circuit, in which the same current flows. In this situation the ballast should have the characteristic of a current source. In particularly important installations, to avoid the extinction of the whole circuit when breaking one of the LEDs, the latter can be shunted with special relays (not shown in the figure) closing the LED electrodes in the event of it breaking. Relay active shunts of *ON Semiconductor Company* can be used as such [7].

In Fig. 4 b, several LED series circuits are connected in parallel to the output device. The ballast in this version can be both a current source, and a voltage source, but in both cases current limiting elements *T* are necessary to equalise currents between parallel circuits. If the currents are less than 20 mA, one can use resistors for this purpose. When the currents are big, it is more expedient to use linear current stabilisers (see below).

3. CLASSIFICATION OF BALLASTS FOR LIGHT EMITTING DIODES

Classification of ballasts for LEDs is presented in Fig. 5.

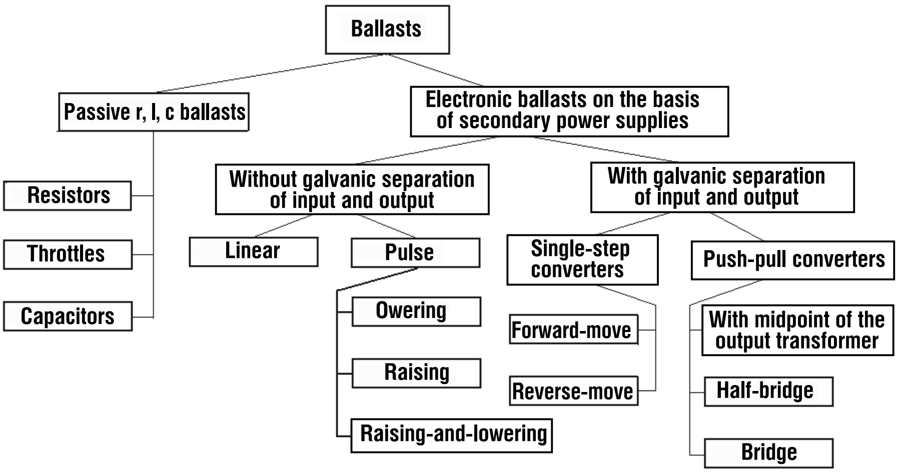

Fig. 5. Classification of ballasts for LED

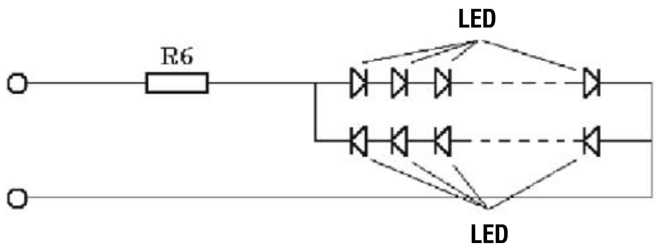

Fig. 6. Diagram of *Acriche A3–4* LED lamp with a resistive ballast

3.1. Passive *R, L, C* ballasts

3.1.1. Resistors

Resistors allow creating elementary LED supplies to be operated in an alternating current circuit. One of possible schemes of such devices is implemented, for example, in the *Acriche A3–4* light-emitting diode lamp (Fig. 6).

The schema contains two antiparallel circuits, and each of them consists of LEDs connected in series (several tens) which are connected to the supplying circuit using ballast resistor R_b. In the positive half-cycle of the circuit, one LED works, in the negative half-cycle the other works. Structurally the resistor is located on the same board with the light emitting diodes. The lamp has two leads which are directly connected to the circuit. It is certainly a big convenience but the lamp tests which were carried out revealed a number of essential disadvantages:

- When changing the supply voltage 220 V ± 10 %, the lamp current changes by +25%/–45% accordingly, and when changing the supply voltage from 195 to 240 V, the lamp power increases from 2.6 to 6.2 W (2.4 times);
- Resistor R_b power losses make about 20 % of the lamp power;
- The lamp represents a nonlinear load distorting the current waveform (Fig. 7) consumed from the circuit. Total harmonic distortion[2] of this current makes for about 50 % which can lead to an overload of the neutral wire at a considerable number of lamps in the circuit. Besides, at such current of the lamp, raised ripples of luminous flux take place.

2 Total harmonic distortion THD, or as it is accepted in the domestic literature, harmonic factor K_r, is equal to percentage of higher harmonics effective value to effective value of the first harmonic. THD and accordingly K_r are determined from the expression:

$$THD = Kr = \frac{\sqrt{\sum_{n \neq 1} I_n^2}}{I_1} \cdot 100,$$

where I_n is effective value of n harmonic current; I_1 is effective value of the first harmonic current.

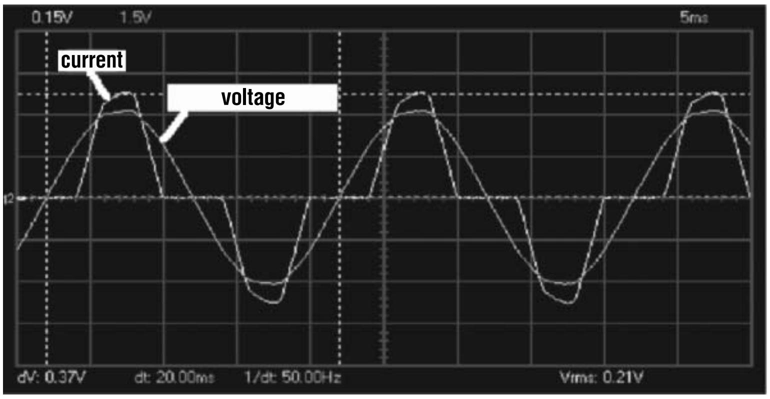

Fig. 7. Oscillograms of current and voltage for *Acriche A3–4* lamp (at mains voltage 220 V)
M_x = 5 ms/div, M_y = 0.015 A/div

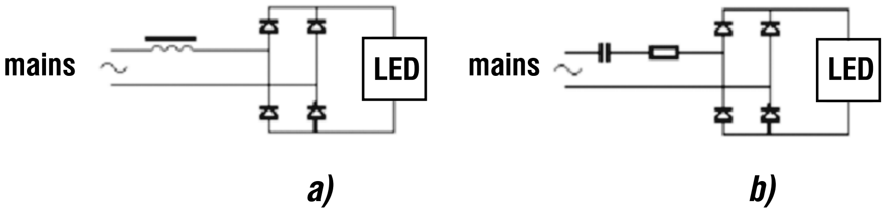

Fig. 8. Ballast with a ballast throttle (a) and with a capacitor (b)

The listed disadvantages limit the application of lamps with resistive ballast by low power area and by the cases when these lamps only make a little part of all circuit load.

3.1.2. Throttles and capacitors

Ballasts for LEDs, in which throttles and capacitors are used as current limiting elements, are given in Fig. 8.

Into the circuit with a ballast capacitor, one should introduce a resistor to suppress current surges when switching on.

Advantages of devices with ballast throttles and capacitors are their simplicity and low price. However because of their large size and mass, as well as due to strong LED current dependence on the circuit voltage, these devices are rarely used.

As to devices with a ballast capacitor, it is necessary to add that they essentially distort the wave form of the current consumed from the circuit: the harmonic factor makes for 30% – 40% which at a considerable number of lamps in the circuit can lead to the neutral wire overload.

3.1.3. Electronic ballasts

Electronic ballasts representing in essence secondary sources of power supply, have primary circulation as LED supplies. They are intended for operation with such specific load which LEDs represent. In accordance with the definition accepted in the converting equipment, these are devices intended to converse input electric power of alternating or direct voltage in order to provide the load with power supply at a set type and quality of output electric power.

Due to several steps of energy conversion, electronic ballasts have almost unlimited functionality allowing to perform all energy conversion operations, which are necessary to config. optimum working and adjusting of LED modes, to provide electromagnetic compatibility of the system with the mains supply and to meet consumer requirements.

Circuitry of electronic ballasts for LEDs is not particularly different to the known circuitry of secondary power supplies which are manufactured for electric drive, power units of various equipment, etc.

As this circuitry has already been developed in detail and is widely known (see, e.g., [3]) its description in the present article is omitted, and only

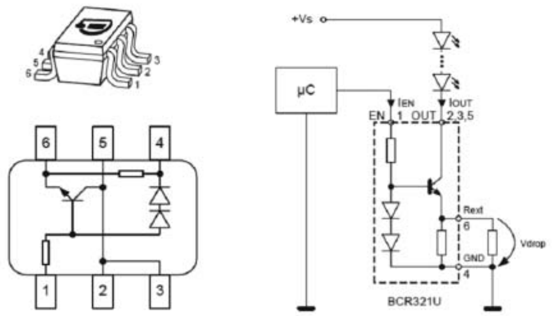

Fig. 9. Linear controller *BCR321 U of Infineon Company*

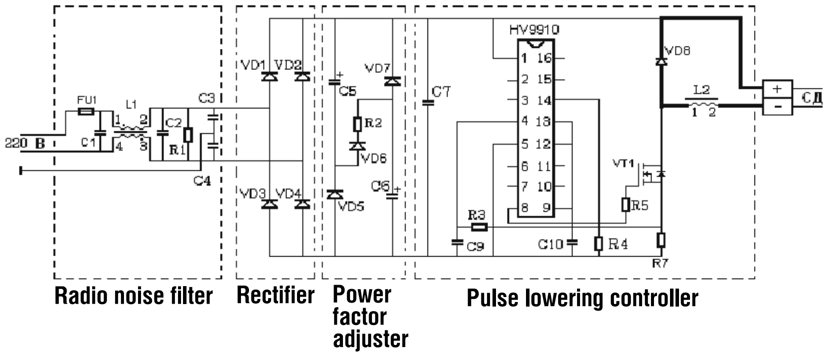

Fig. 10. Electronic ballast on the basis of a pulse reducing controller

some typical examples of manufactured LED supplies given. They belong to different subgroups of electronic ballasts according to the classification given in Fig. 5.

3.2. Electronic ballasts without galvanic separation of input and output

3.2.1. Linear controllers

Linear controllers represent an elementary type of electronic ballast. They only contain three elements: transistor, resistive current sensor and source of threshold voltage. The transistor works in active mode and serves as a variable current limiting resistor. Linear controllers would be appropriate for use as current limiting elements *T* in LED circuits connected in parallel with one ballast of a stable output voltage (Fig. 4 b). In this case they, besides equalising currents between parallel circuits, perform two more important functions: increase dynamic resistance of the circuits, i.e. allow essential lowering requirements for ripples of ballast output voltage, as well as ensuring a possibility of pulse-width control of LED current when correspondent digital signal enters their input. Such stabilisers developed specially for light-emitting diode circuits, are already being produced commercially.

For example, *Infineon Company* produces *BCR* series of linear controllers for current from 10 mA to 2 A (with an external transistor) and for voltage up to 40 V. The appearance and electric diagram of one product of this series (*BCR321 U*) are given in Fig. 9. The main characteristics of this controller are as follows: up to 250 mA current, up to 24 V voltage, up to 1 W dissipated power, 6-lead case *SC74*, a possibility of pulse-width control when entering one digital signal *μC* to the control input from an external controller.

It should be noted that linear controllers would not be appropriate for use with non-stabilised power supplies since in this case raised power losses in controller transistors take place.

3.2.2. Pulse controllers

The most widespread device of this group is an electronic ballast on the basis of a pulse power reducing controller, an example diagram of which is given in Fig. 10.

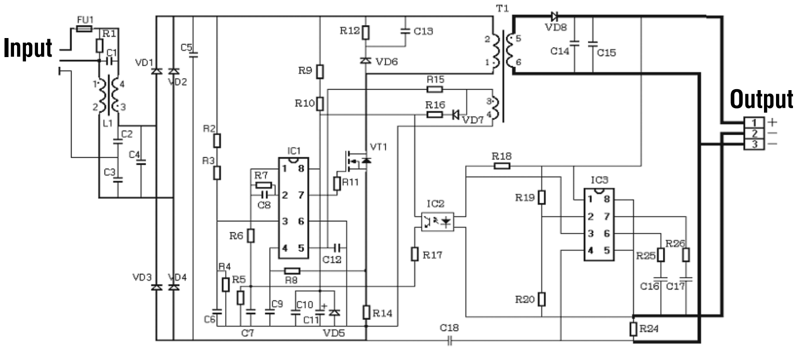

Fig. 11. Electronic ballast on the basis of a reverse-move voltage converter

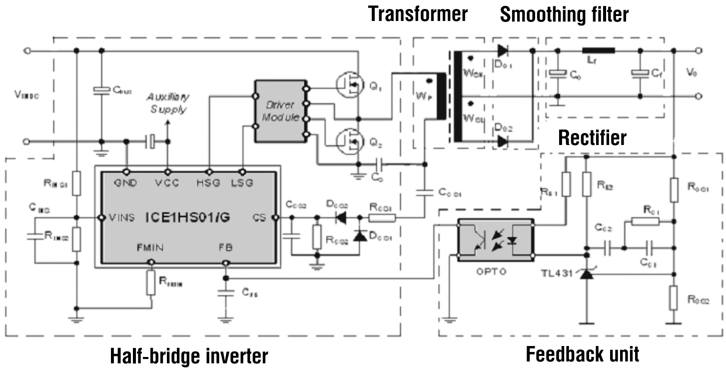

Fig. 12. Ballast circuit for street luminaires of power more than 100 W

The ballast circuit contains a radio noise filter, a rectifier, a passive diode-capacitor adjuster of power factor and a pulse power reducing controller made on the basis of high-effective inexpensive PWM-controler *HV9910* (or *HV9961*) of *Supertex Company.* This controller is capable of working in the voltage supply interval of 8 to 450 V. Constancy of the LED luminance is reached using stabilisation of the output current, either according to its peak value (*HV9910*), or according to it average value (*HV9961*). Output current is direct with saw-tooth high-frequency ripple (20–100 kHz) which excursion is set by throttle L_2 and selected as a rule between 20 % and 40 %.

In circuits of this class, other microcircuits can be also used as a PWM-controller, for example *IRS2540* of *International Rectifier Company*, and to ensure a high power factor and low harmonic distortion factor of the current consumed from the mains, an active equaliser of power factor can be used.

Electronic ballasts on the basis of pulse controllers have found a wide utility with power loads up to several tens Watt, if a galvanic decoupling between their input and output is not required. If such a decoupling is needed, devices of another group (Fig. 5) constructed on the basis of single-step (reverse or direct-move) or push-pull voltage converters are used.

3.2. Electronic ballasts with galvanic isolation of the input and output

A distinctive feature of these ballasts is the availability of a transformer ensuring galvanic decoupling of the input from the output.

One of the most widespread devices in this group is the electronic ballast based on reverse-moving voltage converter, an example diagram is given in Fig. 11 [8].

The circuit contains a radio noise filter, a rectifier and a reverse-move voltage converter operated by *IC1* controller of power factor (model *TDA4853*) of *Infineon Company*. This inexpensive 8-lead microcircuit performs two important functions at the same time: first, it ensures a high power factor and a low level of harmonic distortions of the input current, and secondly, depending on the feedback type (by voltage or by load current) it allows forming any output characteristic. Due to the latter, the device can be both a current source, and a voltage source. In order to accomplish the second function, microcircuit

IC3 (controller of current-voltage *TLE4305 of Infineon Company*) and insulating optical transistor *IC2* are introduced in addition to the circuit. A signal proportional to output voltage comes to the input of controller *IC3* from voltage divider *R19*, *R20*, and a signal proportional to output current comes from current resistive sensor *R2*4. If the load is connected to output plugs 1 and 3, the device is a voltage stabiliser, and if connected to plugs 1 and 2, it is a current stabiliser.

An advantage of the device consists in its relative simplicity and low price as it only contains one power key VT_1 and one wire-wrap element T_1 (with the exception of radio noise filter throttle) performing functions of a storage throttle and transformer in the same time. Therefore many other companies produce devices according to the same scheme. The difference between devices of different companies is in type of the microcircuits only.

So, for example, as a controller of power factor, *Texas Instruments Company* applied *UCC28810* microcircuit, *STMicroelectronics Company* used *L6562 A/AT* microcircuit, *ON Semiconductor Company – NCL30000* microcircuit, and *NXP Semiconductors Company – SSL1750* microcircuit etc..

Optimum output power of this group of devices is 10–100 W (*NXP Semiconductors* C*ompany* considers 250 W power to be the top limit for devices of this group).

Devices for a higher power would be appropriate for development based on push-pull voltage converters.

So for example, based on push-pull voltage converters, *Infineon Company* suggests to produce devices for street luminaires of power higher than 100 W. A circuit of such device type is presented in Fig. 12. It contains a half-bridge inverter with transistors *Q*1, *Q2*, a matching dividing transformer T, an output rectifier and a voltage feedback unit consisting of programmed stabilitron *TL431* and of an optical transistor. A filter of radio noise, mains rectifier and power factor equalizer are not shown on the diagram of this circuit but they are available here. Ballasts of this group have a high efficiency and are not bounded by the top power limit.

4. CONCLUSIONS

LEDs represent nonlinear electrotechnical elements which operate using direct current. To ensure their preset mode when connecting to an alternating current circuit, special supplies are required with rectifiers and current limiting devices.

Electronic ballasts have primary propagation as LED supplies, because they have almost unlimited functionality and allow performing all operations on energy conversion, which are necessary to form optimum starting, working and adjusting LED modes.

Circuitry of electronic ballasts for LEDs does not practically differ from the known circuitry of secondary power supplies. Therefore with due regard for LED specifics, electronic ballast circuitry for them is based on achievements of modern conversion facilities.

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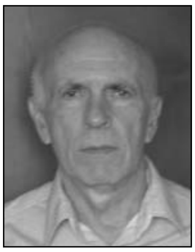

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Light & Engineering
Vol. 19, No. 3, pp. 68-70, 2011

Svetotekhnika
No. 2, 2011, pp. 6-7

ILLUMINATION OF CITIES ILLUMINATION OF A PUBLIC GARDEN NEAR ST.-PETERSBURG STATE THEATRE "BUFF" USING LIGHT EMITTING DIODES

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ABSTRACT

A short description of public garden illumination project using light emitting diodes implemented near one of theatres of the northern capital.

Keywords: public garden, theater, illumination by light emitting diodes (LED), luminaire with LEDs, lighting installation

Fig. 1

The St.-Petersburg state theatre "Buff" celebrated its relocation to a new modern building on Zanevsky Prospekt. In autumn 2010, city authorities arranged for and carried out improvement work on a public garden located near the theatre building.

Work on creating the lay-out, landscaping and small architectural elements in the public garden was carried out under the direction of the chief city landscape architect L.V. Kanunnikova.

As a result of a constructive and fruitful cooperation with the Chief architect of the project, a new public garden has appeared opposite the theater, in which contemporary external illumination supported by original luminaires based on light emitting diodes are installed (Fig. 1). They correspond to the general architectural concept of the public garden and theater building, do not disturb the stylistic integrity of the theatre and give this architectural object a unique image (Fig. 2 and 3).

The illumination project of the public garden was developed by specialists from the Lensovet SPb State Unitary Enterprise. When developing the project, engineers of Kandela Open Company designed and manufactured a luminaire with light emitting diodes, Fig. 4 (CD-42–001 "Buff" type) . The luminaire has the latest design and dramatically differs from its analogues with traditional lamps used for landscape gardening illumination. As a light source, a light-emitting diode module (LEDM) containing 42 light emitting diodes of *Golden DRAGON oval Plus* series of Osram company is used in the luminaire. The LEDs are installed on a round aluminum printed-circuit board 200 mm diameter. Orien-

Fig.2

Fig. 3

tation of the light emitting diodes ensures light distribution that allows optimum illumination of paths in the public garden at a support height of 5 m and a distance of 25 m between them (Fig. 5). The LEDMs are equipped with protection polycarbonate glass 275 mm diameter. The thickness of the luminaires is only 25 mm and they are provided with air filters. Ballasts for LEDMs have *IP66* protection degree and are located in support socles.

The luminaire case is disk-shaped. It is made of an aluminum alloy 600 mm in diameter ensuring LEDM heat removal improved using KTP-8 heat-conducting paste.

A necessary requirement for modern lighting installations is high energy efficiency. In this respect we estimate illumination of the public garden from this point of view. If questions of architectural compatibility are not considered, it should be noted that in St.-Petersburg traditional “Petersburg style” lanterns with arc discharge lamps (ADL) are usually used for the illumination of this type of object. The power of such a luminaire with a 125 series ADL lamp for example makes for about 147 W. The number of supports and distance between them correspond to used ones in this project. Thus power consumption for illumination of the public garden using light emitting diodes is 2.8 times lower, than in case of ADL lamps (1.3 kW as against 3.7 kW). Use of more economic high pressure sodium lamps (HPSL) of 70 W n landscape gardening illumination

Fig. 4

Main technical parameters of the lighting installation and luminaire are as follows:

Number of the lighting supports	25
Average pitch of support installation	22 m
Support height	5 m
Installation power	1300 W
Luminaire number	25
Number of light emitting diodes in a luminaire	42
Luminaire power	52 W
Luminaire luminous flux	3900 lm
Chromatic temperature of light emitting diodes	6500 K
Luminaire power factor	0.93
Average horizontal illuminance on paths axis	18 lx
Warranty period for a luminaire	3 years

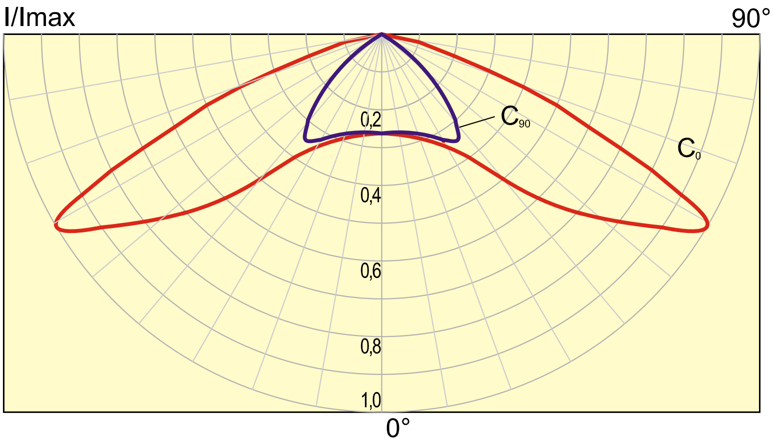

Fig. 5

contradicts light design basis: green herb and leaves in yellow light acquire a brown shade.

In accordance with our calculations, the pay-back period of luminaires with light emitting diodes which are more expensive than luminaires with ADLs, is about 7 years at current tariffs thanks to electric power savings. In this case decrease of expenses for service and maintenance (because of insufficient operation experience) was not taken into consideration, and this period can be reduced by reduction in cost of supports[1].

It is important to also mention the new quality of the achieved illumination: illuminance on paths axis of 3 m width is 15–20 lx (on average, as it was noted above, 18 lx), and unusual uniformity for landscape gardening illumination was reached. Besides, representatives of the Petersburg television who covered opening of the public garden during their broadcast, noted the high quality of colour rendition.

Finally and most important that new illumination created a festive mood for the theatre's audience, which is so necessary for a culture enterprise opening its doors mainly in the evening. For this alone it will certainly be worth increasing about 4 times illuminance standard in accordance with 23–05–95* Building regulations and to increase slightly pay-back period. In conclusion, we invite our light engineering colleagues and power engineering specialists to share an experience of creation and operation of light emitting diode city illumination at our journal.

1 For such installations in St.-Petersburg, more expensive cast iron supports are usually used.

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Light & Engineering
Vol. 19, No. 3, pp. 71-77, 2011

Svetotekhnika
No. 2, 2011, pp. 39-43

LUMINAIRE SYNTHETIC MATERIALS AND THE ENVIRONMENT

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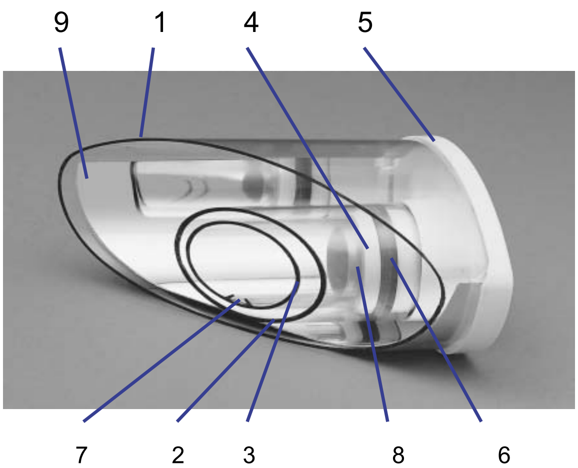
ABSTRACT

Higher protection category luminaires for special areas of application, for example for low temperatures below –50 °C, cannot be designed by relying on a single family of polymer materials alone. Frequently design combinations of duroplastic, thermoplastic and elastomer materials are used. Environmental aspects in connection with the worldwide shortage of raw materials and crude oil are important parameters when it comes to the development of new equipment. For synthetic materials waste, well proven material, raw material and energy-wise recycling alternatives are available.

Keywords: sustainability, environment, continuous operating temperature, ageing resistance, durability, waste control, recycling, reclamation, electrical properties, reliability, entropy, process engineering, closed loop recycling management, product responsibility, uninterrupted service.

1. GENERAL PRINCIPLES

Synthetic materials, respectively polymers are today an integral part of our everyday life. They are important materials in many technology development projects like, for example, aerospace, automotive engineering, electrical engineering or high protection category luminaires. We encounter synthetic materials in the workplace, at home and in our leisure time by way of numerous products like packaging, foils, bath and sanitary products, bottles, boxes, pieces of furniture, toys, electrical appliances, construction materials, windows, luminaires etc.



1 Lamp cover made of clear synthetic material, either polymethyl methacrylate (PMMA) or polycarbonate (PC)
2 Heat accumulation tubes made of polycarbonate (PC)
3 Inner heat accumulation tube, concentric, made of polycarbonate (PC)
4 Inner adapter made of polybutylene terephthalate (PBTP), glass-sphere reinforced
5 Face section made of polybutylene terephthalate (PBTP), glass-sphere reinforced
6 Gasket made of ageing resistant silicone
7 Brass ignition strip
8 Contact cylinder for brass ignition strip
9 Specular reflector made of aluminium, either wide or narrow beam

Original photo: Cross-section of a lamp cover for low ambient temperatures (13) made of different materials

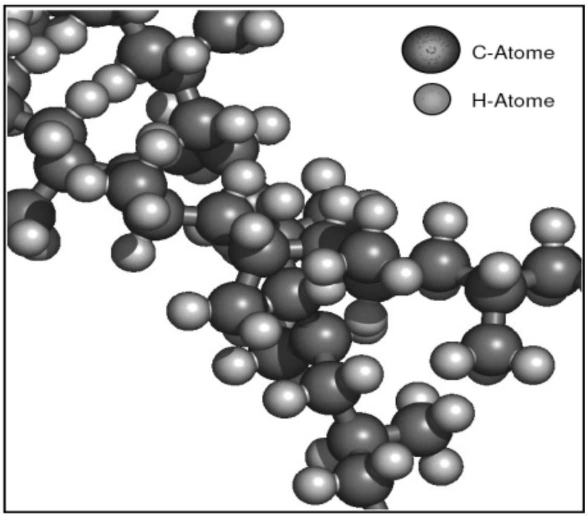


Fig. 1. Space filling model of PP [12]

Synthetic materials consist of millions of very long intermeshed organic molecular chains (polymers), which are composed of many always repeated basic units (the so-called monomers).

For example, the polymer PP[1] consists of repeating polypropylene units (Fig. 1).

An important characteristic of the synthetic materials is that their properties like plasticity, hardness, elasticity, breaking resistance, temperature and thermal forming resistance as well as chemical resistance can be varied within wide limits through the selection of the base material, the manufacturing process and by mixing additives [12].

Basically polymer materials can be divided according to their physical properties as well as their chemical structure in thermoplastic, duroplastic and elastomer materials, which need to be differently characterised [1,12].

Thermoplastic materials consist of long, linear molecules. When applying energy, these materials become mouldable to plastic and finally melt. By employing various reforming processes they can be shaped as desired. After the respective part has cooled down, it maintains its shape. This process is reversible.

Duroplastic materials are synthetic materials which, when heated, closely crosslink. This cross-linking is affected chemically between the molecules of the base material and is an irreversible process, i.e. as soon such a material has cross-linked it can thereafter only be processed mechanically. Duroplastic materials are usually hard and brittle.

[1] PP: polypropylene

Elastomers consist of cross-linked caoutchouc. Here cross-linking is affected by vulcanisation through sulphur by means of peroxides, metal oxides or irradiation, for example. Cross-linking is wide-meshed and therefore flexible. When warmed, elastomers do not soften and cannot be dissolved by most solvents. The plastics industry can be divided into three areas: fabrication of synthetic materials, processing of synthetic materials and synthetic material mechanical engineering.

In 2005, the approximately 3650 vendors of the plastics industry attained with about 374.000 employees a total turnover of 73.1 billion Euro (Table 1). Here the number of vendors active in the fabrication of synthetic materials and synthetic material mechanical engineering of approximately 50, respectively 800 is compared to the approximately 2800 synthetic material processing vendors, significantly lower.

Table 1. Characteristic data of the German synthetic materials industry for the year 2005 [9]

Industrial area	Number of vendors	Workforce	Turnover (in billion EUR)
Synthetic materials fabrication	50	51.700	21.0
Synthetic materials processing*	2.800	275.100	44.8
Synthetic materials mechanical engineering	800	47.500	7.8
Total	**3,650**	**374,300**	**73.6**

* companies with over 20 employed only

In the year 2005 and according to information from Plastics Europe Deutschland e. V., a total of 18 million tonnes of synthetic materials were produced. The different synthetic materials of this quantity consumed in Germany are depicted in Fig. 2. From this it is apparent that especially the synthetic materials PE[2], PP[3] and PVC[4] are used in greater quantities.

These synthetic materials offer different properties and are processed with the aid of special man-

[2] PE: polyethylene

[3] PP: polypropylene

[4] PVC: polyvinyl chloride

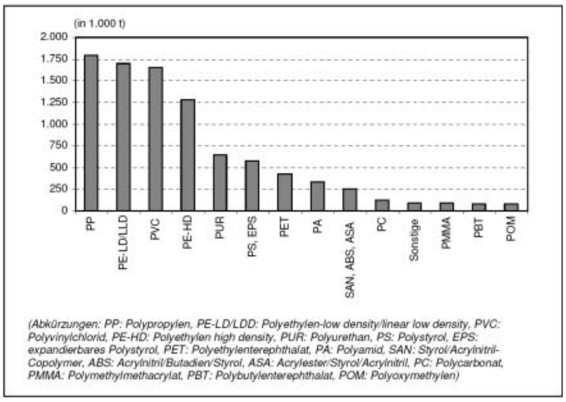


Fig. 2. Consumption of synthetic materials in Germany in the year 2005 [9] Abkürzungen = Abbreviations

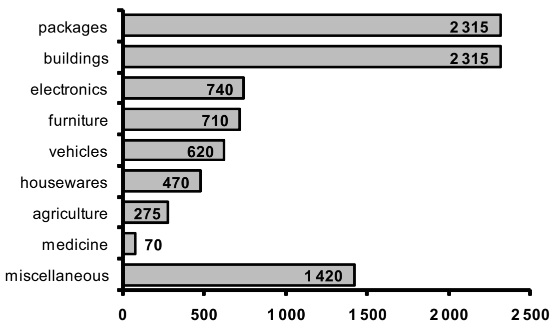


Fig. 3. Percentage distribution of the 8.9 million tonnes of synthetic material products, which reached the end consumer in the year 2003 split according to a different branches [3]

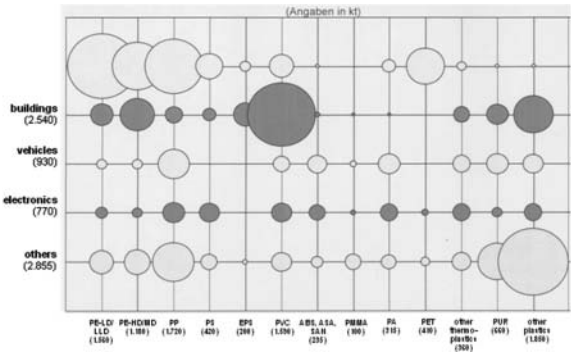


Fig. 4. Quantities of synthetic material types used in 2003 in the different branches for the manufacture of synthetic materials products [3]

ufacturing processes as well as by adding hardening, softening or colouring additives for the purpose of obtaining the desired products [4,5,6,7, 11,12].

2. SYNTHETIC MATERIALS FLOW BALANCE FOR 2003

For the year 2003, a synthetic materials balance is available from Plastics Europe Deutschland e.V. [3].

According to this in the year 2003 approximately 16.8 million tonnes of synthetic materials were produced. Adjusted by non-raw material applications like, for example, polymers which are used for the fabrication of adhesives, paints, resins and fibres; as well as in consideration of the export and import flows and stock level changes, a consumption of synthetic materials for processing purposes needs to be estimated at approximately 12.6 million tonnes in 2003 (similar level as in 2001).

Adjusted by the approximately 2 million tonnes of auxiliary materials like adhesives, paints, resins, fibres, etc. used by synthetic material processing vendors, there results a relevant quantity of manufactured synthetic materials products of 10.6 million tonnes (a 2.9 % increase compared to 2001).

But synthetic material products are not only sold within Germany but also exported, partly as packages, as products for the construction industry (like tubes, profiles, insulating materials) or as vehicle components. When balancing these export and import flows against each other, then approximately 8.9 million tonnes of synthetic material products need to be considered which have remained at the German end consumer (similar level compared to 2001).

To what extent these synthetic material products have reached the end consumer through different industrial branches can be taken from the graph in Fig. 3.

From this it is apparent that more than half of the synthetic material products alone have reached the end consumer through the branches of packaging (foils and hollow items etc.) and construction (pipes, profiles, insulation etc). At decreasing quantities there followed the branches electrical/electronics, furniture, vehicles, housewares, agriculture, medicine and others).

Within the individual branches, different types of synthetic materials are used in the manufacture of synthetic material products (Fig. 4).

For example in 2003, **packaging** was made to approximately 75 % of polyolefins (PE-LD/LLD approximately 34 %; PE-HD/ mD approximately 18 %; PP approximately 24 %). The PET share has in the packaging branch above all, owing to the increased use of PET bottles, doubled from 1999 to 2003 to 10 %.

Table 2. Balanced quantities of acquired, reusable and removed synthetic material waste in Germany for the year 2003 from various waste sources [3]

waste source area	collection overall (kt)	thereof utilization (kt)	thereof disposal (kt)
industrial waste at private disposer	904	465	439
processor	802	710	92
Duales System Deutschland (green point of germany)	731	731	0
residual waste households	669	0	669
bulky	147	7	140
material collection electronic waste	147	39	108
domestic refuse at industial waste	133	0	133
material collection by city waste departmens	118	118	0
car shredder	96	15	81
producer	86	81	5
Interseroh	72	72	0
bond initiative	50	50	0
processor initiative	28	28	0
other collection systems for transport packages	22	22	0
total	**4 005 (100 %)**	**2 338 (58 %)**	**1 667 (42 %)**

In the **construction** branch, PVC material dominates (approximately 46 %), followed by PE-HD/ mD (tubes, for example) and the other synthetic materials.

In contrast to this, there exists in the **vehicle industry** branch a rather widely spread range of applied synthetic materials with slight focusing on PP (approximately 27 %) as well as ABS, ASA, SAN, PUR and PA.

In the **electrical/electronics** branch also different synthetic materials are used due to heterogeneous applications and areas of application.

In the area of **other** branches, chiefly PP and PUR as well as other synthetic materials are used. The "others" branch includes, among other things houseware; furniture, agriculture, medicine, mechanical, equipment and systems engineering, sports, toys and leisure items (including sports shoes) as well as writing and drawing utensils. The category of "other synthetic materials" includes epoxy, phenol and polyester resins; melamine resins and urea resins, blends as well as custom synthetic materials at quantities frequently below 50,000 tons per year.

In connection with the topic of synthetic materials and the environment it is of special importance to consider the waste quantities acquired in Germany and the shares being recycled or removed (Table 2). Here it needs to be assumed that synthetic materials products with a short service life (packaging, for example) can immediately be found in the waste flow again. Products with a very long service life (for example those from the area of construction with partly a service life of over 80 years) exhibit on the other hand only a very low share in the waste flow.

Of the well over 4 million tonnes of synthetic materials waste collected in the year 2003, 58 % is recycled and 42 % is removed.

In 2003 at 904 kt, respectively 803 kt, most of the synthetic materials waste was produced by processing business enterprises. The synthetic materials waste from processing enterprises is commonly very pure and was recycled to almost 90 %. The recycling share of synthetic materials waste disposed of through private waste disposal vendors was on the other hand only approximately 50 %. Such synthetic materials waste was frequently of low purity. In 2003, dumping untreated waste in a landfill was still the most frequently used means of disposing of waste; this was prohibited in the middle of 2005.

In the areas DSD[5] (green dot) and residual waste also large quantities of synthetic materials waste were collected (731 kt respectively 669 kt). When adding the synthetic materials waste in residual refuse to the synthetic materials quantities in the bulky waste (147 kt) then the share of synthetic materials not recycled within the area of households is higher than the share acquired and recycled by the system of the DSD.

The processes mandatory since mid-2005 for residual waste pre-processing will contribute substantially towards the recycling of synthetic materials contained in the residual waste by way of extracting material-wise or thermally-wise usable partial waste flows. Through the modern separating technology used in connection with this, the synthetic material shares can be almost completely separated at very high levels of purity. Practical trials lead to the conclusion that this is so efficient that one could dispense with separately collecting the packaging materials (DSD). This is supported by the fact gained from practice [8], that in urban centres the residual waste contains packaging material quantities almost

[5] DSD: Duales System Deutschland GmbH

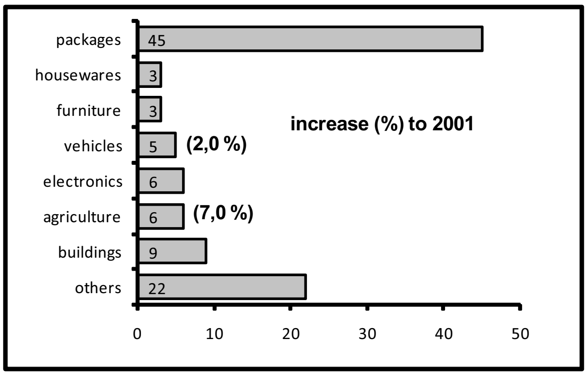


Fig. 5. Quantities of synthetic material waste which were collected in 2003 at German end consumers, split according to the various product ranges [3]

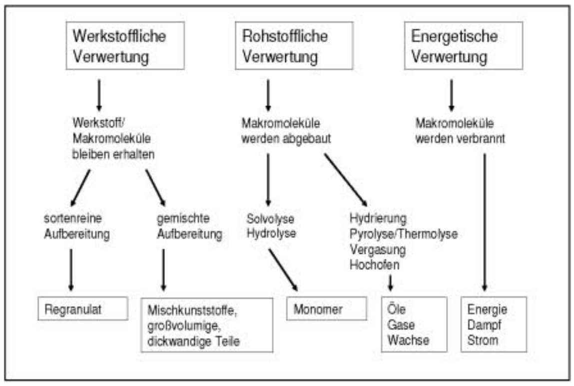


Fig. 6. Overview of ways of synthetic materials recycling [10]

at the same level as they are collected in parallel through the yellow sack.

Over ¾ of the synthetic materials waste (77.8 %) is collected from end consumers; in the producing and processing industry this share amounts to 22.2 %.

When relating the synthetic materials waste collected from the end consumer to specific product ranges (Fig. 5) it becomes apparent that most of the synthetic materials waste (45 %) is due to packaging materials. In the area of packaging materials, the highest waste increases are apparent compared to 2001 (12 %). Thus most efficient collection and recycling of packaging materials is of special importance.

Recycling of used synthetic materials is an important contribution to closed loop recycling management and the product responsibility demanded by the Waste Avoidance and Management Act. Here recycling can be affected in three fundamentally different ways as depicted in Fig. 6.

In the case of **material recycling**, used synthetic materials are mechanically processed. Their chemical structure remains unchanged. The old components are reduced to small pieces, cleaned and separated according to the type of synthetic material. The purer the recycling material obtained in this way is, the more can be used to substitute newly produced polymer granulate.

In the case of **raw material recycling**, the polymer chains are chemically decomposed. The resulting products are monomers or petrochemical raw materials like oils and gases which can be utilised in the manufacture of new synthetic materials or as fuels, for example. Raw materials recycling is suitable for mixed and contaminated synthetic material fractions.

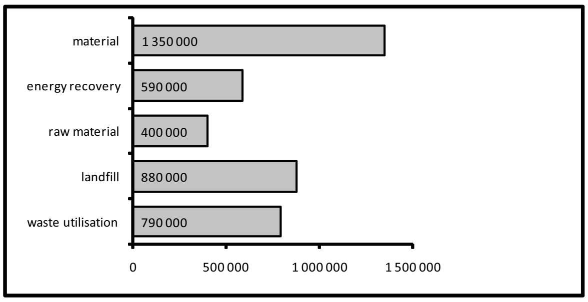


Fig. 7. Type of recycling and removal in 2003 in Germany of approximately 4 million tonnes of collected synthetic material waste [3]

In the case of **energy recovery**, the energy contained in the polymers is released by combustion while at the same time utilising this energy for generating electric power and/or producing steam, respectively making available process heat. Energy recycling is suited for mixed and for contaminated synthetic materials fractions, in particular for those which are much contaminated.

Which type of recycling or removal is utilised for the total of approximately 4 million tonnes of synthetic material waste can be taken from Fig. 7.

From Fig. 7 it is apparent that of all recycling processes, material recycling is of the greatest importance. In the case of this recycling method it is today possible through modern and well-proven separating and processing techniques to obtain pure recycled granulate. However, this method is costly and demands complex process engineering. If from the recycled granulate synthetic materials products shall be produced, which are not particularly demanding material-wise (thick walled noise protection walls or grass paving stones made of synthetic material), then the requirements regarding the purity of the recycled granulate need not be high. In this case separating and reprocessing complexity can be restricted to the necessary level.

Energy recovery is, according to Fig. 7, quantity-wise the second most important way of recycling synthetic materials. Here generally the synthetic materials waste is contained in specially processed substitute or secondary fuel mixtures used for the generation of energy. The energy can be generated in plants which are erected exclusively for burning secondary fuels or by co-combustion in coal-fired power plants or cement kilns where a tolerable share of substitute fuel can be used. However, the scope of energy recovery based on synthetic materials differs widely in practice. Only provided the energy produced by the plant serving the purpose of energy recycling is utilised as comprehensively as possible (by way of generating electricity and simultaneously providing district heating, for example) or like in the case of cement kilns by substituting otherwise required sources of primary energy, will the actual degree of recycling the energy formerly contained in the synthetic materials, be very high.

As can also be seen in Fig 7, in the year 2003 still a share of 42 % of all synthetic materials waste was removed i.e. burned in waste incineration plants or dumped in landfills. Due to the fact that since mid-2005 dumping of untreated waste in landfill is prohibited, today also these synthetic materials, instead of being dumped, are recycled with the aid of waste processing technology as components of secondary and substitute fuels mixtures and supplied to thermal recycling.

From the aspect of energy efficiency and climate protection attention needs to be paid not to supply energy-rich valuable synthetic material waste to such waste incineration plants intended only for waste removal instead of optimised utilisation of the potential energy contained in the supplied waste.

3. SUMMARY

Numerous products can be manufactured based on synthetic materials, which meet most varied requirements and exhibit most varied properties. The vendors active in the area of synthetic materials fabrication, synthetic materials processing and synthetic materials mechanical engineering are constantly working on chemical and engineering developments. Quantity-wise, the synthetic materials PE, PP and PVC, which we encounter in everyday life by way of packages, textiles, foils as well as carpeting and window profiles, are of special importance. From the material flow balance for Germany is apparent that the quantity totalling 8.9 million tonnes of synthetic materials products produced in 2003, these being in particular packages and products for construction engineering, reached the end consumer. The majority remained in use by the end users so that at 4 million tonnes in 2003 only half that amount is noted as synthetic materials waste.

When looking at the recycled and removed quantities it must be noted that in 2003 a share of 42 % of the synthetic materials waste was not recycled but only removed instead. The cause for this was in particular dumping privately disposed of business waste as well as residual and bulky waste in landfills which in 2003 was still allowed.

Because of mandatory waste pre-processing since mid-2005 in Germany, it can be assumed that today the quantities of synthetic materials waste removed in 2003 are being reprocessed to material-wise and thermally-wise utilisable material mixtures and are being supplied in to recycling systems. In the case of thermal recycling attention should be paid that the energy potential contained in the synthetic material waste is utilised as comprehensively as possible with the available plant technology (i.e. by simultaneously generating electricity and providing long-distance heating).

In so far, well-proven materials, raw materials and energy recycling alternatives are available for synthetic material waste. Through these alternatives a utilisation of high ecological efficiency (i.e. with a benefit to the environment which is as high as possible at tolerable costs) is possible for all synthetic materials waste collected in Germany, depending on mixture and quality.

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Light & Engineering
Vol. 19, No. 3, pp. 78-86, 2011

Svetotekhnika
No. 1, 2010, pp. 13-19

THE ART OF BERLIN LIGHTING

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ABSTRACT

This article presents a brief historical review of street lighting in Berlin. It focuses on more than one hundred years of evolution of architectural lighting of building facades in the city. In recent decades, Berlin was has been active construction and reconstruction of architectural lighting, which led to the formation of a completely new light and colour medium and lighting image of the city. In the historical city centre large ensembles of light were created, which are spontaneously combined into a single urban lighting system. Examples of the most successful lighting solutions are discussed.

Keywords: architectural lighting, lighting design, lighting architecture, lighting panorama, lighting ensemble

Berlin has a special place in the history of urban lighting. In this, as in other, areas of art, science and technology there have been ups and downs, bright and tragic events. The invention of electric lamps in 1870–80 in Europe and the U.S. (P.N. Yablochkov, A.N. Lodygin, T. A. Edison and others) caused the evolution of new and spectacular visual effects, now referred to as lighting design. Berlin was among the first cities that implemented electric lamps to functional street lighting and architectural lighting of facades of noteworthy buildings. Already in 1887, two of the city's main cathedrals were illuminated by arc discharge lamps. In 1895, Emperor Wilhelm II initiated the first in history "Festival of Light". These days, "festivals of light" have become very popular in many cities around the world. Germany, through the works of utopian writer P. Scheerbart in 1906, gave a comprehensive definition of expressive effects of electric light – Lichtarhitektur (Light architecture) which received international acclaim.

The First World War slowed down the progress of the country, but in the 1920's avant-garde movements in architecture and art evolved rapidly. Supporters of a new material for architectural expression – electric light – were E. Mendelson, B. Taut, H. Scharoun, E. Mei, L. Hilberseymer, M. Breuer, W. Gropius, L. Mies van der Rohe, M. Wagner, brothers G. and B. Lukhardt, etc.

Berlin, as the capital, was most concerned about its status and prestige because of the military defeat that challenged, and not without success, the leadership of Paris as the first "city of light". Many architects drew inspiration from the experience of lighting installations in New York; others rejected it, creating something more contemporary. Discussions about the architecture of light were part of famous debates in the Weimar Republic. The Nazis used persuasive visual, metaphorical and symbolic effects of electric light for their ideological purposes by applying the key ideas and achievements of the previous years. A. Speer, chief architect of the Third Reich was experimenting with the powerful anti-aircraft searchlights, creating stunning "Cathedrals of Light" (Lichtdom) [1, 2].

The Second World War once again interrupted progress. Much of the progress in the field of artistic lighting was forgotten or faded into the background. Berlin was divided into two cities. The capital of the GDR was hardly touched by the energy crisis of 1970, but West Berlin felt its consequences. In 1979, after visiting East Germany, I shared my impressions of architectural lighting in East

Berlin, Weimar, Leipzig, Dresden and Erfurt in paper [3]. The most striking impression on me was made by the illumination of a 368-meter tower at Alexanderplatz in Berlin because of its artistic effect and techniques far superior than the lighting of the Ostankino Tower in Moscow and the Eiffel Tower in Paris. The powerful radial light beams rotating over a spherical volume of a cafe at a height of 200 m, ripped up the night sky, uniting the space of the city divided by the Wall and ideology at the cosmic horizon level. The second unquestionable achievement was the illumination of some baroque and modern fountains in Berlin and Dresden. I also noticed the stylish street lamps in the pedestrian zones of some cities in the GDR, which Russia did not have at that time.

In general, having evaluated architectural lighting of buildings in the capitals of the Soviet Union, Poland, France and the GDR in the late 1970's I can say that, in general, the quality was quite comparable. But the capitals of those countries differ in the number of illuminated objects, the diversity of applied methods, techniques and regimes of illumination, which, together with the individuality of architecture and urban settings, provides for each of them its own original light image.

In the terms of lighting technology, that was a transition period from old incandescent lamps toward discharge lamps, dominated by mercury and high pressure sodium (HPS) lamps as well as metal halide (MH) lamps that had recently been developed. In social terms, architectural lighting was not a truly urgent and global problem, and the art of lighting design was yet a significant creative challenge: the passions on this topic in intellectual society were not boiling, as they were in 1920–30.

The unification of Germany in 1989 and returning to Berlin the status of national capital in 1991 led to the architectural and construction boom at the turn of the century. The city was called "a major construction site" in Europe, where almost all the celebrities of modern architecture participated. A byproduct effect was happening in the city's lighting.

In 2005 I participated in "Lux Europa" and in 2009 in the Second International Conference of the Association of Professional Lighting Designers (PLDA), which were held in Berlin. There I had an opportunity to observe the progress in the city's lighting. First – my general impression. No information exists on the general plan of Berlin lighting – the most common conceptual design document, which outlines the basic goals, objectives, principles and parameters of urban lighting. They could be particularly guessed from the presence (or absence) of urban spaces zoning: in the first place based on the chromaticity of the lamp radiation in street lighting installations, optically forming various scale and function illuminated areas in traffic and pedestrian zones.

In part, various designs of street lighting fixtures may also be used in street lighting (such as in Paris). We could not find the presence of these means in Berlin. The colour and the design of lamps in various parts of the city are very different, and even now West and East Berlin differs from each other. In the first, many streets with car traffic are illuminated with fluorescent lamps, and pedestrian streets – with exotic gas lanterns (tokens of history of Berlin, London, Vienna and some other Western cities). In East Berlin most of the lamps are HPS and MH. However, in both parts of Berlin one can see also both compact fluorescent CFL and MH lamps. Retro-style lamps are more common in West Berlin. The city is very green; in fact every street is a boulevard, but there are no decorative lighting fixtures present, even in parks. Tree canopies in summer make many illuminated streets look like shadowy tunnels (Kurfürstendamm). The giant Tiergarten park at night is dark and scary (except for the major axial artery "Street of June 17", that "sweeps" the park from east to west). We could not find any special attention toward illumination of the most important structural elements of the city planning system – a natural "skeleton" of the city such as green spaces and water.

The illumunation of various architectural ensembles is another thing. The most famous one is the modern masterpiece in this genre – a variety of architectural blocks at Potsdamer Platz with the nearby Berlin Philharmonic, New National Gallery and the "Memorial to the Murdered Jews of Europe".

Obvious and undisputed light-dominant at night in the city center is the self-luminous, 103-meter high, glass tower of the Sony Center that occupies a small triangular block (architect H. Yang, lighting design – Ya Kersale, 1996–2001 (Fig. 1). Behind this tower there is a complex of glass buildings that are forming a fantastic oval in plane "Forum" (Sony Plaza), covered with a translucent "Dome" having an original "Mount Fuji" silhouette of folded petals resembling a daisy from below (Fig. 2). The "Dome" is equipped with a backlit dynamic colour installa-

Fig. 1 Western panorama of Potsdamerplatz illumination

Fig. 2 The Sony Center tower as seen at night from the Sony Plaza

tion on the "daisy's" outer perimeter. It looks very impressive in the light panorama of Berlin Centre, and also creates at night an emotional atmosphere of the Forum space underneath the Dome. Together with other luminous elements (stained glass offices, elevators, cafes, restaurants and a theatre, built–in paving lights, illuminated benches, trees, fountains, etc.) that are reflected in the glass facades, the Dome itself creates, together with the sounds, movements and scents of the air, a surreal Alice's world of looking through the glass, in which material elements dissolve, the sense of gravity dulls, giving birth to unexpected sensation of vibrating space. One becomes an organic part of this medium, dissolved in it without regret of losing one's ego, feeling comfortable and excited. The courtyards between the Sony Center buildings, which are not as multi-functional and crowded, only reinforce this unusual sense of unreality. Emergency lighting systems with fluorescent lamps built into the buildings' glass facades sparkle and glare with the movement of visitors in a Gulliver's kaleidoscope. The focal point of the forum is a fragment of the old hotel "Kaisersaal" that has miraculously survived the WWII bombing. It is enclosed in a glass shell as a precious artifact integrated into the structure of the first floor of the new centre and illuminated in this "aquarium" with dynamic RGB light emitting diodes. He immediately attracts attention at the entrance to the "forum" from the square.

The adjacent more structurally complex and extensive quarter on the south side of Potsdamer Strasse, the construction of which was financed by Daimler-Benz, is more diverse in function and architecture and is not such a dynamic and integrated luminous body as the Sony Center. The entrance into the quarter is marked out by two towers of Chicago-style office building 88-meter high with red glazed brick facade (architect. Kollhoff H.) illuminated with flood lights. Anther building, an18-storey glass tower with ceramic façade details (architect. R. Piano) has local lighting that gives it subordinate importance in silhouette-dominant triad of towers (Fig. 3).

Within this quarter a miniature "Marlene Dietrich Platz" attracts attention with a decorative pool in front of the "Comedy Musical" and a glass façade of the Imax cinema, glowing in blue light (architect R. Piano). Diverse in architecture but picturesque only at day time, the composition of the area is losing its splendor at night: the focal space covered by the great canopy of the main entrance to the "Comedy musical" is not sufficiently saturated with light, as one would like, and this flaw cannot reinforce other elements of the light ensemble. Original park sculptures located here and there in the neighborhood of Potsdamer Platz, unfortunately, do not always have proper individual attention to lighting.

The illumination of the eastern part of Potsdamer Platz is not yet complete: the adjoining octagonal Leiptzigerplats has not yet acquired a comparable brilliance. In the Potsdamer Platz centre there are two subway glass pavilions (U-Bunn and S-Bunn, arch. Bureau "Hilmer and Shattler ") that are in the best traditions of the Mies van der Rohe architecture style and R. Kelly lighting design. A virtually unknown detail: three fiber optic hollow light-guides obliquely rise and shine at night over the paving and at daytime cast back a fraction of solar and celestial light on the underground levels of subway platforms.

The western "spine" of this twofold quarter adjoins the famous post-war buildings of the National Library (1966–78) and the Berlin Philharmonic (1960–63), both by the architect H. Sharun. The latter with its characteristically spiky silhouette, intricate forms and front panels anodized as an imitation of the golden brass, while being illuminated by searchlights, shines against a background of geometric pattern of Sony Center buildings illuminated with cool-white fluorescent lights.

Another famous building: a masterpiece of Mies van der Rohe – the New National Gallery (1965–68) located to the south, made an indelible impression on me when I saw it. (I did know it from pictures and drawings since my student years), this is definitely the number one architectural object in the whole of Berlin. Nighttime illumination of this Gallery is not permanent in nature. I saw it once with the highlighted functional interior ceiling lights and, at other times it was quite dark, with the exposition

Fig. 3 Three major office towers in light panorama of Potsdamerplatz: left- arch. P. Pyano, centre-arch. H Kollkhoff, right- arch. H. Yan (Sony Center)

lights on the first floor, while photographs show it with the expressive-linear graphic neon lights, following the ceiling joists. This suggests the existence of a multi-regime lighting system or occasional upgrades of lighting installation in a ground glass volume of the museum (Fig. 4).

The Ebertshtrasse leads from Potsdamer Platz to the Brandenburg Gate and the Reichstag, passes the "Memorial to the Murdered Jews of Europe" (in place of the demolished Imperial Chancellery) the outstanding work of monumental art (architect P. Eisenman, 2004). The Memorial arouses the sense of horror, which, probably, was the design's objective. In the evening it is enhanced by glowing, as if from the hell, backlighting some of the "streets" – spaces between the concrete coffin-shaped parallelepipeds (Fig. 5).

Directly behind the Brandenburg Gate, which are the key elements between West and East Berlin, at the intersection of east-west axes (Street of June 17 – Unter den Linden) and north-south (Ebertshtrasse), there is another large-scale ensemble of the capital caliber – the German Parliament

Fig. 4 The New National Gallery: two lighting regimes

quarter in the vast territory of the "Federal strip", which connects earlier separated parts of Berlin via the rivere Spree. The focal point of the ensemble is the Reichstag building (reconstructed by N. Foster (1999)) on the landscaped Republic square, on the north side of which stand the Federal Chancellery and the buildings of parliamentary committees and services: Paul-Lobe-Haus on the left, west bank of Spree, and Marie-Elisabeth Lyudes House on the right, east bank. Visually, this area is adjacent to the new, refined, stylish main train station, Hauptbahnhof (in place of the historic Lehrter Banhof) on the north bank of the river, while to the south – a complex of buildings on Pariser Platz with the pompous Brandenburg Gate, the restored legendary Hotel Adlon, the new buildings of the Academy of Fine Arts (architect G. Behnisch), DG-Bank (F. Gehry), etc.

Quite traditional lighting of the Reichstag by floodlights of medium intensity is not very impressive, in spite of its famous Fosterov dome, because of the proximity of a number of buildings of the Office of the Chancellor (architect A. Shultes and S. Frank, 2001) and the "House" parliamentary committees (architect S. Braunfels, 2001), the illumination of which is much more diverse and dynamic. The main glass facade of the huge Paul-Lobe-Haus (200 m long, 100 m wide), facing west toward the building of the Federal Chancellery, is brightly illuminated on the sides of a symmetrical composition, the centre of which has a deep perspective as viewed from the square interior; it has a coffered ceiling with upper natural and artificial

Fig. 5 Illumination of the "Memorial to the Murdered Jews of Europe"

Fig. 6 Night view of the Marie –Elisabeth –Lüders–Haus from the glass bridge over the Spree connecting it with the Paul-Lobe-Haus

light. The passage unites under one roof ten identical eight-storey office blocks and eight cylindrically shaped meeting rooms of parliamentary committees with courtyards between them. The open composition of the complex structure of the glass buildings and open courtyards symbolises the transparency of democratic politics pursued by Parliament and the German government. And it is vividly reflected by the organic synthesis of form, materials and lighting design of the building.

Similar in architecture to the main facade, the eastern one faces the Reichstag embankment and is connected by the glass bridge over the Spree with Marie –Elisabeth –Lüders–Haus. This is a very picturesque place with the lighting harmoniously combining the large luminous planes made of stained glass; the illuminated soaring roofs; "starry" points of ground lighting looking like the night sky inverted in the paving of pedestrian areas on the embankments; the dynamic reflection diverse in brightness, colour and pattern elements in the mirror of a narrow river (Fig. 6).

The impressive building of the Office of the Chancellor occupies the western part of the "Federal strip" on the left bank of the Spree. Its eastern facade facing a front yard in the direction of Paul–Löbe–Haus attracts attention with the diversity and elegance of light patterns and the complexity of lighting

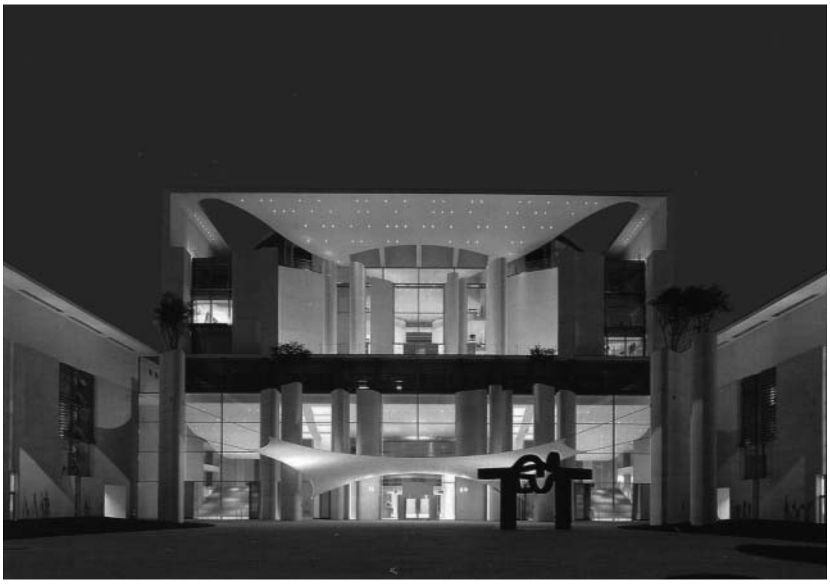

Fig. 7 The eastern façade of the Office of the Chancellor at night time

Fig. 8 The last version (2002) of stationary architectural illuminating of the Brandenburg Gate

composition: multifaceted well-lit interiors are very well visible from the street. The viewer is actively "pulled" into the centre and the depth of the symmetrical facade. Here it is even more evident the authors' desire to metaphorically demonstrate to their citizens and the world the openness of the political "kitchen" of the government (Fig. 7).

Architectural lighting of facades within this ensemble is complemented by the rational, though not devoid of elegance, illumination of the surrounding area. Local streets and pedestrian areas are illuminated by reflected light of torchere-like light fixtures on poles; the crowns of young trees along all those paths are illuminated by ground lights; on the lawns in front of the main facade of Paul–Löbe–House small fountains operate in a dynamic mode illuminated with multi colored LED lighting. The vast green area with no heavy traffic in the heart of Berlin radiates order, complete peace and prosperity.

Returning to the perfectly illuminated classic Brandenburg Gate (during the last century also it has known other versions for lighting design [4]) that serves as a historical emblem of the city and a symbol of its reunification (Fig. 8), we are coming to the Parizenplatz, which completes the most powerful architectural axis East – West of East Berlin, the main street of the capital of the kingdom of Frederick the Great, the Third Reich and East Germany – Unter den Linden ("Under the Linden street "). This street, a boulevard, connecting Parizenplatz from Alexanderplatz, is a complete urban ensemble, preserving its historical appearance due to reconstruction work conducted after the war by the DDR. By the end of 1970 s the street was shining on the background of the surrounding city. A number of facades of monumental historical buildings were illuminated (Museum of German History, the National Gallery, Opera House, etc.). Now the German government methodically and thoroughly "sands out" all the remnants of the half-century long activities of German communists. The Palace of the Republic built in 1976 on the Museum Island, that shone a festive light, has been demolished; the cascade of decorative pool in the area under the TV tower near Marienkirche is illuminated, but not as bright as before, and the lighting of the tower itself has lost its flavour – a fan of moving light beams around it. However, the magnificent Berlin Cathedral has been restored and very representatively highlighted (Fig. 9). The illunmination of several restored façades of other noteworthy buildings has also been updated. As a result, this street somewhat reminds the Champs Elysees in Paris.

Fig. 9 The Berlin cathedral and the TV tower on the Alexanderplatz

Another original architectural and lighting ensemble, similar in style to Sony Center is a multifunctional complex on the Hardenberg square near the subway station "Zoologischer Garten", historically known as the legendary Café Kranzler. In the immediate vicinity is the dominant historical district – the Kaiser Wilhelm church (Fig. 10), and close to it – "Europa Centre" and "the Elephant Gate" leading to the Zoological Gardens. This luminous ensemble also spreads their "metastasis" into the neighborhood: along the Budapest street to hotel "Interkontinent" and further to the famous buildings of the embassies of Scandinavian countries, along the area Hardenbergshtrasse to the Ernst Reuter square with the illuminated avant-garde expressive sculpture; along the Kantstrasse to the Western theater and the office tower Kant -Dreieck with a giant illuminated "yo-yo" Hahnenkamm on the top; along the Kurfürstendamm with illuminated display windows of expensive shops; along Yoahimshtrasse by Swiss-hotel to the House of the Berlin Festival and beyond.

Fig. 10 Illumination of the memorial complex of the Kaiser Wilhelm church

Light architecture of the multifunctional complex "Krantzlerek," in which, besides trade, public and office buildings situated, the Hotel Kempinski, deserves special attention. Its facades that are dynamically illuminated in the glass sharp corner of the high-rise building attract one's attention upon just approaching. However, one feels a true "high" the moment one comes into the courtyards of the complex. The authors (H. Yang and J. Kersale) use, with

Fig. 11 The inner courtyard in the Krantzlerek complex is a kaleidoscopic shining kingdom

even greater ingenuity than in the Sony Center, the mirroring effect of light in the elements of the glazed facades, which leads to optical illusions of space transformation and kaleidoscopic animation of the architectural details (Fig. 11). The courtyard area is full of small architectural forms, articles and exotic items. In one of the courtyards there are originally designed birdhouses placed among the trees. Of course, the electric light at night interferes with the birds, but they are hiding and sleeping inside and in the daytime they sing and chatter. Several sculptures of the symbol of Berlin – a bear standing on its rear paws – meet pedestrians at the entrance and lighting columns scaled to the size of man together with the ground point and linear lighting fixtures contribute to the orientation in micro spaces of the courtyards.

Evening strolls through Berlin generate a lot of positive emotions for the curious observer. They offer in comparison to the daytime, a different impression of the city's face, far from perfect, but the original, dynamically and creatively formed, quite unique, and very expressive. The image of the night Berlin is not a copy of the daylight one, no matter how good it may be. Despite the focus on saving electricity, the dominant rationale in Europe, consciously or spontaneously the "city of light" is being created that enthusiasts and utopians dreamed about hundred years ago. In 2008 Berlin resumed the "festival of light" that immediately became popular, although occasional light shows had already been arranged in previous years on significant occasions (Millennium, etc.) in the area around the Great Star Victory Column and on the Parizerplats at the Brandenburg Gate (G.Hof). The tendency, whether natural or deliberate, to create a unique light fabric of the city as a system light ensembles of various scale, and dominants at the nodal points of lighting network, can be easily noticed even by direct observations and analytical conclusions. The above examples of well-illuminated installations in Berlin can be multiplied, but they will only confirm the abovementioned impressions.

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DEVELOPING A NEW STANDARD FOR LIGHTING DEVICES

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ABSTRACT

The draft standard «Lighting Devices. Lighting Requirements and Test Methods» GOST R, a new Russian standard for lighting devices, has been developed and submitted for approval. The document was developed by VNISI Open Company of S.I. Vavilov on its own initiative with financial support from BL Group Open Management Company.

Keywords: draft standard, lighting devices, lighting requirements, test methods, lighting device (LD), luminous efficiency**,** luminous efficacy

INTRODUCTION

As of today, the situation with the standardization of lighting devices (LDs) is as follows. All requirements and test methods of LDs are established in GOST R IEC 60598–1-2003 «Luminaires. Part 1. General requirements and test methods» and in the complete set of standards GOST R IEC 60598–2 «Luminaires. Part 2. Detailed requirements», except for lighting requirements and test methods which are regulated by the following list of applicable standards:

- GOST 17677–82 «Luminaires. General specifications»;
- GOST 15597–82 «Luminaires for production buildings. General specifications»;
- GOST 8607–82 «Luminaires for illumination of inhabited and public rooms. General specifications»;
- GOST 8045–82 «Luminaires of external illumination. General specifications»;
- GOST 7110–82 «Hand luminaires. General specifications»;
- GOST 6047–90 «Searchlights of general purpose. General specifications».

There were several reasons for developing the standard presented in this paper.

1. There was a necessity to complete the lighting requirements missing from the specified GOST 60598, selecting them into an independent standard, taking into consideration that similar demands and test methods are used to a large extent for many LD lighting characteristics of different purposes.
2. There was a necessity to extend the provisions of applicable standards to LDs with light emitting diodes, as the new light source generation, taking into consideration their specific features.
3. There was a necessity to update the content and description of some provisions, requirements and test methods of applicable domestic standards in order to approach them to the correspondent international standard documents.

In this way, the newley replaced GOSTs specified above will be abolished by the enactment of the new standard.

MAIN FEATURES OF THE STANDARD

The developers of the standard were faced with some problems connected with the necessity to include lighting requirements and correspondent test methods for LDs with light emitting diodes (LED). Firstly, these problems are connected with the fact that such LDs are manufactured inseparable, representing a comprehensive whole: a light source plus a device, and consequently should be characterised not only by parameters traditional to LDs (light distribution class, luminous intensity curve (LIC) type, protection angle, etc.), but also with parameters inherent to LSs (light sources): luminous flux, burning duration in hours (service life), correlated colour temperature, etc. As a consequence of the above it was necessary to revise some parameters. For example, the LD efficiency parameter was abolished, and instead for LD luminous efficiency evaluation LD luminous efficacy was added (as an analogue of LS luminous efficacy), and LD luminous efficacy coefficient, which is to some extent an analogue of LD efficiency, was also introduced.

This was aggravated by the fact that for the development period of this standard, there were no correspondent standards on light emitting diodes themselves neither in Russia nor abroad. Many substantial aspects of light emitting diode application and test methods (for example, determination of service life) still have not been developed as standards and are of an estimative and debatable nature. Therefore in some cases, the developers of this standard had to include requirements of an experimental nature, not yet tested in practice.

Another important feature of the standard is the use of recent terms, concepts and designations of the LD photometry field. The standard had to express LD light distribution using photometric measurement systems generally accepted in world practice. In modern lighting installation design, use of computer lighting program is typical. Therefore LD measurement and light distribution presentation in a unified standardized configuration, in particular as tables and files of photometric data, is an indispensable condition of correspondent products promotion to the market. Contemporary photometric facilities meet this requirement as they are equipped with software automatically forming measurement results as standardized files.

STRUCTURE OF THE STANDARD

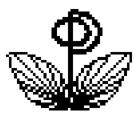
The standard contains 11 sections: «Application field», «Standard references», «Terms and definitions», «Designation», «Classification», «Lighting requirements to …» LDs of different types (5 sections) and «Test methods», as well as three necessary and four reference appendices. The material contains 26 tables, 39 pictures and 8 bibliographic references. Its total volume makes 73 pages of A4 format.

KEY POINTS PRESENTED IN THE STANDARD

1. Number of terms in the section «Terms and definitions» is mainly limited to those which are new and not standardized in accordance with GOST 16703–79[1], without which understanding the standard proves difficult. And it was considered that other terms of this standard are contained in the specified GOST. However the new draft standard contains many terms, which are either absent in GOST 16703–79, or present under another name or another definition.

The developers deliberately made this decision taking into consideration that in parallel with development of this standard, work has begun on updating the specified terminological standard, in which all specified differences will be reflected in full.

2. For the first time, a designation symbol confirming LD correspondence to requirements of the present standard, is introduced into the standard:



3. Boundary values of form factor are clarified when classifying typical LICs of luminaires.

4. For luminaires of utilitarian external illumination, classification by LIC type in the equatorial plane is expanded, and CIE classification by light distribution in glare area is added.

5. For searchlights, classification by symmetry of light distribution and by light scattering angle is added.

6. In the section on requirements for luminaires of indoor illumination for production and public buildings:

- Protection angles areas, luminance limitation zones, and values of overall luminance depending on luminaire class luminance limitation are added;
- Values of efficiency lower limit depending on version of optical system and on luminaires application areas, are grouped and corrected;
- Features of luminaires with light emitting diodes are taken into consideration, in particular requirements to luminous efficacy and luminous efficacy coefficient are added.

1 GOST 16703-79 “Light devices and systems. Terms and definitions”

7. In the section on requirements for luminaires of external illumination:

• Requirements for regulation of luminous flux maximum usage coefficient by illuminance and of luminous intensity maximum gain factor of luminaires for illumination of streets, roads and squares are excluded as not meeting modern day requirements for LDs of this type and almost not used when designing LI;

• Requirements for regulation of luminaires, the light distribution of which cannot be described with LICs, for example illuminated bollards, luminous columns, luminous screens-reflectors on supports etc., are added;

• Values of a lower efficiency limit for luminaires of utilitarian and functional-and-decorative illumination are fixed, and for luminaires with light emitting diodes, correspondent values of luminous efficacy and luminous efficacy coefficient are set.

8. For searchlights, requirements for regulation of scattering angles depending on light distribution type are specified.

9. Additional requirements for LDs with light emitting diodes are selected into an independent section. These requirements characterise specific features of the LDs. In this section:

• Requirements for regulation of correlated colour temperature are given;

• Rate of LD luminous flux decrease to its stabilisation time is fixed;

• Requirements for maximum deviations of luminous flux and correlated colour temperature from the rating values upon influence of a limit ambient temperatures, are added.

10. In the section "Test methods":

• General methodological requirements to measuring equipment in accordance with international standards are specified, a table of component values of relative errors for various measurement facilities and methods is given;

• Traditional methods of lighting parameter measurements are described taking into consideration modern approaches to LD photometry, for which the following are typical: *a*) clear and unequivocal regulation of LD orientation relative to the photometric device (i.e. choice of photometric measurement system, for example, «$C-\gamma$») depending on LD type and on its light distribution; *b*) the use of a standard measuring direction grid depending on symmetry type of LD luminous intensity distribution; *c*) the calculation of measured values derivatives in accordance with hard set calculation algorithms; *d*) presentation of the photometric measurement results in a standardized configuration, as unified files of the photometric data;

• New methods of photometric measurements are introduced. They appeared in recent years based on fundamentally new measuring facilities, in particular on use of near area goniophotometers with digital meters of luminance to measure luminous intensity distribution, and when replacing luminance meter with a traditional photometric head – to measure LD luminous flux;

• Measurement of the LD protection angle is added with a visual method using a goniophotometer rotating device;

• A method for determination of luminous intensity distribution using LD illuminance distribution measurement is added for LDs, which cannot be installed on a goniophotometer due to their dimensions and/or mass;

• Requirements to characteristics of spectrometers and spectrocolorimeters are regulated for LDs with light emitting diodes when measuring chromatic parameters. Methods of determination of correlated chromatic temperature, decrease and stabilisation time of luminous flux, as well as test methods of stability and recoverability of light and chromatic parameters at temperature exposure are given.

11. The appendices contain information as follows:

• Appendix A contains a table specifying luminaire class by luminance limitation, depending on their use in rooms with various requirements for the limitation of blinding effect characterized with discomfort factor *UGR*;

• Appendix B contains a table of correspondence of test method points to requirements points that allows quick orientation through the standard;

• Appendix C contains pictures illustrating LD photometric measurement systems and ratios between meridian and equatorial angles in these systems;

• Appendix D contains pictures illustrating LD photometric centre position depending on optical layout and optical properties of the applied materials;

• Appendix E contains examples of standardised tables of luminous intensity for conditional LDs with different luminous intensity distribution curves;

• Appendix F contains examples of LD luminous flux and luminous intensity curve average value calculations with different luminous intensity distribution curves;

• Appendix G contains a table of chromaticity coordinates of correlated chromatic temperature maximum deviation quadrangles used when plotting a chromaticity diagram.

CONCLUSION

There was a clear need for the development of the standard in question was. The standard will be an important step in the development of present day illumination facilities, paving the way towards the creation of new effective LDs, primarily of LDs with light emitting diodes as the new generation of light sources. Besides, it will help to block market ways for sub-standard products and serve as a powerful stimulus for bringing domestic lighting standards closer to their international analogues. And finally, publication of such a standard is one more step in updating Russian reference and technical bases.

The standard was developed by a creative team, which included A.S. Chernyak (as the Head), A.A. Korobko, T.L. Flodina, G.V. Fedyukina, G.S. Sarychev, G.N. Gavrilkina, R.I. Stolyarevskaya and T.N. Nikiforova (Standardisation bureau manager).

The draft standard was subjected to important technical expert appraisal by leading enterprises and organizations: Svetlana-optoelectronics, Optogan, NIIIS State Unitary Enterprise, LZSI, ASTZ, VNIIZhT, L.I.S.T., TPEP, KETZ, Reflaks, Mossvet, etc., presented their comments and notes. The authors are grateful to them for these.

The developers express special thanks to the specialists who took an active part in discussion of the project and made valuable comments: J.B. Aizenberg, V.M. Pyatigorsky (VNISI), V.G. Boos MOSZ), D.M. Khodyrev (BL TRADE), E.V. Dolin (NP PSS), A.A. Bogdanov (Svetlana-Optoelectronics), O.P. Pinchuk (VNIIZhT) and S.G. Nikiforov (L.I.S.T.).

The developers recognize that taking into consideration the great novelty of the standard due to the reasons above, as well as a short development period, the result is still far from perfect and probably contains errors and inaccuracies of various kinds. Therefore they will consider with thanks any constructive proposals and comments for correction and improvement of the standard and try to take them into account when revising.

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Light & Engineering
Vol. 19, No. 3, pp. 91-94, 2011

Svetotekhnika
No. 3, 2011, pp. 44-47

ORGANIC LIGHT EMITTING STRUCTURE APPLICATION INTO DISPLAY MATRICES

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ABSTRACT

A brief overview of the principles of design and operation of color displays, as well as the parameters of existing and theoretically predicted organic light emitting diode structures in comparison with other means of information display (LCD, plasma panels and LCD with backlight LEDs).

Keywords: organic light-emitting diodes (OLED), colour image, OLED displays, advantages, disadvantages, forecast of characteristics

Energy-saving lighting [1] and information display [2] are some of the most rapidly growing and socially important areas of science and technology. At the same time, ever-increasing volumes of multimedia information (including advertising), and the need to save time for obtaining and assimilating information by consumers, contribute to the development of the means of presenting information (MPI): displays, TVs, video walls, screens of mobile devices, indicators, etc. Currently, along with our traditional MPIs – cathode ray tubes (CRT) and liquid crystal display (LCD) panels – the modern means are being actively developed, such as: plasma panels (PP) and LED (solid state) matrices (Fig. 1).

The modern LED technology in lighting and information display is now being developed on the ba-

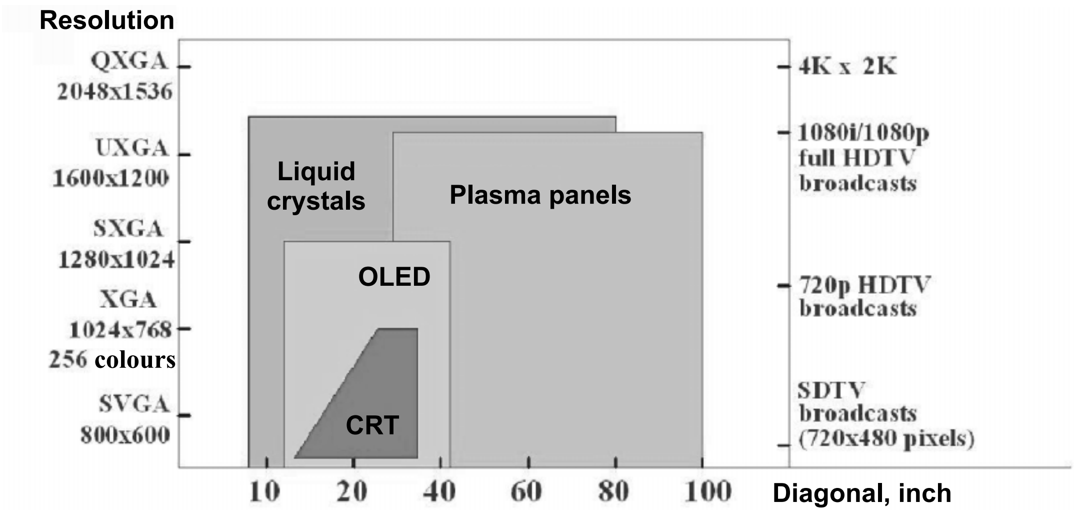

Fig. 1. Applications of displays of various types depending on the resolution and screen size (as of 2010): LCD – liquid crystal display; PP – plasma panel; OLED – organic light emitting diode, CRT – cathode-ray tubes
Side notation: left – standards of screen resolution; right – high definition television screens.
The x axis is screen size (diagonal in inches)

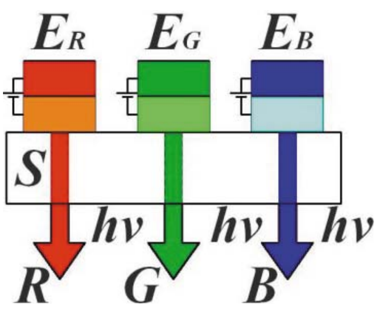

Fig. 2. Scheme of forming a color image using separate RGB LEDs: E_R, E_G, E_B – corresponding light-emitting diodes; S – transparent substrate

in comparison with that of "phosphor" one is that it is able to control such characteristics as luminous flux, chromaticity and colour temperature. Its major shortcomings – the need for selection of the OLED structures with peaks of radiation at three different spectral regions having the same brightness; "colour shifts " resulting from the different rates of degradation of various OLED due to their material differences; and unequal heat transfer from the edges and the center of the matrix.

In the method using a white radiation source and colour filters, the radiation of three white light sources (or one of equal brightness) passes through colour filters (Fig. 3 a). Here the principle of a LCD display is being used that does not require emit-

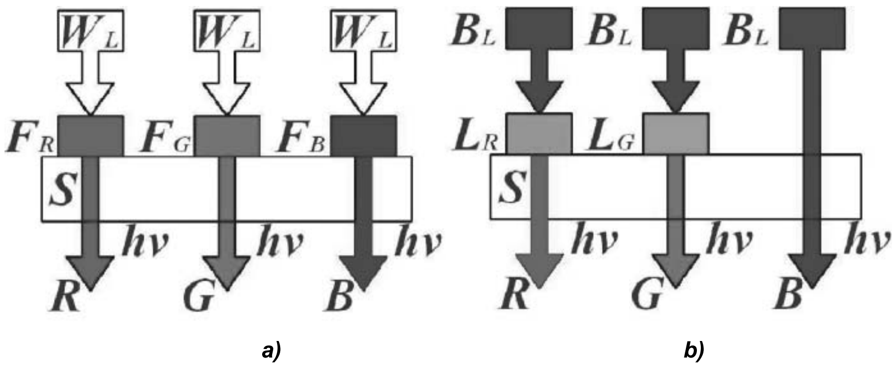

Fig. 3. Two schemes of obtaining colors in organic light-emitting diode structures: W_L and B_L – white and blue emitters; F and L – corresponding R, G and B color filter and phosphor

sis of light-emitting diodes (LEDs) and organic light-emitting diodes (OLEDs). The principles of LED and OLED are similar enough, and from the mid-2000 s the technology based on MDA structure was rapidly developing [3–5], which is associated with the ease of manufacturing of flexible OLED matrices.

Currently, the most promising are the following three ways to produce a colour image based on OLED [6, 7]:

– Using separate RGB emitters;

– Using the source of white light and colour filters (WOLED + CF);

– Transformation of the spectrum (Color Changing Media, CCM).

In the method with separate RGB emitters a colour image as a whole is produced similarly to RGB technology in CRT: radiation from three OLEDs produces light beams of primary colors R (red), G (green) and B (blue), which are mixed in the correct proportions with the use of lens optics (Fig. 2). The main advantage of this method

ters of different colours. The main advantage of this method is the same rate of emitters degradation, and its shortcomings are relatively low light output of display matrices (due to radiative losses in filters), and hence the need for high-efficiency white-light emitters.

The method of spectrum conversion consists of using a phosphor that converts radiation of blue emitters into two longer-wavelength radiations: red and green. The blue emitter radiates "directly" (Fig. 3 b).[1] The main advantage of the method is that it is not necessary to form on the substrate three emitters of different colors. Its disadvantages are: a smaller lumen output (compared to the RGB matrix) due to losses in the phosphor; the need for high stability of the blue emitters radiation; a faster rate of ageing of phosphors than that of the blue emitters.

1 Sometimes UV emitters are used instead of blue ones, but an additional transformation to blue radiation with a phosphor is needed.

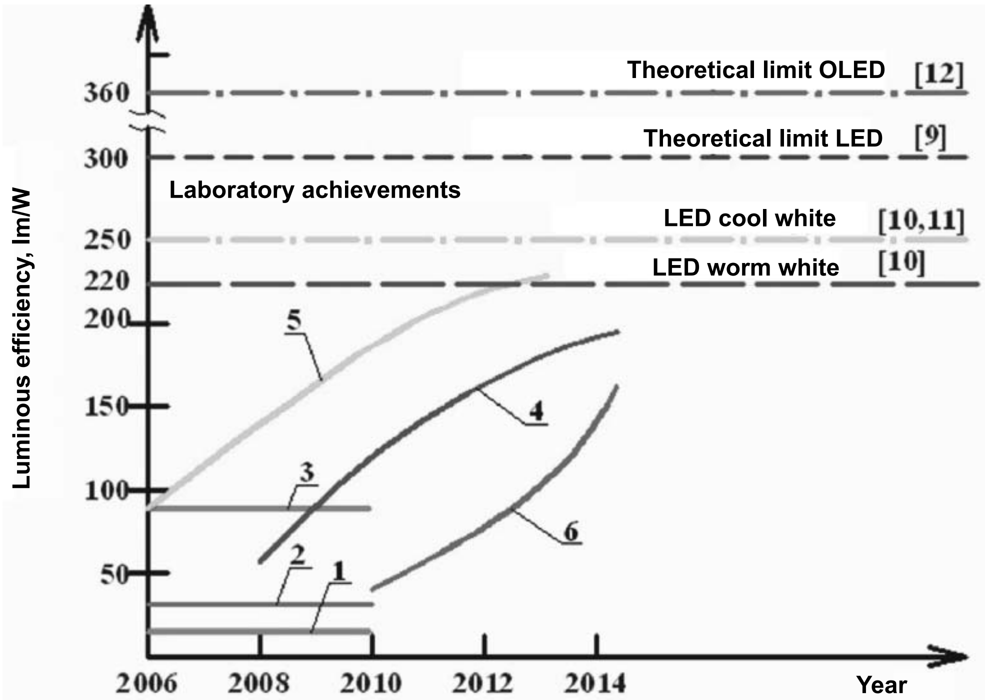

Fig. 4. Progress in luminous efficiency (lm/W) of various types of light sources:
1 –general purpose incandescent lamps; 2 –halogen lamps; 3 –fluorescent lamps; commercial samples per [10]: 4 – light emitting diodes (LEDs), warm–white, 5 –cold–white LEDs, 6 – organic light emitting diodes (OLED), warm–white

At present, in order to obtain a colour image, OLED structures are used both as "personal" display matrices (e.g., in mobile phones, televisions, laptops) and as display devices (e.g., in devices for air and auto industries) (Table 1), and also as composite video modules (video–walls) for collective usage (e.g., information and advertising displays and placards for transport terminals).

The main feature of video–module technology is the ability to create screens of arbitrary size to satisfy customer requirements (Table 2), and their rapid transport to the place of operation and switching. For designing video–walls all types of modules in Table 2 can be used.

The main advantages of SOI over conventional OLED (LCD, PP and LCD with backlight LEDs are (see Table 1 and 2): fast response time, no problem with "angle viewing", low power consumption and high contrast images. However, their main disadvantage is short life time and high cost. In addition, thus far there is no commercial OLED matrix larger than 15'' (in late 2010, there was information only on the pilot batches of such matrices having 21'' size [8]).

Thus, today OLED matrices serve just to maintain the image of the companies involved in such innovations, or to satisfy the ambitions of those wealthy people wishing to join high technology. However, despite that, the OLED structures have high potentials that could be realized in very near future: high resolution and high light output (Fig. 4); high quality colour rendering; and the ability to create OLED devices on virtually any material (including flexible), seamless, high impact, etc.

The theoretical and practical foundations of mass production of OLED structures are indicators of the possibility of simpler and cheaper manufacturing of OLED displays in comparison with that of LCD displays.

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VOLUME 19 NUMBER 4 2011

LIGHT & ENGINEERING

(SVETOTEKHNIKA)