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An Interview with professor Chao-Ming Fu at LED Forum 2015

The IX International LED Forum was held in November 2015 as part of the annual Moscow International Trade Fair "INTERLIGHT" powered by LIGHT+BUILDING. Professor Chao-Ming Fu chaired the Region panel – TAITRA at this forum.

The Taiwan External Trade Development Council (TAITRA) was founded in 1970 for the purpose of advancing Taiwan exports and ensuring their competitiveness in the world market. Within the last 40 years the Council has played a key role in the development of the economy of Taiwan. The activity of the Council is aimed at ensuring access for foreign businesses on Taiwan's markets. TAITRA is proud of its information and distribution network, which includes over 800 highly qualified specialists working at the head quarter in the city of Taipei and at more than 50 offices worldwide. Together with its partner companies, such as the Taiwan Trade Centre and Taipei World Trade Centre, TAITRA has created many opportunities for conducting trade, using effective strategy of the advance of goods.

Professor Chao-Ming Fu met with Dr. Raisa Stolyarevskaya and he was kind enough to answer a few questions for the readers of Light & Engineering after the forum via by e-mail.

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1. How would you evaluate the current state of illumination in Europe, North America, and in your country?

The current state of illumination in these countries can be characterised as developed. Both Europe and North America strive for maximum energy efficiency: LED-technologies, which are widely used in these regions, are state-of –the-art. Unique properties, such as low power consumption, broad selection of emission wavelengths, compactness and fast turn-on time, etc., have made LEDs an indispensable component for interior/exterior lighting applications, for examples: house lighting, car lighting, display, mobile device and modern traffic lighting, etc. For the lighting industry there is still plenty of room for development in these regions. If we focus on Russia, we can also see that the state of illumination here is also progressive: for example, many department stores have started using LED-lamps because they are more energy efficient. Moreover, high luminosity LEDs are also utilised for advertising, to make it more dynamic and attract attention. I also noticed that the decorative lighting used in Moscow, for example, in Pushkin Square is also implemented by gorgeous LEDs decorated trees.

2. In your opinion, what are main disadvantages of the latest illumination devices?

The main disadvantages of current LED lighting products are still their high cost in terms of the price per lumen when compared to conventional lighting devices. Moreover, LEDs suffer from technological issues, such as heat dissipation, since LED performance largely depends on the ambient temperature of the operating environment. The LED light output dependent on diode-junction temperature of LEDs; the higher the temperature, the lower LEDs light output, and thus lower power efficiency. Moreover, if LEDs run at high a temperature, it makes the LED less reliable in terms of light quality, since the heat dissipations cause a variation in the light spectra and aging process of brightness of a white-LED. Another issue of LEDs is flickering, which is occurs as a result of voltage ripple in the LED driver – LEDs flicker at high frequencies causing a strobe effect for susceptible people.

3. How well, in your opinion, do up-to-date illumination standards meet the requirements of domestic, industrial, and transport users, and how should standards be improved?

Standardisation in LED lighting safety is essential for all human activity. Over the past years, numerous International Standards Organisations and working groups have developed standards and critical factors such as LED system lifetime and performance. Standards of LED illumination are being adopted as a viable alternative to traditional lighting Standards, due to unique characteristics and specific energy features of solid state lighting. Present LED illumination standards have been processed to meet the requirements of people, industry and transport. Yet, any standards developed soon become obsolete due to the rapid development of this technology. Thus, the standard development process has to keep pace with technology development.

4, 5. To what extent does the scope of scientific research in the illumination field correspond with the problems of energy efficiency and improvement of living conditions? Do you consider the primary goal of modern lighting research and development to be the pursuit of light emitting diodes illumination, or are there other, more important directions?

The work of scientists and engineers fully corresponds with the problem-solving needs of LED illumination devices. Firstly, the problem of heat dissipation, which is regarded as one of the most serious research questions, is being widely addressed. The second problem, which researchers focus on, is related to the electro-optical efficiency of LEDs. Now researchers in Taiwan, for example, use quantum dot adapted into active layer of LED to raise the luminous efficacy of LEDs. The third problem currently addressed by research, deals with striving for white colour output LED-lamps. White light can be formed by mixing several coloured LEDs; the common approach is to use red, green, and blue (RGB). Another approach to generating white light is by using phosphors together with a blue LED. For example, by incorporating a phosphor in a blue LED to convert it to yellow light, the white LED can be formed by mixing yellow light with blue to produce light that appears white. Yet, due to aging, the light spectra of LEDs may shift, and so there is still room for improvement. Another LED issue is related to area lighting.

Since an LED is often small in area, integrated optical components are employed for lighting a wider area. For the practical realisation of solid-state lighting, many scientific efforts have been devoted to resolve these issues.

6. Do you think that the current state of metrology for light engineering meets current and near future requirements?

The metrological base and current test setups required for the accurate measurements of radiometric, photometric and colorimetric quantities, have been progressively developed for technological innovations, which are specific to LEDs. For example, luminous intensity is the most frequently measured parameter. The underlying concept for measuring luminous intensity assumes a point source of light; the concept of "averaged LED intensity" has been introduced for near field conditions. This concept no longer corresponds to the physically precise definition of luminous intensity at a fixed distance. To realise this concept in practice, the measuring adapter for an LED test socket must conform to the CIE standard conditions. Another example is the fact that different sets and types of LEDs generate different spatial radiation patterns: a precise knowledge of the angle-dependent distribution of radiation is necessary. A goniometer is used to analyse the radiation pattern of an LED, and a goniophotometer offers another method for determining luminous flux and radiant power. Today's light engineering and its new applications have placed increasingly stringent demands on the optical characterisation of LEDs, and specific expertise is needed in order to obtain precise and reproducible measurement results.

7. What directions of further development of light sources, illumination devices and installations seem most fruitful to you?

The drive for efficiency is pushing for a major evolution in the utilisation of lighting. The higher the operating temperature of LEDs, the more quickly the light will degrade, and the shorter their useful life will be. Thus, thermal management is probably one of the most important factors in the successful performance of LED products over their lifetime. Another key factor is the development of high quality LEDs with the greatest efficiency of light emitted in response to electric currents. State-of-the-art technologies, for example, using Quantum Dot to enhance electro-optical transformation have been developed to make white light LEDs more efficient. In addition, the perception of LEDs is that they are expensive currently. However, the cost of running the light encompasses the total cost of ownership over its lifetime. Technological efforts in mass-production with more cost efficiency will make the LED light more spacious.

8. What modern materials and technologies do you consider to be mastered by the lighting industry?

Since a significant proportion of the cost of LED manufacturing remains concentrated in the die-level packaging stage, manufacturers will need to address die-level packaging processes or perform packaging activities at a wafer level in order to realise the required cost reductions. Wafer-level processing, such as substrates and epitaxial growth, comprise a smaller percentage of the final device cost, but improvements of wafer processing can have a significant impact on packaging costs and device performance.

Substrate materials are also considered appropriate for lighting manufacture. The first successful LED was created by growing high-quality gallium nitride crystal on a layer of aluminium nitride placed on a sapphire substrate. One of the most promising spheres researchers are focusing on nowadays is growing LED on silicones. There is even research into growing the crystals in transparent glass – this technology is developing to fit specific kinds of lighting application. Moreover, improvements in chip structure and fabrication to solve the problem of heat degradation of chip materials are still the challenge of White-LEDs for the reliability of their high-power lighting products.

9. What solutions to the collection and recycling of used lamps and luminaires exist in your country?

• There are recycling programmes in Taiwan, for example, we separate garbage. Batteries and lamps should be recycled separately; we know that. While LEDs have the advantage over fluorescent lamps in that they do not contain mercury, they may contain other hazardous metals such as phosphor and/or arsenic used in LED dies. Work to reduce the amount of these materials in the lamps is underway, but they are still used.

• Russia's size means that environmental quality problems may be less pressing, but if there will be more pollution, the problem will grow. In Taiwan methods to defend the environment are taught in schools. If all the spheres of lighting in Russia switch to LEDs, the country will have to develop specific recycling programmes and regulations for their recycling, otherwise, the vast usage of LEDs may cause an ecological problem.

10. What is the competitiveness of the lighting industry on the international market?

The technological development of LED products has evolved rapidly over the last two decades. Manufacturing developments have accelerated to keep pace with these technological developments and have enabled the introduction of a broad range of high-efficiency lighting products. Nowadays, competitiveness in this industry is extremely high, there a several well-known companies that produce great products, hold exclusive technologies in terms of LED patterns. Despite the success to date of several companies, further work is required to continue to reduce manufacturing costs to accelerate the adoption of LEDs, and to ensure products meet the levels of quality and reliability demanded by the markets.

The main question here is price. Newly entrant companies can still compete with global giants by differentiating markets for suitable applications for illumination with various purposes.

11. In your opinion, what are the primary goals of the lighting industry?

To produce harmless, cost- and energy efficient lamps – these are the primary goals of lighting industry. The long-term for the lighting industry and for LED-producers is to reduce the greenhouse effect and create most energy efficient systems – smart lighting for houses, which adjusts to the current illumination needs of their inhabitants.

12. What problems of lighting education do you consider as key?

The key problems of lighting education correspond with the problems of environmental protection education. In Taiwan we have a National Program for Energy Education, one part of it is LED – we educate the students from school level on the problems of lighting, how to use light more efficiently, how to save energy resources.

13. What is your evaluation of the state and prospects for natural illumination?

Natural illumination is diverse. Of course, we can speak of technologies capturing sunlight, which are widely accepted options for illumination applications. Many research projects have focused on illumination with sunlight as a means of green energy and healthy lighting. Natural light illumination systems have collecting, transmitting, and lighting elements. Most daylight collectors use dynamic concentrators; such as Sun tracking systems. And, the transmission component uses a large number of optical fibbres. However, the daylight collector systems and transmission component are expensive and less cost effective. There is research on building a collector and optical transmission for house lighting, although it is far from cost effective for practical use. Nevertheless, the widespread adoption of such a Natural light illumination systems could substantially reduce energy consumption worldwide.

15, 16. What is your opinion on the none-vision effects of light? What do you think about blue light hazard?

Blue light hazard refers to a blue light in the wavelength spectrum of 400–500 nanometres or higher, which has the potential to harm the retina of human eye when looking directly at it for an extended period of time. The risk that blue light poses to the eye depends on the amount of exposure. Blue light hazard level depends on exposure to blue light. According to reported light comparison experiments, in general, safety between LED lamps and fluorescent lamps of the same colour were about the same.

Of course, people try to reduce UV light in the lamps, and researchers are working on this problem. Photo-biological safety standards have been established and safety levels have been set for possible blue light damage. From the point of view of optical engineering, currently most standard LEDs are at a safe level.

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INTERCULTURAL COLOUR TEMPERATURE PREFERENCE OF CHINESE AND EUROPEAN SUBJECTS LIVING IN GERMANY [1]

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ABSTRACT

Intercultural differences between user preferences of illuminant colour temperatures[2] (e.g. warm white, neutral white or cold white) are reported in literature. The present study concentrates on a new aspect of white tone preference: its object scene dependence (red objects, blue objects and colourful scenes) along the Chinese-European geographical axis. The aim is to design and apply lighting products for improved user acceptance on the global market. The objective is to point out the subjects' colour temperature preference of illumination depending on the object scene (reddish, bluish or mixed colours) with relation to the cultural background (Chinese or European origin) and the gender (male, female) of the subject.

Keywords: white tone, colour temperature, preference, intercultural

1. INTRODUCTION

It is known that there are intercultural differences between user preferences for illuminant colour temperatures or white tone, e.g. warm white, neutral white or cold white (BODROGI et al., 2014). The present intercultural study concentrates on the *object scene dependence* of white tone preference along the Chinese-European geographical axis. The aim is to provide guidance for the design and application of lighting products for improved user acceptance on the global market. The objective of the present paper is to point out the subjects' colour temperature preference (i.e. white tone preference) of illumination depending on the object scene (reddish objects, bluish objects or a scene with objects of numerous different colours) with relation to the cultural background (Chinese or European origin) and the gender (male, female) of the subject.

2. METHOD

Three arrangements of real coloured artificial objects (red-orange, blue-lilac and "colourful", the latter containing objects of numerous different colours) were fixed on three white plastic boards. Objects included the MacBeth ColorChecker Chart®, artificial flowers, candles, pots, bowls, yarn, glove, soap, etc. see Fig. 1.

These coloured object combinations were illuminated diffusely and homogeneously by seven white LED light spectra from a spectrally tuneable, stable LED light engine in a white chamber of a viewing booth (see Fig. 2) at seven different colour temperatures: 2719 K, 2960 K, 3501 K, 3985 K, 4917 K, 5755 K and 6428 K (see Fig. 3). Every one of these seven LED test spectra had R_a >97 and R_9 >97. The luminance of a white standard positioned at the bottom of the booth, equalling 743±9 cd/m^2.

Subjects of Chinese and European cultural background (38 men and 38 women, between 22 and 52

[1] Based on the report published in Proceedings of the 28th CIE Session, 2015, Manchester

[2] Colour temperature means the correlated colour temperature (editor reference)

Fig. 1. Three arrangements of real coloured artificial objects (left: "red-orange", middle: "blue-lilac", right: "colourful" arrangement) used in the experiment; the "colourful" arrangement included the MacBeth ColorChecker Chart®

years, 30 Chinese and 46 European; all of them living in Germany and having normal colour vision) looked into the chamber of the viewing booth containing one of the three object combinations at a time (Figs. 1 and 2). Subjects adapted for one minute to one of the seven LED test spectra (Fig. 3).

After the adaptation to one of the seven LED spectra shown in Fig. 3, subjects had to assess their preference of the colour appearance of the current object combination under the current white LED spectrum. Observers had to mark their preference rating on a scale between 0 (worst) and 100 (best) with a pencil. This marking was repeated for every arrangement of objects (red-orange, blue-lilac, "colourful") and every colour temperature three times. For the third time, observers had to finalise their response by with a pen on the score sheet. This third response was recorded electronically and analysed.

According to the above procedure, the white tone preference dataset obtained consisted of 1596 scaled preference values ranging between 0 and 100 i.e. 7 white LED spectra x 3 arrangements of objects (red-orange, blue-lilac and "colourful") x 76 observers.

3. RESULTS AND DISCUSSION

First, the significance of the effect of culture (or region of origin): Chinese or European; gender: male, female; object combination: red, blue, colourful; and colour temperature: seven CCTs (ranging between 2719 K – 6428 K) on the dependent variable *scaled preference* was analysed by ANOVA. The effect of culture, CCT, culture x gender, culture x CCT, gender x CCT, combination x CCT and culture x gender x CCT were statistically significant at 5% significance. To elucidate this finding and to find out usable preference tendencies, the mean scaled preference values (*P*) of the observers (ordinate) and their 95% confidence intervals were plotted against CCT (abscissa), for every object combination (3), culture (2) and gender (2) separately, Fig. 4.

Taking a look at the twelve *P* (CCT) plots in Fig. 4 (3 arrangements of coloured objects x 2 genders x 2 regions of origin), the following tendencies can be seen:

Chinese women prefer the colour appearance of reddish objects under an illumination with a CCT between 2700 K – 3500 K, bluish objects between 4900–6400 K and the colourful combination between 3500 K – 4000 K (latter tendency was not significant).

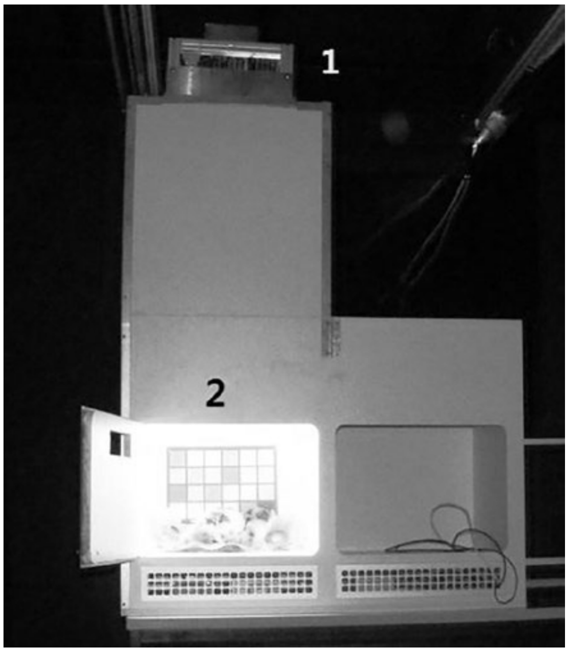

Fig. 2. White chamber of the viewing booth. Only one chamber was used (labelled 2 in the Figure) . This chamber contained the arrangements of artificial objects (one arrangement at a time; here the "colourful" combination is shown). The LED light engine was placed at the top of the viewing booth (No. 1). Luminance level: 743±9 cd/m^2

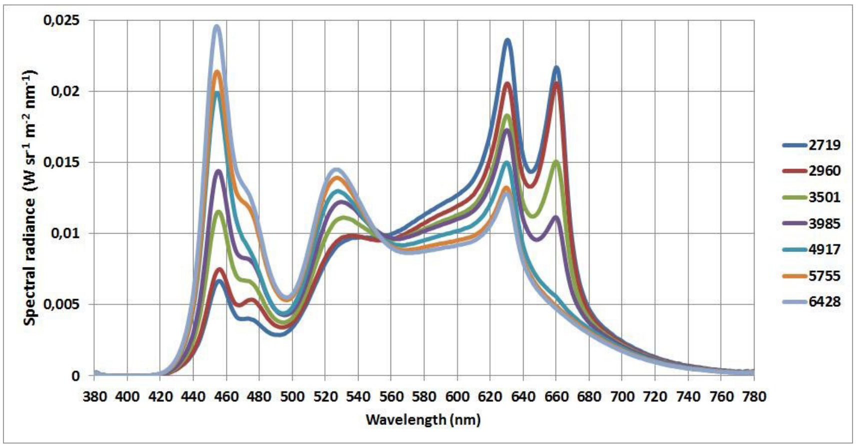

Fig. 3. Spectral radiance of the seven LED test spectra used in the experiment measured at a white standard (luminance level: 743±9 cd/m^2). The CCT of the seven LED spectra can be seen in the legend

Chinese men prefer reddish objects at about 4000 K and bluish objects and the colourful combination between 4000 K – 6400 K.

European women prefer reddish objects between 4000 K – 4900 K, bluish objects between 4900 K – 6400 K and the colourful combination between 4900 K – 5800 K.

European men prefer reddish objects at 4000 K while they prefer the bluish objects and the colourful combination between 4000 K – 5000 K.

4. CONCLUSIONS

In this study, Chinese and European observers living in Germany assessed the preference of the colour appearance of arrangements of reddish objects, bluish objects and objects of numerous different colours under high-colour rendering (R_a >97, R_9 >97) LED illumination at seven different correlated colour temperatures ranging between 2700 K and 6400 K. Chinese women preferred warm white CCTs (2700 K – 3500 K) for reddish objects in contrast to Chinese men and Europeans. Apart from this tendency (Chinese women, reddish objects), a general preference of about 4000 K (in certain cases up to 5000 K) could be observed which was more explicit for the bluish and colourful combination than for the red combination of objects. Europeans obviously do not prefer warm white (2700 K – 3500 K) for blue and "colourful" objects. This last tendency was

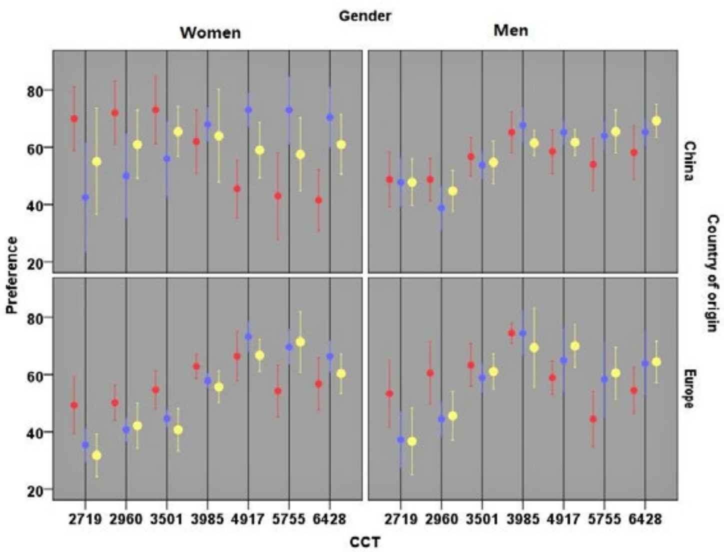

Fig. 4. Mean scaled preference values (P) of the observers (ordinate) and their 95% confidence intervals (ordinate); CCT (abscissa), for every arrangement (first dot at every CCT: red; second dot: blue; third dot: colourful, see Fig. 1), region of origin (China or Europe) and gender (women or men)

not so explicit for Chinese men and also less explicit for Chinese women. These results contribute to a more conscious application of LED lighting products of different correlated colour temperatures to different objects scenes for a improved user acceptance on the global market.

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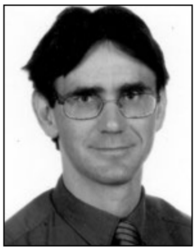

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THE EFFECTS OF HIGH LUMINANCE OBJECTS ON PERIPHERAL TARGET DETECTION IN MESOPIC CONDITIONS

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ABSTRACT

Advanced visual research is involved in the study of the dependencies of visual response on the distribution of adapting luminance across the visual field. In this work, two different street lighting adaptation conditions were applied by having the subjects to adapt to different background images in a laboratory setting. The difference in the background images is that one includes street luminaires and other light spots, whereas the other does not. Ten subjects (mean age 30 years) participated in the experiment. The subjects were asked to indicate the detection of targets appearing at different eccentricities (from -75^0 to 75^0). The results indicate that the high luminance objects affect peripheral target detection in mesopic lighting conditions. Contrast threshold values for the targets close to high luminance objects and in the periphery (20^0, 30^0,45^0 and 60^0) with non-uniform surroundings were decreased in the background without street luminaires and other light spots.

Keywords: mesopic photometry, adaptation, contrast threshold, peripheral vision

INTRODUCTION

A definition of the visual adaptation field in terms of its extent and shape is needed in order to implement the CIE 191 system of mesopic photometry [1], which is valid luminance in range 0.005 cd/m^2–5 cd/m^2. Visual performance at mesopic light levels is affected by luminance distribution of the background where the eye is adapted. Previous studies indicate that local luminance of the target is an essential factor in peripheral target detection in non-uniform backgrounds rather than average luminance of the background [2, 3, 4]. This supports the local adaptation [5] approach, which assumes that each part of the retina adjusts its light sensitivity independently.

Perception of objects on non-uniform backgrounds depends on the object location and luminance distribution of the background [6]. In this work, peripheral target detection at different background luminance was studied to find out the effects

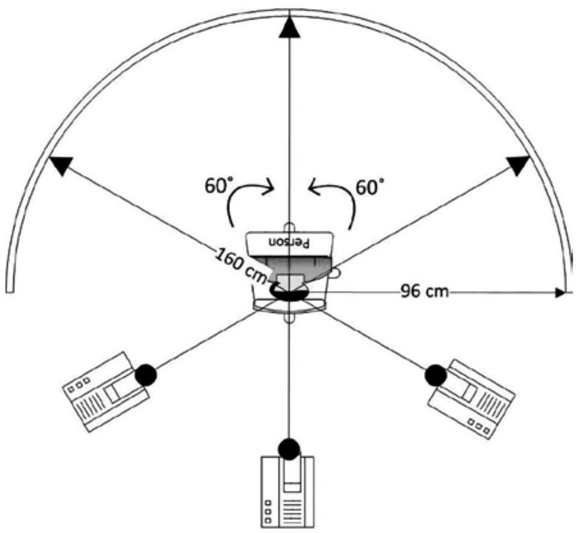

Fig.1. Experimental set-up: the distance between the subject and the fixation point is 96 cm, the distance between the projector and the corresponding central point of the projection is 160 cm, the angle between projectors is 60°

Fig. 2. Background images a) with luminaires, b) without LED lamp luminaires

of luminance distribution and target eccentricity on visual performance.

Contrast threshold and luminance difference threshold measurements have been applied in studies related to visual adaptation [6, 7, 8, 9, 10]. It is a useful method applied to analyse visual sensitivity.

In driving conditions, the visual field includes both very low luminance (e.g. unlit parts outside the road area) and high luminance of the street luminaires and oncoming car headlights causing discomfort glare. The effects of glare on peripheral target detection have been analysed in some studies [11, 12, 13, 14], which indicate that glare sources in the visual field affect the visual performance since it reduces the target visibility.

In this study, two background images were used in a laboratory setting to measure contrast threshold for targets appearing at several eccentricities. The difference in the background images is that one includes street luminaires and other light spots, whereas the other does not.

That luminance of the street luminaires in this study is not as high as in real driving conditions. However, they affect the luminance distribution of the visual field. The aim of the work is to find out the effects of reducing the luminance range of the visual field on peripheral target detection in mesopic conditions. The results are expected to make a contribution to the definition of visual adaptation field in terms of its extent.

METHODS

A large screen illuminated by three projectors (Ben Q 1007) was used to create the visual field background and the stimuli (Fig. 1). The size of the visual field provided by the screen was 180˚ × 44˚.

In the experiment two street scenery images were presented to test subjects. Both of the presented images were versions of one image taken in Otaranta street in Espoo, Finland. Otaranta street is a quiet suburban street illuminated with LED luminaires. The image was taken by a 60 D Canon camera combined with an 8 mm fish-eye lens located in front of the car from between the headlights. The cars headlights were on low-beam mode.

First street scenery image used in this experiment was the image taken as described above. No editing, other than cropping it to correct proportions, was made. The aspect ratio of the original image was different from that of the screen in the experiment setup and therefore the cropping was necessary.

The second street scenery image used was cropped as the first one. This image was also edited so that the small and bright areas were darkened. Mainly, these light spots were the street luminaires and lights from buildings near the horizon. Thus we obtained an image with light spots and an image without light spots to comparably study the test subjects' ability to detect the targets presented. The large light areas such as the road surface were identical in both images. The second image did not present a scene without street lights; it presented an illuminated scene without light spots.

All of the image editing was done using Adobe Photoshop version 13.0.1. The two images can be compared in Fig. 2, where *(a)* is the image with the light spots and *(b)* is the image without them.

Circular targets with the size of 1.5˚were projected onto the background at 25 different locations. Target locations cover 10˚ and 20˚ circular fields of view and include horizontal eccentricities of –75˚,–60˚,–45˚,–30˚, 30˚ 45˚, 60˚, and 75˚ (Fig. 3).

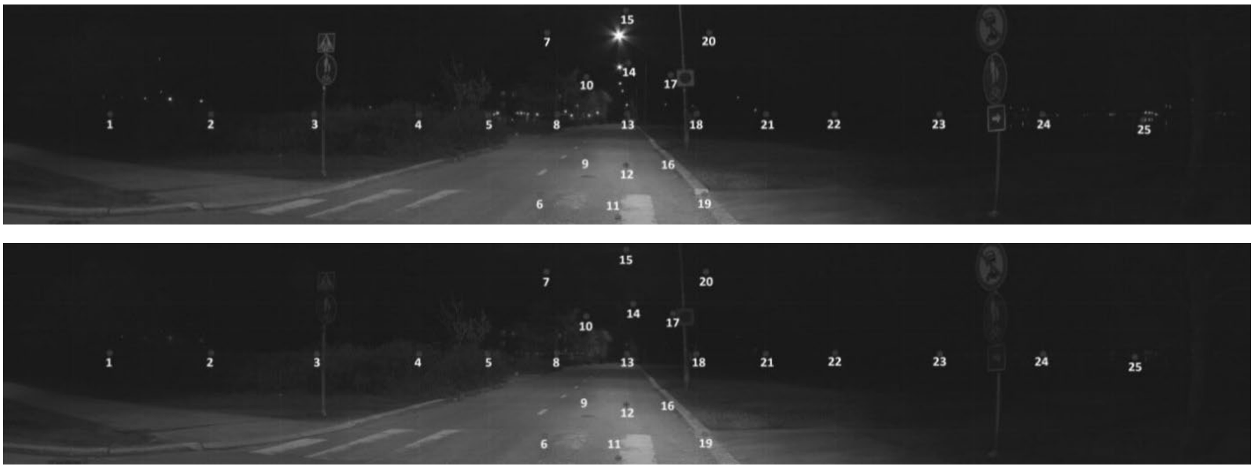

Fig. 3. Target locations illustrated with numbers in the background image of the street scene with LED (above) and without LED (below) luminaires. Number 13 is the fixation point

There were two luminance levels for each background. Luminance of the background scenes were adjusted by applying neutral density filters. Filters with 0.6 optical densities were used for the high luminance image and filters with 0.9 optical densities were used for the low luminance image. Luminance values were measured by LMK spectrophotometer and LMT 1009 luminance meter. Luminance of the 1.5˚ field in the background scenes, where targets are projected, were recorded as background luminance for the target. Target luminance was increased until it reached a value twice the amount of its background luminance. The subjects' task was to indicate if they detect the target or not. The term 'contrast' in this study refers to the ratio in the following equation:

$$C= (L_b - L_t)/L_b,$$

where C is the contrast, L_b is the background luminance of the 1.5˚ field, onto which target is projected, and L_t is the luminance of the 1.5˚ target.

Ten subjects (mean age 30 years) participated in the experiment. The subjects had normal colour vision measured by the Ishihara colour vision test. The subjects were given 5 minutes to adapt to the background luminance before the experimental sessions. After the adaptation, the subjects were asked to fixate at the cross in the centre of the screen and press the button when detecting the targets. The viewing was binocular. The time between the target appearances (between 500 ms and 2000 ms) and the order of target locations were randomised. Exceptionally low contrast values (<mean – 2 *standard deviation) were discarded from the results to eliminate anticipation.

During the experimental session, the subjects' eyes were monitored by an infrared camera to check that they were fixating at the cross at the centre of the screen. Subjects were warned verbally if they moved their gaze. The targets were presented in a random order and each target location was repeated three times. A break of 60 seconds between each repetition was used to avoid eye fatigue.

RESULTS

There were two different luminance levels for each background image (with luminaires and without luminaires), which are referred to as low and high luminance in this paper. Target locations for each background image are indicated by numbers in Fig. 3. The target numbers and the corresponding location in terms of horizontal and vertical eccentricities according to the fixation point (number 13 in Fig. 3) are given in Table 2. The dots with numbers 8, 9, 10, 12, 14, 16, 17 and 18 represent the targets in the 10˚ field of view, whereas those with numbers 5, 6, 7, 11, 15, 19 and 20 refer to the targets in the 20˚ field of view. Other numbers correspond to the targets at horizontal eccentricities of –75˚,–60˚,–45˚,–30˚, 30˚ 45˚, 60˚, and 75˚. Location of the targets with numbers 11 (20˚), 14 (10˚) and 25 (75˚) are shifted gradually not to be overlapped with high-luminance objects in the scene.

Low Luminance

The luminance level of the background images was adjusted by applying neutral density filters. In low luminance background image, filters with

Table 1. Mean value of the contrast threshold values (CT) in low luminance conditions for the targets in road scene with and without LED luminaires with their numbers (№) based on Fig. 3*

	low luminance		With LED				Without LED			
№	**h (deg)**	**v (deg)**	**L (cd/m^2)**	**CT**	**Std.**	**Miss. (%)**	**L (cd/m^2)**	**CT**	**Std.**	**Miss. (%)**
1	-75	0	0.1	1.0	0.00	100	0.09	0.94	0.15	79.17
2	-60	0	0.1	0.79	0.25	48.15	0.09	0.62	0.29	24.14
3	-45	0	0.12	0.71	0.26	25.93	0.12	0.42	0.20	0.00
4	-30	0	0.09	0.46	0.17	0.00	0.08	0.30	0.07	0.00
5	-20	0	0.28	0.72	0.26	33.33	0.12	0.48	0.32	3.33
6	-12	-16	1.56	0.19	0.08	0.00	1.3	0.17	0.06	0.00
7	-12	16	0.06	0.30	0.08	0.00	0.06	0.26	0.09	0.00
8	-10	0	0.26	0.52	0.18	0.00	0.12	0.73	0.20	14.29
9	-6	-8	1.6	0.17	0.05	0.00	1.3	0.19	0.07	0.00
10	-6	8	0.08	0.30	0.10	0.00	0.07	0.27	0.12	0.00
11	-2	-20	2.8	0.12	0.07	0.00	2.4	0.09	0.05	0.00
12	0	-10	2.8	0.08	0.03	0.00	2.7	0.06	0.01	0.00
13	0	0	0.14	0.43	0.16	3.45	0.11	0.32	0.13	0.00
14	1	10	0.09	0.22	0.08	0.00	0.08	0.22	0.08	0.00
15	0	20	0.08	0.60	0.29	25.00	0.06	0.39	0.35	6.67
16	6	-8	1.05	0.61	0.19	3.85	0.93	0.41	0.14	0.00
17	6	8	0.07	0.24	0.10	0.00	0.06	0.21	0.06	0.00
18	10	0	0.11	0.56	0.19	0.00	0.1	0.44	0.19	0.00
19	12	-16	2.75	0.33	0.19	16.67	2.24	0.14	0.11	3.33
20	12	16	0.07	0.24	0.16	0.00	0.07	0.17	0.07	0.00
21	20	0	0.08	0.21	0.07	0.00	0.07	0.22	0.16	0.00
22	30	0	0.07	0.29	0.10	0.00	0.06	0.27	0.10	0.00
23	45	0	0.09	0.28	0.11	0.00	0.08	0.21	0.04	0.00
24	60	0	0.1	1.01	0.00	100.00	0.09	0.59	0.29	23.33
25	74	-2	0.1	1.01	0.00	100.00	0.08	0.96	0.12	76.92

*Corresponding locations are indicated in terms of horizontal (h) and vertical (v) eccentricities. L is the luminance of the 3-degree field of view where 1.5-degree target was imposed. Std. is the standard deviation for the mean value of contrast thresholds. Miss. is the percentage of the missed targets.

0.9 optical densities were used. Luminance range of the background image with luminaires is between 0.05 and 19 cd/m^2 (average luminance of the whole screen is 9.03 cd/m^2) and without luminaires between 0.05 and 7 cd/m^2 (average luminance of the whole screen is 2.9 cd/m^2).

The measured mean contrast thresholds are shown in Table 1. Mean contrast threshold values for the targets located in horizontal axis (targets with numbers 1, 2, 3, 4, 5, 8, 13, 18, 21, 22, 23, 24, 25) are shown in Fig. 4. According to the Table 1, the lowest contrast threshold values were measured

Table 2. Mean value of the contrast threshold values (CT) in high luminance conditions for the targets in road scene with and without LED luminaires with their numbers (№) based on Fig. 3

	high luminance		With LED				Without LED			
№	h (deg.)	v (deg.)	L (cd/m^2)	CT	Std.	Miss. (%)	L (cd/m^2)	CT	Std.	Miss. (%)
1	-75	0	0.22	0.99	0.06	91.7	0.18	0.93	0.15	66.67
2	-60	0	0.22	0.99	0.08	87.5	0.18	0.59	0.27	20.00
3	-45	0	0.27	0.77	0.28	46.2	0.24	0.54	0.21	6.67
4	-30	0	0.2	0.46	0.25	7.4	0.17	0.34	0.11	0.00
5	-20	0	0.66	0.72	0.27	33.3	0.26	0.49	0.21	3.33
6	-12	-16	3.83	0.22	0.13	0.0	3.34	0.18	0.08	0.00
7	-12	16	0.15	0.29	0.14	0.0	0.13	0.23	0.07	0.00
8	-10	0	0.61	0.68	0.22	13.3	0.26	0.67	0.23	3.33
9	-6	-8	4.24	0.20	0.15	0.0	3.2	0.17	0.05	0.00
10	-6	8	0.2	0.29	0.10	0.0	0.18	0.23	0.09	0.00
11	-2	-20	6.4	0.16	0.11	23.8	6.12	0.09	0.05	0.00
12	0	-10	7	0.07	0.03	0.0	6.32	0.07	0.02	0.00
13	0	0	0.39	0.32	0.09	0.0	0.26	0.32	0.19	0.00
14	1	10	0.21	0.31	0.15	0.0	0.19	0.22	0.08	0.00
15	0	20	0.17	0.54	0.29	24.1	0.14	0.31	0.12	0.00
16	6	-8	2.3	0.58	0.23	3.6	2.11	0.41	0.15	0.00
17	6	8	0.17	0.23	0.11	0.0	0.15	0.19	0.09	0.00
18	10	0	0.28	0.40	0.26	0.0	0.22	0.40	0.19	3.33
19	12	-16	5.75	0.27	0.13	42.9	5.36	0.16	0.09	0.00
20	12	16	0.16	0.23	0.18	0.0	0.15	0.17	0.07	0.00
21	20	0	0.21	0.21	0.07	0.0	0.19	0.17	0.05	0.00
22	30	0	0.16	0.25	0.10	0.0	0.14	0.24	0.09	0.00
23	45	0	0.2	0.27	0.20	3.6	0.18	0.24	0.11	0.00
24	60	0	0.23	1.00	0.03	96.2	0.19	0.69	0.29	33.33
25	74	-2	0.25	1.01	0.00	100.0	0.2	0.93	0.14	56.67

*Corresponding locations are indicated in terms of horizontal (h) and vertical (v) eccentricities. L is the luminance of the 3-degree field of view where 1.5-degree target was imposed. Std. is the standard deviation for the mean value of contrast thresholds. Miss. is the percentage of the missed targets.

for the targets on the road surface (№ 6, 9, 11, 12) where there is no effect of high luminance objects on target detection. No differences were found in contrast thresholds between low luminance background images for the targets at 20˚ and 30˚ (№ 21 and 22). However, lower contrast thresholds were obtained for the targets at 60˚, 10˚, –20˚, –30˚, –45˚, –60˚ in the background image without luminaires (Fig. 4). For the target number 8 at –10˚, contrast threshold is high relative to those for targets at other locations in the 10˚ field of view due to the luminance distribution of its surrounding. It is surrounded by light

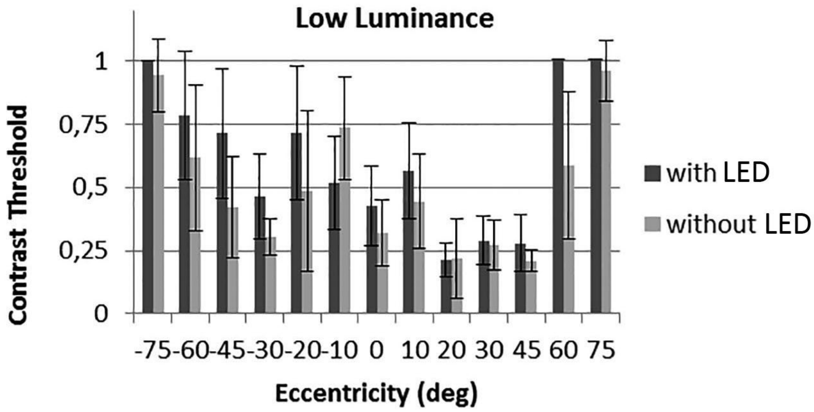

Fig. 4. Contrast threshold of the targets (number 1, 2, 3, 4, 5, 8, 13, 18, 21, 22, 23, 24, 25 in Fig. 3 in horizontal axis in both high and low luminance images of the road with LED luminaire. Error bars indicate the standard deviation of the mean

spots and small trees, which looks more complex to other part of the background. However, contrast threshold for that target becomes higher in the background with no luminaire. This cannot be attributed only to low local luminance, which is equal to 0.12 cd/m^2 since target number 5 at –20˚ has the same background luminance. It is accepted as an unexpected result. Contrast threshold becomes lower for targets at the edge of the road scene (number 16 and 19) in background with no luminaires than in the background with luminaires. For targets appearing close to the luminaires (number 14 and 15), the only difference in contrast threshold is obtained for detection of target number 15 when background image is changed.

High Luminance

In high luminance background image, filters with 0.6 optical densities were used.The luminance range of the image with luminaires is between 0.1 and 37 cd/m^2 (average luminance of the whole screen is 14.65 cd/m^2). For the image without luminaires, it is between 0.1 and 15 cd/m^2 (average luminance of the whole screen is 7 cd/m^2).

Mean values of contrast thresholds for the targets in high luminance background images are shown in Table 2. Mean contrast threshold values for the targets located in horizontal axis (targets with numbers 1, 2, 3, 4, 5, 8, 13, 18, 21, 22, 23, 24, 25) are shown in Fig. 5. As in low luminance images, the lowest contrast threshold values are measured for targets appearing on the road surface (no. 6, 9, 11, 12). There were almost no differences in contrast thresholds between two backgrounds in high luminance levels for targets at 20˚, 30˚ and 45˚ (№ 21, 22 and 23) (Table 3). Also, the mean contrast threshold values are almost the same at –10 ˚, 0 ˚ and 10 ˚ eccentricities. However, as in low luminance background images, the contrast thresholds were lower at eccentricities 60 ˚, 10 ˚ –20 ˚-30 ˚-45 ˚-60 ˚ in the background image without luminaires (Fig. 4).

Targets number 14 and 15 are located beside the luminaires, which are in 10˚ and 20˚ field of view respectively. For the background image with no luminaires, the contrast thresholds were lower for the target number 14, which is contrary to the low luminance image. Moreover, the miss rate is zero for target number 15 when high luminance objects are removed from the background. Difference in contrast threshold values in this location is also higher in high luminance images.

Statistical Analysis

In order to analyse the effect of target location and target luminance on contrast thresholds, a two-way ANOVA test was applied. The results indicate that effect of target location, luminance and interaction between them on contrast threshold are significant (Table 3). Moreover, t-tests were applied to see the effect of the luminance level of the background and existence of high luminance objects in the backgrounds. Luminance level of the background does not have any significant effect on contrast threshold, t (998)=0.14, p=0.89; whereas the effect of high luminance objects on contrast threshold is significant according to t-test results: t (998)=-5.04, p=0.00.

Statistical analysis verifies the effect of high luminance objects on contrast threshold. The lumi-

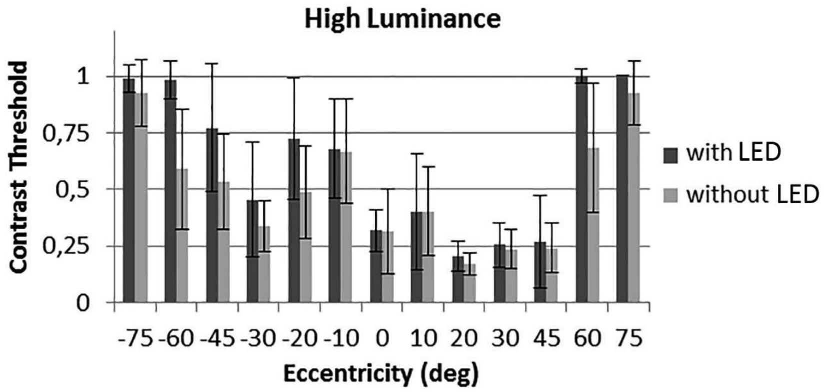

Fig. 5. Contrast threshold of the targets (number 1, 2, 3, 4, 5, 8, 13, 18, 21, 22, 23, 24, 25 in Fig. 3 in horizontal axis in both high and low luminance images of the road with LED luminaire. Error bars indicate the standard deviation of the mean

nance level is doubled or halved by applying neutral density filters. However, the t-test does not present any significant effect of luminance level of the background on contrast threshold, contrary to our expectations. A higher increase in the luminance level may also present a statistically significant effect on visual sensitivity.

DISCUSSION

Night-time driving scenes include several objects of variable luminance. Luminance distribution in the adapted background affects visual performance. Glare sources cause veiling luminance, which make target detection more difficult. However, in this study, luminance of the objects (37 cd/m^2), which is referred to as high luminance objects, are much lower than glare sources (>1000 cd/m^2) in real driving conditions, since it was impossible to provide these luminance values by the projectors in the set-up. Therefore, veiling luminance caused by luminaire in backgrounds is too negligible to be taken into account. However, it is still possible to see the effect of high luminance objects in the backgrounds on detection of targets.

Removal of luminaires from the background affects peripheral target detection. The contrast thresholds were lower for targets at the right periphery (20˚, 30˚ and 45˚) compared to those at same eccentricities at left periphery, since the luminance distribution of the background at right periphery is uniform. On the other hand, surrounding areas of the target locations in the left periphery include trees in both backgrounds and small bright spots in the background with luminaires. This indicates that luminance distribution of the immediate background affects the detection of targets in periphery. Targets at left periphery have lower contrast thresholds in the background with no luminaires.

There were no differences in contrast threshold between the targets with uniform luminance surrounding in 10˚ and 20˚ field of view. However, at low background luminance, contrast thresholds differ in targets at 0˚ and 10˚ eccentricities (number 13 and 18) when luminaires and other light spots were removed contrary to high luminance background images. It can be attributed to higher visual sensitivity at lower adaptation luminance.

It is difficult to detect the target located beside the biggest luminaire in 20˚ field of view (number 15). The effect of removing the luminaire from background can be seen clearly for that target. The rate of missed targets in that location is also high (Table 1 and 2) relative to other targets in the near periphery (10˚ and 20˚eccentricities). After removing the luminaire from the background, luminance distribution becomes uniform and the contrast threshold decreases and rate of missed targets becomes zero. Another target located near the luminaire is in 20˚ field of view (number 14). However, effect of removing luminaires in that location can only be seen in high luminance background.

The difference between the two backgrounds in this study is the existence of high luminance objects. The removal of the luminaires in this study did not affect the road surface luminance. Therefore, this background image should be considered a result of simulation, which does not represent real driving conditions where the road is lit by luminaires, which are not included in the visual scene. However, removal of luminaires and other light spots affects the contrast thresholds for targets mostly in the far

Table 3. Results of two-way ANOVA for contrast threshold values (Significant parameters indicated in bold ($p < 0.05$))

Source of variation	Contrast Threshold	
	F	*p*- values
Target location	68.25	0.00
Target luminance	4.84	0.00
T. Location x T. Luminance	4.84	0.00

periphery (-60˚,–45˚, 45˚ and 60˚). Statistical analysis also indicates that the effect of high luminance objects is significant on peripheral target detection. It can thus be proposed that visual adaptation field is increased when glare is reduced by considering the luminance of the glare sources in real driving conditions.

CONCLUSIONS

In this work contrast thresholds in night-time driving scenes were measured for peripheral targets located in various eccentricities. The removal of high luminance objects affects visual sensitivity of targets near these objects and also in the far periphery with non-uniform surroundings. Experiments with actual glare sources are expected to indicate bigger differences in peripheral target detection. It is proposed that glare sources in real driving conditions should be taken into account while estimating the size of the visual adaptation field.

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THE DOMESTIC SCHOOL OF LIGHT DESIGN: STRATEGY AND TACTICS

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ABSTRACT

The article analyses current domestic issues in light design and prospects for the creation of the school of Russian light design, its strategy and tactics.

Keywords: light, light design, school of strategy and tactics, development comprehensive approach, light culture

Designing the subject-spatial medium has a long history, which began with ancient civilisations and continues to this day, now showing changes in what people understand to be the role of light.

Traditionally, working with light was the domain of the architect, who acted simultaneously as an architect and a landscape architect and as a designer, which today we call the light designer. The development of modern society, the formation of new social requirements, the quick growth of technologies and changing preferences in for the aesthetics of an environment have become the preconditions, which gradually transformed light design into a new interdisciplinary direction, which combines art, design, architecture and light engineering.

Integrating the image expressiveness and artistic composition methods, as well as the functional aesthetics of design objects, with the newest scientific and technical achievements in the fields of optics and engineering, light design today has become a major element of the visual culture.

The growing social interest to in light design, its significant role in the arrangement of public space and its ability to influence public consciousness, transforms this direction into a separate culture area, in which "territorial" solution to acute problems of modern society becomes possible.

So the dialectic nature of the light design and its integrating nature make it possible to address several contradictions: between aesthetic and art (design), simulation and world view architectonics (light culture), private and public (society and social institutions), authorship and public anonymity (subjective).

Considering the situation, which has developed in modern domestic (Russian) light design, the following characteristics are prevalent:

• Despite high levels of activity in working with the light medium, there is an obvious deficiency of original ideas as a consequence of the absence of a comprehensive approach;

• The domination of private interests threatens the creative potential, and the initially social nature of light design, not taking into account the creators' responsibility for the results in public and cultural spaces;

• Personal motivations for individual professional growth are insufficient;

• There are no criteria of professional quality both in educational, and in design.

An analysis of these trends leads to the conclusion that the level of development of domestic light design does not correspond with its level of social and cultural importance. It is worth noting, that even amongst the professional community, let alone the general public, there is no a consensus on the tasks of the light design, its philosophy, ideology, methodological basis and general principles for specialist training.

A review of discussions in the light-design community, as well as the state of the light medium and public attention to illumination aesthetics, shows that the most pressing task for today is the development of a comprehensive approach to light design as a component of public space, formulating a special culture area: the light culture.

What does it mean to develop the strategy for such a comprehensive approach? In the first instance, it is the creation of an open debatable space for joint consideration of the most important aspects of this activity, such as identification, ideology, philosophy and methodology of the light design, specialist light design specialty education by experts from different areas (architecture, art, design and light engineering).

Considering the light design in these terms will allow revealing strategically important bases for its further development: to correct the purposes, tasks and light design functions according to the modern conditions and requirements for the quality of the light medium, which in its turn will make it possible to declare the prospects and self-sufficiency of the domestic school of light design.

The "school" concept is used here as a term describing the line of activity characterised by certain basic principles and by a number of distinctive properties (for example, Bauhaus school, Russian ballet school, Constructionism school, etc.).

At present, there are many educational institutions and organisations engaged in the light design sphere in Russia.

Being familiar with both theory and practice of light design, the authors have carried out an analysis of the current state of the domestic light design using the following criteria: current issues, global competitiveness, and state of the market. They have also analysed the experience of large-scale educational institutions, which train light designers in Russia and Europe: the Moscow Power Institute, the Moscow Institute of Architecture, the St.-Petersburg State University of Technology and Design, the St.-Petersburg National research university of information technology, mechanics and optics (Russia), *Sapienza*, *Lighting Academy* and *Laboratorio Luce* (Italy), *Hochschule* in Wismar (Germany), *CFEA* and *I.A.E. de Lyon* (France), and *Light and Space Academy* (Finland). The authors have also considered the specific character of the modern social and cultural situation.

The purpose was to create an educational programme, which would meet the high training requirements for modern light designers. The result of the research pointed to the conclusion that one of the major components for the general strategy of development of a domestic school of light design must be a methodology for comprehensive educational training of competitive specialists, who are able to participate actively in the formation of the light culture, and to raise level of social inquiry into the quality of the light medium.

As a basis of the methodology and implementation of the educational programmes, the authors offer the following principles:

• Light design is a creative laboratory, in which the formation of ideas arising at the interface of science, arts and engineering occur;

• The integrating nature of light design allows for new foundations, joint development and cross-fertilisation of technological and artistic fields;

• Light design creates an open space for debate and discussion of current issues in modern society.

The methodology of comprehensive training based on these principles must promote the adoption of a certain mentality for future specialists: to be complete thinkers, considering project from different aspects, have creative potential, technical abilities, as well as social, culture and economic factors.

The comprehensive approach is focused on acquiring knowledge of technical subjects (light engineering, electronics, etc.), on special topics (light medium of a city, light technologies, psychophysiology of visual perception), and the arts (light culture, environmental aesthetics, form). The multifaceted nature of such an education assumes that the students obtain abilities and experiences of setting and achieving creative project goals based on the complete vision of a specific situation.

This approach will allow not only developing creative abilities, generating ideas and accomplishing them in practice, but also forming authorship and responsibility of future light designers for the results of their work in the public space, which is extremely important.

CONCLUSION

It is difficult to imagine another phenomenon as important to a person as light. Dialectics of light, its ability to be at the same time the All and the Nothing makes it one of the most powerful instruments of influence upon public consciousness and constantly raises a question for a light designer: whether to manipulate or to motivate. There is an objective necessity to create a strategy for the development of domestic light design through forming professional school and light culture, primarily through the idea of new humanism.

As part of this, solutions to societies most topical problems become possible: overcoming social exclusion, substantiating a new humanistic starting point, which maximises scientific, artistic and technological potentials, reviving the public nature of the public space, as well as creating conditions for group and personal identification in the modern space of society and culture.

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ILLUMINATION OF CLASSICAL ARCHITECTURE MEMORIALS IN SEARCH OF AUTHENTICITY[1]

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ABSTRACT

The article discusses modern principles of illumination for classical architectural buildings, using examples of the illumination of St. Peter's cathedral and of the basilica di Santa Maria Maggiore in Rome, piazza dei Signori in Vicenza, etc.). The desire to reflect truthfully the building tectonics by means of artificial illumination had engendered a variety of methods, none of which are ideal. The authors insist that when architectural landmark illumination projects are developed, it is not only light designers and architects who should take part but also architectural historians.

Keywords: illumination, light design, classical architecture, architecture history, tectonics

Despite the intensity with which illumination of architectural landmarks is discussed, the wealth of literature available on the subject, as well as the living examples of illuminated buildings themselves, the only conclusions we can draw with any confidence is how ***not*** to do it, especially in respect of classical architecture. In the1990 s, in both large and small Russian cities old buildings, previously occupied by Soviet offices, were transformed en masse into post-Soviet offices and headquarters, simultaneously obtaining facade illumination. Often the light sources were installed at foundations of the porticoes, and searchlights illuminated their columns or pilasters with harsh light directed from the bottom upwards. Anybody in the least way connected with architecture felt discomfort seeing columns or pilasters, which were "torn off" by the light flux from their foundation as if they were up in the air (often from half way up), while their capitols were lost somewhere in twilight. It is easy to identify a source of this discomfort: it is the disturbance of the structural logic of architectural system, according to which columns cannot float; they must stand firmly on their bases and bear the weight of the building.

Since then a considerable amount of time has elapsed, and there are examples of illumination of architectural buildings, including classical ones, which demonstrate good understanding of light design theory and practice [1, 2]. Architects take an active part in the solution of the problems connected with illumination of architectural landmarks. The Light architecture festival, which took place this spring in Moscow, is an example of this. The festival was managed by the Union of Moscow architects [3]. But even today we cannot say that a universal recipe for architectural illumination of classical buildings exists, or even specify one indisputable example, which could be a guideline for new work. Most likely, neither such a recipe, nor such an example exist, at least because the buildings in question were constructed, when both illumination methods, and ideas about a building's "night image" were absolutely distinct from the modern. Nevertheless, the search for technical and expressive illumination methods continues today, including buildings from the era when classics principles dominated in architecture: antiquity, Renaissance, baroque, classicism.

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Fig. 1. Night-time illumination of the basilica di Santa Maria Maggiore in Rome, a project by Acea Company

And here again each project represents a different interaction between classical styles and modern illumination principles.

Deriving dome sort of generalised approach to classical architecture illumination in a daily context, instead of a "festival" one, it is possible to note three things: not competing with day-time feature accents, a delicate distribution of said accents and installation of the equipment so that it is as concealed as possible. A rather popular method applied today is revealing vertical elements through contrast, when the illumination of the surface behind columns is most bright. Therefore, the columns appear to be clearly accentuated and uniformly illuminated. One can observe this method in particular today, in the illumination of the Parthenon in the Athenian acropolis. The ancient temple of Athena Parfenos, is a great memorial of the golden age of Hellenic cultures of Pericle's period is illuminated as if it shines from within. Its night image is not dramatic but harmonious, majestic and unemotional. The Parthenon looks like this since 2004, when many things changed before the summer Olympic Games in Athens, including architectural illumination. The masterplan of illumination for the centre of Athenes, including architectural and archeological landmarks, was developed by the Head of the *Concepto* studio R. Narboni, author of such light-design bestsellers as "Illumination of public spaces" [4] and "Landscape Illumination" [5].

As to comparatively recent projects, in which such a method is applied, the illumination of the court of the neo-renaissance Palazzo Turati in Milan developed by *Antonio Citterio, Patricia Viel and Partners* Company is one example. The courtyard, which imitates in its main features courts of the Florentine palaces of the fifteenth century, is surrounded by an arcade on granite columns. The columns and arches have grace and quiet rhythm in their step

Fig. 2. The Baroque facade of the basilica di Santa Maria Maggiore in Rome

Fig. 3. Romance campanile of the basilica di Santa Maria Maggiore in Rome

against the background of the wall surface, which is illuminated brighter.

Another project worth mentioning is the architectural illumination of the basilica di Santa Maria Maggiore in Rome carried earlier this year (Fig. 1–3)[2]. It was developed by *Acea* Company, which also supplies Rome with water and electric energy [6]. One can say that there are two ideologies to this project: the first is connected with saving resources, the second shows a delicate approach to an architectural landmark, in which layers of different era are united. The project uses luminaires with light emitting diodes with a correlated chromatic temperature T_{cc} = 3000 and 4000 K, which allows creating a "seamless" illumination. The power of the luminaires varies from 13 to 86 W, and minimum energy is consumed: compared to the previous illumination system, 70% of electric energy is saved. Another aspect is architecture. As well as in the previous *Acea* project, which was the successful illumination of St. Peter's cathedral in Rome (Fig. 4, 5), the light sources are located differently. Some of them are installed near to illuminated areas, or even built within architecture elements (as a rule, in cornices), which makes it possible to accentuate separate bulks. Other luminaires installed on roofs of neighbouring buildings and on the domes of the basilica itself, smooth out the contrast between these bulks giving integrity to the whole building.

But what is integrity in this case? Basilica di Santa Maria Maggiore in its present form represents an ensemble of different sections from different time periods, earliest of which comes from to the fifth century. Almost each subsequent century left its mark on the image of this construction. The main space of the church is the early Christian basilica decorated with unique mosaics. Over its main bulk, a campanile dominates, which dates from the Romantic era. At the very end of the sixteenth century, pope Sixtus V, who became famous due to his enormous plan of rebuilding Rome, commissioned architect D. Fontana to attach a chapel (Cappella del Santissimo Sacramento) to the temple, which would become the tomb of the pope. At the beginning of the seventeenth century, pope Paul V charged F. Ponzio with building another chapel symmetrically reflecting the first. In the same century, K. Rinaldi reconstructed the apses of the temple creating a ladder of surprising beauty turned to the main square of Esquilino hill. Then in the 1740 s, F. Fuga finished the ensemble with an expressive facade with deep arch portico loggias. Hence, there is a considerable difference between different time period parts of the church, in terms of style and hence tectonics. At least Even those parts, which come from the baroque era, are essentially different one from another: Rinaldi's baroque (seventeenth century) and the baroque of Fuga

[2] First seven photos are made by D. Karelin.

Fig. 4. Night-time illumination of the cathedral and of square of St. Peter in Rome. A project by Acea Company

Fig. 5. Night-time illumination of the cathedral of St. Peter in Rome.

(eighteenth century) are different from each other. If in the seventeenth century we see a free, unobstructed movement of substance, which constantly changes; in the next century we hear powerful, solemn chords interrupted by long pauses.

How did the project team deal with illuminating in this complex ensemble? They took the whole construction as a polysynthetic bulk, without any conceptual accentuation of the time difference between its components. In other words, the building has appeared in front of them as a model consisting of abstract stereoscopic bodies and partitions: parallelepipeds (main bulks, including the bell tower), hemispheres (domes of the symmetric chapels), cylinders (dome drums), which are separated from each other by clearly articulated intermediate and crowning cornices. Nevertheless as a result, the general impression was in our opinion somewhat compromised, because the baroque features from the seventeenth century became more static in the evening illumination, and the baroque of the following century gained more dynamism than is usual due to the contrast of chromatic temperatures of the luminaires inside and outside the portico loggias. Incidentally, it is exactly this contrast which gives a substantial dramatic nature to the campanile image: to such a degree that it becomes even more "baroque" than those parts of the basilica, which really relate to this epoch.

Maximum accuracy is a principle of modern illumination of architectural landmarks. This is clear from the examples of the Parthenon in Athenes, the Pantheon in Rome, the Admiralty in St. Petersburg or the Basilica Palladiana in Vicenza. Introduce something that is not specific to their image, something which stands out on its own is absolutely inadmissible. These principles underlay the new illumination project for Piazza dei Signori in Vicenza, which was mainly completed in 2011 [7] (Fig. 6).

Fig. 6. Night-time illumination of Piazza dei Signori in Vicenza. A project by Gemmo company from 2011

Fig. 7. Illumination of the Loggia del Capitaniato in Vicenza

Already for several years, this image has been an important nightly feature for all residents and visitors to the city, forever glorifying the genius of Andrea Palladio. Palladio is the protagonist here as his two constructions are located on the square: Basilica Palladiana (earlier palacco della Raggione) and Loggia del Capitaniato (Fig. 7). The project itself was a gift: *Gemmo* Company presented it to the city to mark the company's own ninetieth anniversary. At the same time, such a great transformation of the main square of the city also marked another date: 500 years since the birth of Palladio, which was celebrated in 2008 and became a trigger for the restoration of many buildings in Vicenza, including the basilica.

The illumination intention was developed long before the important dates. Twelve years ago, students from the Architectural University of Venice, M. Selmo and F. de Rossi defended a project of illumination for the Piazza dei Signori in Vicenza as their graduation submission. Their main idea was, "to avoid any affectation" and to create an illumination "similar to powder, without flare spots, which would reveal light and shadow features of the architecture without strengthening them" [7, p. 43] (Fig. 8). Clearly since that time the possibilities of light emitting diode illumination, which was envisaged from the very beginning, expanded considerably, and this helped the authors to overcome some limitations, which inevitably were imposed upon the project connected with outstanding architectural landmarks (Basilica Palladiana, Torre del Tormento and Loggia del Capitaniato). The main limitations concerned the location of the equipment: the Administration of the Heritage of Vicenza officially approved the project, however, the installation of illumination devices on three main buildings, the Basilic, the Loggia, and the Torre were forbidden. Therefore, the floodlights and searchlights directed at different parts of the buildings, are installed on neighbouring buildings. In Vicenza, as well as in many other cities, there is an effort to fight light pollution (this issue is addressed by *Veneto Stellato Association* Company, which did not approve of the project at first). For this reason, firstly all light beams are directed from the top downward, and secondly, the illumination level varies: one light mode operates until midnight, and another, 30% less intensive, operates after midnight.

As a whole, the illumination requirements of the Piazza dei Signori were as follows: 1) an imitation of natural illumination ("moonlight"), which maintains the light and shadow modelling of the facade surface intended by Palladio; 2) absence of harsh light and flare spots; 3) there are no rays directed from the bottom upwards. The last requirement is based not only on the measures against light pollution but also with the retention of building tectonics in mind. The main architectural idea, which guided the authors of the illumination project, was a simplicity: "Simplifying everything, which is possible, we come close to the solution of Palladio: to the squire loggia with "openings", – this was the thing, which needed to be accentuated using light" [7, p. 49]. As a result, all of the constructions on the Piazza dei Signori have obtained illumination by means of floodlight, which to some extent simulates a uniform light of the full moon.

All of the illumination is achieved using light emitting diodes. P. Perucci, a designer of *Disano illuminazione* Company, which implemented the project, said that the preference was given light emitting diodes, because they provide the best light-and-chromatic characteristics and allow saving electric energy. For the illumination of the Basilica, searchlights with T_{cc} of 4000 K (a neutrally white light) were selected to accentuate the whiteness of the marble from Piovene and greenish shades of the dome. The illuminance of the facade is up to 15 lx. For the Torre del Tormento tower, several searchlights with narrow light beams were used. In the tower's illumination, an accent is made on the clock niches and on the frieze of Vicente stones. For the Loggia del Capitaniato, light emitting diodes with T_{cc} of 3000 K in the bottom part and of 4000 K in the top part were selected to accentuate the red bricks and white stone frieze accordingly. As to the Loggia, the designers certainly tried their best to counterbalance light fluxes and to make them less intensive in the bottom storey.

This project of architectural illumination can be considered as an example of the delicate approach to the architectural masterpieces. Soft, uniform light with small chromatic gradations creates a sensation of natural (lunar) illumination, the sources of which are imperceptible to the untrained eye, as if the moon itself pays tribute to Palladio. However, this moon is a bit strange – it is focused on architectural values, its light magically penetrates under the vaults of galleries surrounding the Basilica and it does not change the direction of its rays until morning. Nevertheless, here night-time tectonics" of the building are probably correspondent to its day-time tectonics" in a maximum degree.

Today, this correspondence (tectonic identity) is considered to be an important aspect of light design and stimulates the search for artificial illumination methods which approach the natural. However it should be noted that this is not a universal recipe but just one answer to the question, what we, modern people, expect from an architectural landmark as a whole and from its night image in particular. After all, it is almost impossible to reconstruct the night image of the Roman Pantheon or Parthenon in Athens. Were they lit only by moonlight only, or had there been any additional artificial illumination? Was such artificial illumination constant or only festive? How did the contemporaries perceive it, how important was the symbolism of light connected with architecture in each era? Would it have seemed strange for example, for Athenians at the time of Pericles that in twilight and in darkness, the Parthenon cella bulk becomes most luminous, which according to the symbolical logic is mysteriously hidden behind the peristasis screen? Incidentally, the cella bulk day-time image corresponds to the symbolical logic. To what extent was R. Narboni right when in the project illuminating the Notre-Dame de Paris cathedral he accentuated the stone mass and materiality of the cathedral, while creators of the cathedral made efforts for its dematerialisation?

Besides, there is reason to think that during different periods, even when classical architectural forms with tectonic logics dominated (Renaissance, baroque, classicism), illumination assumed a full transformation of the building in comparison with its day-time image. For instance, the tradition of illumination of Venetian palaces remains to this day: fires floating round the landing place, bright illumination to the central hall in *Piano nobile,* where the leading role is played by a huge chandelier, which as though it hangs over the glaring water's smooth surface. And all this together absolutely ignores any order of tectonics of the facade designed by J. Sansovino.

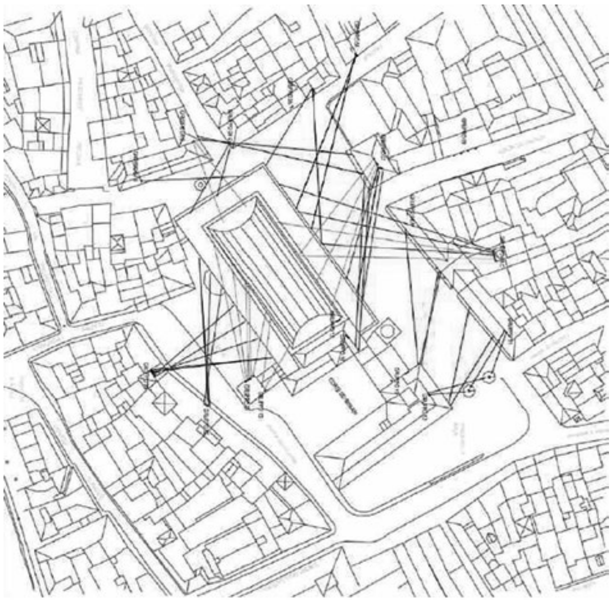

Fig. 8. Layout of the location of illumination devices on Piazza dei Signori in Vicenza

Thus a tectonic sensation, which is usually assumed as the basis of modern illumination of classical architectural landmarks, should not be considered as dogma and a rule set in stone. Modern concepts about tectonics themselves can change to the same degree as modern feelings about classic approaches. Any modern project of illumination of a classical architectural landmark is a hypothesis, which remains hypothetical with all of its associated argumentation and concerns not only for illumination but for our understanding of the classical style as a whole. Thus, each project of architectural illumination is a new dialogue of the light designer with the architectural landmark; it is a new discussion about tectonics, symbolism and time. It is desirable that the circle of participants in this discussion is wider, and that historians of architecture, restorers and architects are included in the deliberation, considering what types of results are being sought from the artificial illumination of architectural masterpieces.

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SPORTS ILLUMINATION OF SKI TRACKS IN THE TERRITORY OF THE ROSA KHUTOR FREESTYLE CENTRE

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ABSTRACT

Using the example of the Rosa Khutor freestyle ski centre, part of the Krasnaya Polyana complex, features of lighting design as well as start-up and adjustment work of installations for the sports illumination of ski slopes are described.

Keywords: sports illumination, ski slope, freestyle, mogul, ski acrobatics, half-pipe

In 2013, Spektor Lab Open Company lighting bureau implemented a project of sports illumination for ski tracks in the territory of the Rosa Khutor freestyle ski centre, part of the Krasnaya Polyana complex. The centre includes tracks for half-pipe, mogul and aerial skiing intended for international level competitions and TV broadcasting in the *HDTV* format. All three trails have a common finishing line area with stands for spectators. This article describes the process of designing, assembling and commissioning of lighting installations of sports illumination.

CHARACTERISTICS OF SKI TRACKS

Freestyle skiing is a sport, which is part of the Winter Olympic Games programme. Varieties of freestyle include mogul, aerial skiing and half-pipe.

Mogul tracks are straight lines with a constant incline, on which snow hillocks (moguls) are located in a chess-board fashion. During the down-run, the athlete must perform two jumps from springboards located on the trail. Three components are assessed: how skilfully the track is passed, speed and the jumps.

On the aerial skiing track, the athlete speeding up in the acceleration area must perform as many complex acrobatic jumps as possible from one of three springboards set at different heights. Unlike other tracks, here the judges' box is placed alongside the track, opposite the springboards, and not at the finishing line.

A half-pipe trail intended both for skiers, and for snowboarders, has a semi-tube (half-pipe) configuration. The athletes move from the wall to wall and perform jumps and tricks jumping out of the half-pipe.

ILLUMINATION DESIGN

When it comes to the illumination of these tracks, the significance of each object is important. Tracks intended for training and regional level competitions, as well as those for recreational skiing, are minimally illuminated to provide for the use of tracks at night. However, for international competition tracks, which attract thousand spectators through TV broadcasts, illumination which enables competing in the hours of darkness, for the most influential broadcasting hours, is important.

The design process began from identifying the principles of the illumination. Ski tracks described in this article are certainly not the first, of their kind and level in Russia, but they are the first which have had such high illumination requirements due to the need for *HDTV* broadcasting provision. Although professional sporting competitions are widespread in Russia, and lighting engineers have tried and tested many installations, even publishing methodical documents, in this case we were dealing with an absolutely new and unusual subject. The lack of domestic experience was compensated by studying examples of foreign experience. In the first instance, we looked to solutions deployed in Vancouver, Canada.

Athletes themselves proved an invaluable help. They helped us to understand, how the skier moved, where their sight was directed during the jump and what the jump trajectory was. This enabled us to identify the lighting surfaces properly, both along the trail, and vertically in the area of the springboards.

Similarly, with the help of specialists from the television company, cameras locations were determined. Many different devices were used to capture effective and exciting shots, including stationary and portable cameras, mobile cameras following the athlete along the track, cameras installed in the snow under the springboards, or suspended from above over the track. Calculating illuminance for mobile cameras was almost impossible, and calculating for special effects and wide shot cameras was not judged to be critical. Therefore, calculations were only made for stationary cameras and for the most typical locations of portable cameras.

As a result, a classical "top-lateral" illumination layout, which is typical for many other sporting installations, was selected. The feature only consisted in targeting light devices (LD). In the plane of the track, the cameras' targeting lines, and the observers' lines of sight are inclined to the horizon, therefore, targeting angles are calculated not from vertical but from the perpendicular to the track surface in the locations of LD installation.

Further, it was necessary to determine the most basic illumination requirements. In Russia, specific standards [1] are in place. Rationing of illumination for TV shooting was applied before the Olympic Games of 1980 [2]. In EU countries, another specific standard [3] operates. There are also CIE international recommendations on the illumination of sporting installations for the purposes of television broadcasting [4–6]. As far as the illumination of a specific object goes, this is usually determined by the commissioning body together with representatives of the sporting federation and the broadcaster undertaking the competition filming.

The following normalised parameters of *HDTV* mode filming were accepted: mean vertical illuminance $E_{v\cdot mean}$ directed to the camera equal to 2000 lx, irregularity coefficients $E_{v.min}/E_{v.max} = 0.4$, $E_{v.min}/E_{v.mean} = 0.6$, $E_{g.min}/E_{g.max} = 0.6$ and $E_{g\ min}/E_{g.mean} = 0.7$. An emergency TV broadcasting mode was also provided for in the event of short-term interruptions of the basic power supply. In this case: $E_{v\cdot mean}$ directed to the camera = 1000 lx, $E_{v.min}/E_{v.max} = 0.3$, $E_{v.min}/E_{v.mean} = 0.5$, $E_{g.min}/E_{g.max} = 0.5$ and $E_{g\ min}/E_{g.mean} = 0.7$. To provide a safe down-run of athletes as the basic illumination lamps are re-ignited, an emergency down-run mode without the use of discharge lamps was provided for, with $E_{g.mean}$ = 100 lx and $E_{g\ min}/E_{g.mean} = 0.4$. Here E_g is horizontal illuminance on the slope surface.

As the LDs for working illumination, floodlights *Thorn Mundial C* and *Mundial R* with MHL *OSRAM HQI-TS 1000 W/D/S* and *HQI-TS 2000 W/D/S* were selected. For the emergency down-run mode, floodlights *Thorn PRT 15* with halogen lamps *OSRAM Haloline 1500 W* were used. Some of the *Mundial* floodlights were equipped with units of instant re-ignition to provide for a TV broadcasting emergency mode. The selected MHLs provide a high level of colour rendition ($R_a > 90$) and correlated chromatic temperature 5900 *K,* sufficiently corresponding to natural daylight. It was designed so that the difference in colour perception between artificial and natural illumination was not felt in twilight.

FEATURES OF THE LIGHTING CALCULATION

The next step was the lighting calculation, for which two important features of ski tracks should be taken into consideration: inclined calculated planes and diffusely reflecting snow cover with a high reflection factor (from 60 to 95%). Therefore, the reflected light component must be accounted for in the calculation. For this project, a snow reflection factor of 60% was accepted.

These specific features seriously limit the choice of design software. For example, the *Calculux Area* program [7] developed by *Philips Lighting* specially for sports illumination, does not calculate for reflected light, and the *ReluxPro* program [8] does not calculate E_v directed to the camera on the inclined plane. The only known program, which has all the functions needed for the task, was *DIALux* [9].

Just before the design stage, it was necessary to select the height and pitch of the supports for floodlight installation. The higher supports, the less effec-

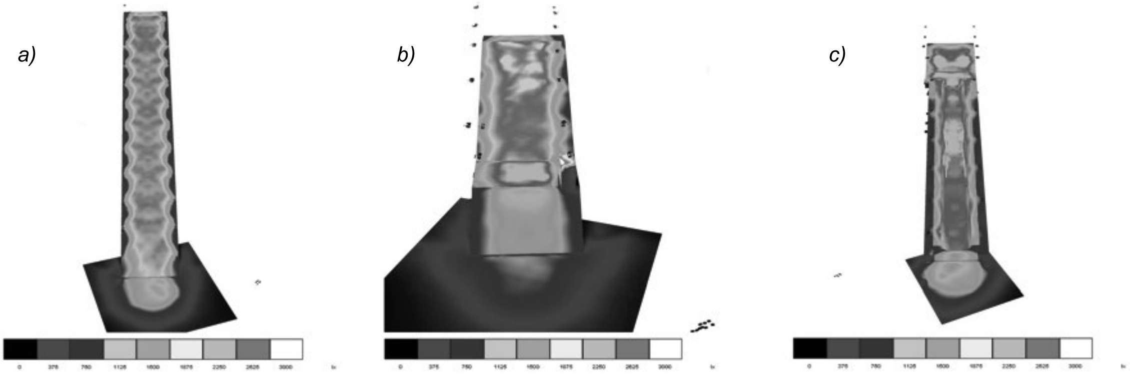

Fig. 1. Design distribution of horizontal illuminance on the surface of mogul (a), aerial (b), and half-pipe (c) tracks

tive the luminous flux of the floodlight used. In addition, the cost of the supports themselves increases exponentially with increased height; on average, it is cheaper to use a greater number of low supports than a lesser number of the high ones. However, the minimum height of supports is limited by the requirements for blinding effect reduction. As a result, the height of supports in the project varied from 15 m to 25 m depending on the width of the track. The height of two supports behind the stands to illuminate the finish area was selected separately. Because of the large size of this area, the height of the supports was 50 m.

To illuminate the finish area, additional floodlights on temporary supports directly in the finish area were provided.

The obtained distributions of E_g are given in Fig. 1, and the numbers of floodlights and power in different modes are given in the Table.

The lighting calculation and the list of floodlights and targeting angles is not the end of the light engineer's work. Here we come to the most interesting stage: the installation of the proposed design, which is also complex task.

MOUNTING OF THE LIGHTING INSTALLATIONS

Preparation for the mounting begins from connecting each light to a specific cell in the battery, so that they are not shielded by other lights or by structural elements. As a result, a summary Table of placing and targeting of the searchlights is formed, in which each light has its a specific type, switching on group, battery cell number and targeting angle listed. It is important that the rotation angles in the horizontal plane are transformed from absolute into relative, which are counted taking into consideration the battery structure that facilitates the mounting operation and improves targeting accuracy. Slope angles in the vertical plane in this case are counted from the absolute vertical, which is easily determined using modern measuring devices.

After the lights are installed and connected, their targeting is performed. To manage this process, specialists from *Spektor Lab* were invited, and workers doing the mounting engaged to adjust slope angles and to turn the lights relative to the supports. Unlike in the case of regular sports fields, marking out ski

Table

Mode	Number of searchlights, pcs (Total power, kW)		
	Mogul	Aerial	Half-pipe
Technological mode	14 (29.1)	8 (16.6)	12 (24,9)
Colour TV broadcasting	111 (226.2)	72 (149.5)	146 (303.0)
Emergency TV broadcasting	120 (278.1)	99 (205.4)	188 (390.1)
HDTV broadcasting	251 (512.6)	175 (365.3)	340 (705.5)
Emergency down-run (without use of discharge HP lamps)	42 (63.0)	33 (49.5)	62 (93.0)
Total power of a lighting installation, kW	575.6	414.8	798.5

Fig. 2. Illuminated track for mogul

Fig. 3. Illuminated track for aerial skiing

Fig. 4. Illuminated track for half-pipe

slope targeting points directly on the track surfaces is not possible, because the calculation of these point co-ordinates is very complex, and their marking out on the slope is complex too. The horizontal finishing area is the exception. For this reason, the targeting is adjusted according to the angles of inclination/turn, and measuring devices, which allow working out the angles to one degree accuracy, are required.

Besides, working out angles relative to the "battery " angles, it should be considered that battery position in space in most cases does not coincide with the design position, as it is difficult to achieve accuracy when installing such large structures. In this case, the 30 ^{o} slope made it impossible to use cranes, and the batteries were mounted on the ground and installed on the supports using a helicopter. As a result, the uncertainty of rotation angles of the batteries relative to the track was in the tens of degrees.

In order to correct for this in the targeting Tables, it was necessary to measure the rotation angles of the batteries relative to the track. To solve this problem, geodetic engineers were involved to provide the specialist knowledge and equipment.

It should be noted that an additional difficulty in the targeting process on a ski slope is its considerable extent and height difference, which can reach several hundreds of metres. In winter time this distance has to be overcome on fresh friable snow. Therefore, both mounting organisations and technical personnel should have access to the necessary means of transport, for example, snowmobiles.

ADJUSTMENT AND CORRECTION OF LIGHTING INSTALLATIONS

Finally, after the targeting of all lights, the long-awaited moment arrived, when the adjusted lighting installations were switched on. Certainly, even with all the attempts for accuracy in the process, the light picture differs from the design. The following are the most likely reasons: dark spots (as a rule, arising because of failed lamps), and bright spots (a result of errors when targeting single lights). One can find the error source swaying the lights one after another, or alternately installing opaque screens in front of each of them.

During the trial switching on of the installations one interesting feature was revealed: even those strict requirements for illumination uniformity coefficients for *HDTV* broadcasting, which were in place for this project, appear to be insufficient for ski tracks. As it was already mentioned above, snow represents a diffusely reflecting surface with a high reflection factor, and cameras and spectators see this surface at a very close angle. This means that even a little non-uniformity of E_g distribution on such tracks is very noticeable, especially if it has a cyclical nature connected with support pitch. In this case, a sort of "zebra" effect appears on the track, which in this project, fortunately was eliminated in situ by retargeting some of the lights.

The commissioning process of the lighting installations was completed by check measurements of E_g, which showed a good match with the measurement results in the design data (Figs 2–4).

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A STUDY OF THE SUITABILITY OF LED LIGHT SOURCES OVER CONVENTIONAL LIGHT SOURCES IN A MUSEUM ENVIRONMENT

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ABSTRACT

The core of the museum is the exhibition. Effective exhibit lighting can be achieved by providing standard light levels as well as lowering the IR and UV components at the same time to minimise running energy costs. These requirements can be efficiently fulfilled with comparatively low power consuming light-emitting diode (LED) lamps. LED lamps offer a long service life and high efficacy (lumen/Watt). LEDs are available in different colours, have lower Ultraviolet (UV) and Infra-Red (IR) content and provide better Colour Rendering Index (CRI), which is good for museum displays. Lighting design in museums requires a sensitive and flexible approach to providing optimum display conditions for museum exhibits. The energy conserving lighting design methodology based on LED will help to secure a green future by enlightening the past perfectly.

Keywords: SPD, LPD, illuminance, UV, photosensitive

INTRODUCTION

A museum's primary responsibility is the study and care of its collections and the effective public display of those collections. Thus, lighting has been considered to be the second most important responsibility of the exhibition designer. If lacking effective lighting, even the most interesting collections and important displays are ineffective. Lighting, however, can cause or accelerate the degradation of certain kinds of museum objects. So, the purpose of this study is to clarify the suitability of different light sources to the museum environment. Finally, through experiments and designs it has been shown that LED sources are best for sensitive artefacts and displays in museums.

VISIBILITY AND ILLUMINANCE LEVELS

The illuminance level of a museum should be carefully controlled in such a way so that no damage occurs to artworks by optical radiation. According to IESNA [1], the maximum illuminance level on highly susceptible materials is 50 lx. Now, from the experimental result that was carried out on Japanese Paintings (mosaic colour samples of Red, Yellow, Green, Blue natural mineral pigments and Gold leaf) it was found that the subjective feeling under LED-RGB at 10 lx is almost same as with white fluorescent lamp and LED-BY at 700 lx [2]. It is for the fact that the SPD (spectral power distribution) of LED lamps are different from those of conventional light sources like fluorescent lamp.

So, the colour appearance under LED light sources seems to have changed than from under other conventional sources. From the experimental results it can be said that LED-RGB lighting is preferable over other light sources at low illuminance levels.

DETRIMENTAL EFFECT OF LIGHT SOURCES ON ARTWORKS

The illuminance level is regulated to a low value to keep the colour fade damage as low as possible. On the contrary, according to Hunt Effect [3], the

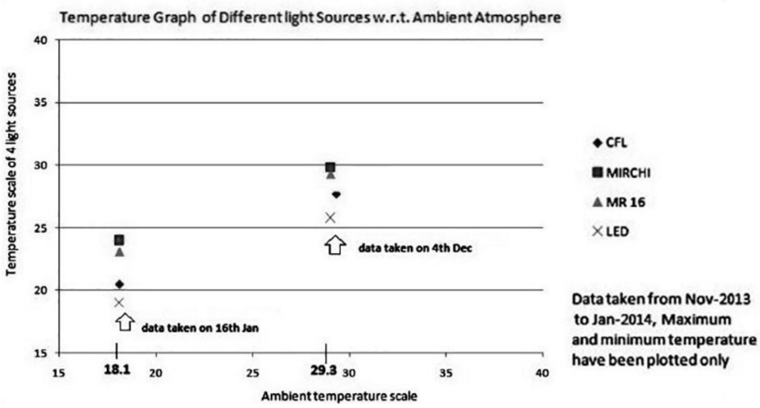

Fig. 1. Temperature Graph of Different Light Sources w.r.t. Ambient Temperature

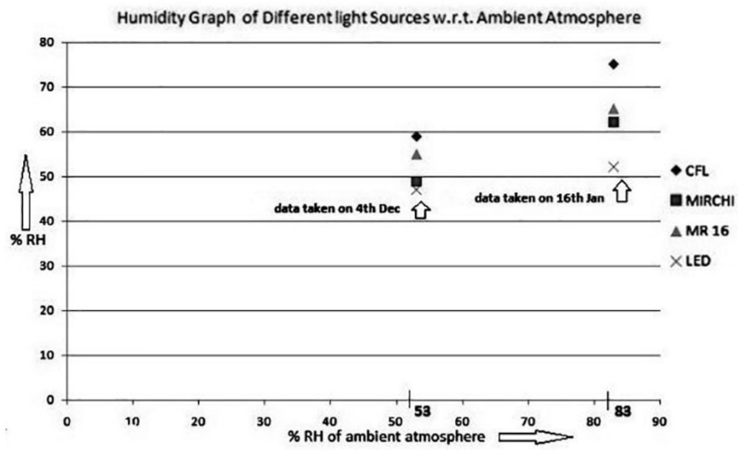

Fig. 2. Humidity Graph of Different Light Sources w.r.t. Ambient Atmosphere

brightness and colourfulness of chromatic objects decreases when illuminance decreases. Different laboratory experiments were conducted in Jadavpur University Illumination Engineering Laboratory to examine the detrimental effects of different light sources on paintings. A closed box experiment is being performed in the laboratory where paintings are exposed under four different types of lamps. This experiment gives an idea of the damaging effects of different light sources on paintings. According to IESNA, for very sensitive exhibits, yearly 1, 50,000 lx hour exposure is the limit for museum painting, at 50–75 lx over a day, 8 hrs per day, 6 days in a week, 300 days in a year. So per day, light exposure becomes 500 lx hour, or 3000 lx hour per week, 1, 50,000 lx hour per year being the limit. For experimental purposes, a limited period of 30,000 lx hour cycle has been chosen, particularly for watercolour paintings. According to 'Bunsen Roscoe Reciprocity law' and photochemical reactions [4,5], damage by light is directly proportional to light intensity multiplied by exposure time. Following this law, 100 lx for 6 hours in a day, 5 days in a week can expose 3000 lx hour [6]. Over the whole period, the experimental values have been analysed. As paintings are very much sensitive to rises in temperature and humidity, so, among the experimental values the only variation of temperature and humidity are mentioned here. The sample data of temperature and

Fig. 3. General View of Scroll Painting of Bengal Gallery

Table 1. UV components in μW/cm^2 in Different Light Sources

Lamps	UV-A	UV-B	UV-C
	μW/cm^2	μW/cm^2	μW/cm^2
CFL	9	0.3	0.8
Halogen Mirchi	1.9	0.1	7.5
Halogen MR16	1.7	0.1	7
LED	8.5	0	0.7

Table 2. Measured average Illuminance values

Name of Painting	Illuminance value (measured without glass cover in showcase, lx)
Debate between Ganga and Durga	290
Krishna Leela	226

Table 3. Existing power consumption of Bengal Gallery

Types of lamps	No. of lamps	№ x Power	Total power, W
Halogen MR 16	26	26×50	1300
T12 cool white	4	4 X (40+12)	208
Total			1508

relative humidity in the winter session from Nov. 2013 to Jan. 2014 are shown in Fig. 1 and Fig. 2 respectively [7].

Considering both Fig. 1 and Fig. 2, it can be said that the temperature rise and change in relative humidity is less in the chamber with the LED source than the chambers with other light sources. So, it is expected that the rate of damage of a painting is lower under LEDs than other light sources.

As derived from the experimental results mentioned above, it can be concluded that the cracking of paint, i.e. the damage which is caused by continuous heating, and fading of colour i.e. photochemical degradation of the surface which is caused by moisture content, is lower in the case of LED than with other light sources. So, the existing recommended level of illuminance might be increased in case of LED museum lighting, increasing the brightness and colourfulness of the paintings satisfying the cause of Hunt Effect.

Fig. 4. DIALux simulated picture of Existing Lighting System of Bengal Gallery of Howrah Zilla Museum

EFFECT OF UV RADIATION ON PAINTINGS

Ultraviolet (UV) radiation is very harmful to art or painting galleries because its depth of penetration is very high. Many polymers, textiles, papers, different types of paints are degraded by UV radiation [8]. There are different types of UV radiation, dependent upon their wavelength and energy levels. Among them, UVC is the most harmful than the other types, i.e. UVA and UVB, because the wavelength is very short and has a high energy level. So, light sources containing UVC are more harmful and can damage many artefacts. Data has been collected and presented in Table 1 in terms of (μW/cm^2) of UV (UVA, UVB, UVC) components from different light sources, which have been used in the experiment done in the laboratory [6].

The table above depicts that there is no component of UV-B in the LED lamp tested, and also, the UV-C component is lower compared to other light sources being used. So, LED light sources are less harmful than other light sources. LEDs are suitable for museum lighting design, especially for photosensitive objects (i.e. paintings, textiles).

ENERGY EFFICIENCY OF DIFFERENT LIGHT SOURCES

A survey has been carried out to study and examine the existing lighting situation and its efficiency in museums of West Bengal, India [6]. Analysing the

Table 4. DIALux Summary Sheet for proposed design of Bengal Gallery

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\,m}/E_m$
1	perpendicular	40	35	52	0.88	0.67	/

survey results, it was found that for most of the cases lighting design is not energy efficient. For example, it was surveyed that the Bengal Gallery of Howrah Zilla Museum (Howrah, West Bengal), consists of Scroll Paintings and is designed by conventional light sources in a technically inappropriate way.

Fig. 3 shows the general view of the existing lighting system of Bengal gallery of Howrah Zilla museum.

The illuminance level on the paintings was measured by luxmeter (METRAVI 1332) and the following results were obtained (Table 2).

It can be seen from the survey result that the average illuminance level on the paintings varies from 230 lx to 300 lx whereas, according to IS 3646 [9] recommendation for highly photosensitive material, the illuminance limit is 50 lx. Also, the total power consumption of that gallery has been calculated, shown in Table 3.

So, it was found that the gallery consumes 1508 W in only 50.4 m^2 area and the LPD of is 29.92 W/m^2. Now, according to ECBC 2011 [10] recommended LPD for a museum should be 11.8 W/m^2 or less. As a result, it can be said that the level of illuminance and energy consumption of Bengal Gallery differs from recommended standards.

Fig. 4 shows the DIALux (a Lighting Simulation Software) simulated version of existing lighting system of Bengal gallery of Howrah Zilla museum. This Fig. 4 demonstrates the excessive illuminance level on the paintings.

So, the gallery was redesigned with LED tubes and an LED spotlighting systems [11] using a DIALux simulation and the following results have been found (Table 4 & Table 5).

Using this proposed design will reduce LPD to 1.64 W/m^2, which is within ECBC 2011 recommendations. Also, from the DIALux summary sheet, it can be seen that the illuminance level on the paintings is an average 40 lx, which is within IS 3646 recommendations. As a whole, it is evident that redesigning and replacing the existing lighting system with LEDs will help to reduce the consumption of energy. With this, the illuminance level can also be maintained within the standard recommendations.

Table 5. Power Calculation for proposed design of Scroll Painting of Bengal Gallery

Type of Lamp	No. of lamp	Power	Total Power, W
19 W LED tube	3	3 X19	57
1 W LED narrow beam spot light	26	26 X1	26
Total			83

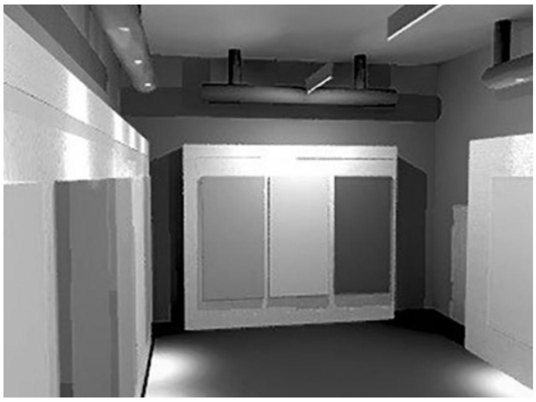

Fig. 5. DIALux simulated picture of proposed Lighting System of Bengal Gallery of Howrah Zilla Museum

Fig. 5 shows the DIALux software simulated version of the proposed lighting system of the Painting Gallery of Howrah Zilla Museum. Fig. 5 demonstrates the required illuminance level on paintings as well as the brighter appearance of the whole environment.

CONCLUSIONS

A successful design of museum lighting should consider appearance, artefact conservation and energy saving. LED lighting is perfectly suited for museum lighting because of its unique features [12]. Considering the UV content, temperature rise, humidity and other detrimental effects of light sources on photosensitive materials, LEDs are more effective than other conventional light sources. Also, LED yields low energy consumption. Moreover, LED lighting can enhance the aesthetics and atmospheric perception for viewing the artifacts, which in turn satisfies the Hunt Effect. Therefore, lighting design with LED light sources is a conservative lighting design methodology, which should be preferred above other conventional light sources in pursuit of common historical interest.

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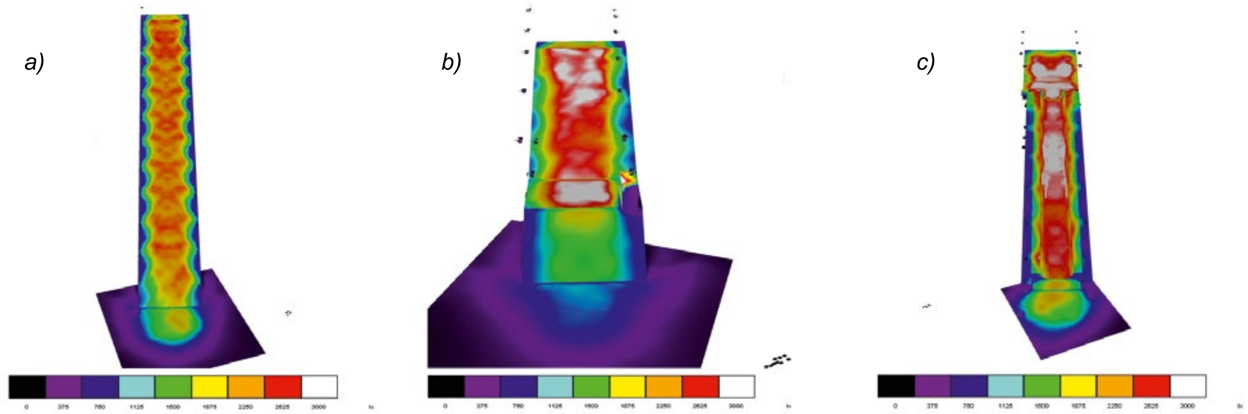


Fig. 1. Design distribution of horizontal illuminance on the surface of mogul (a), aerial (b), and half-pipe (c) tracks

Fig. 2. Illuminated track for mogul

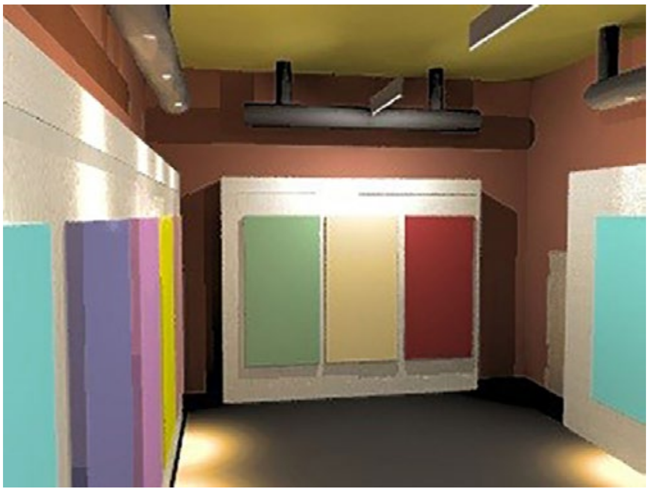
Fig. 3. Illuminated track for aerial skiing

Fig. 4. Illuminated track for half-pipe

Fig. 3. General View of Scroll Painting of Bengal Gallery

Fig. 4. DIALux simulated picture of Existing Lighting System of Bengal Gallery of Howrah Zilla Museum

Fig. 5. DIALux simulated picture of proposed Lighting System of Bengal Gallery of Howrah Zilla Museum



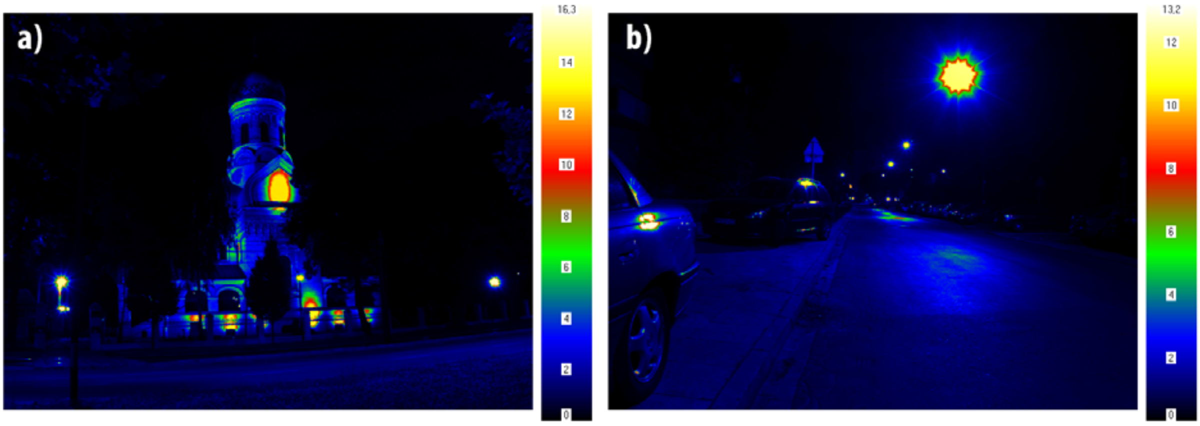


Fig. 1. Example luminance distribution on the surface of a) – church and b) – street

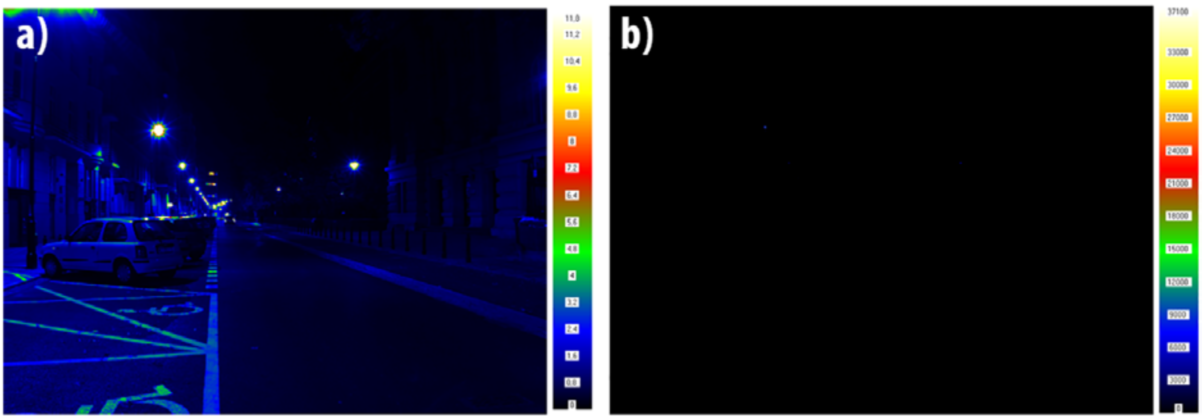


Fig. 2. Example luminance distributions on the street surface a) digital luminance camera exposure/range parameters set to record road surface luminance distribution, b) exposure parameters to record luminance values of luminaires (luminaires seen as individual pixels)

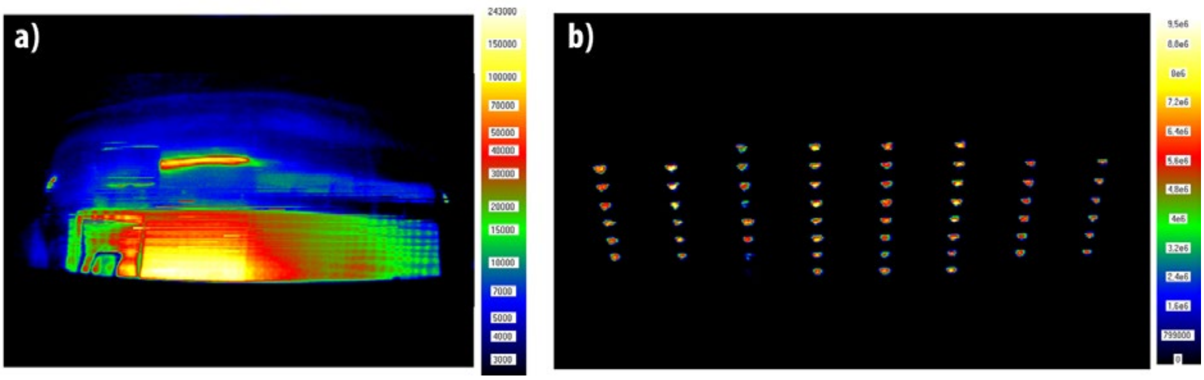
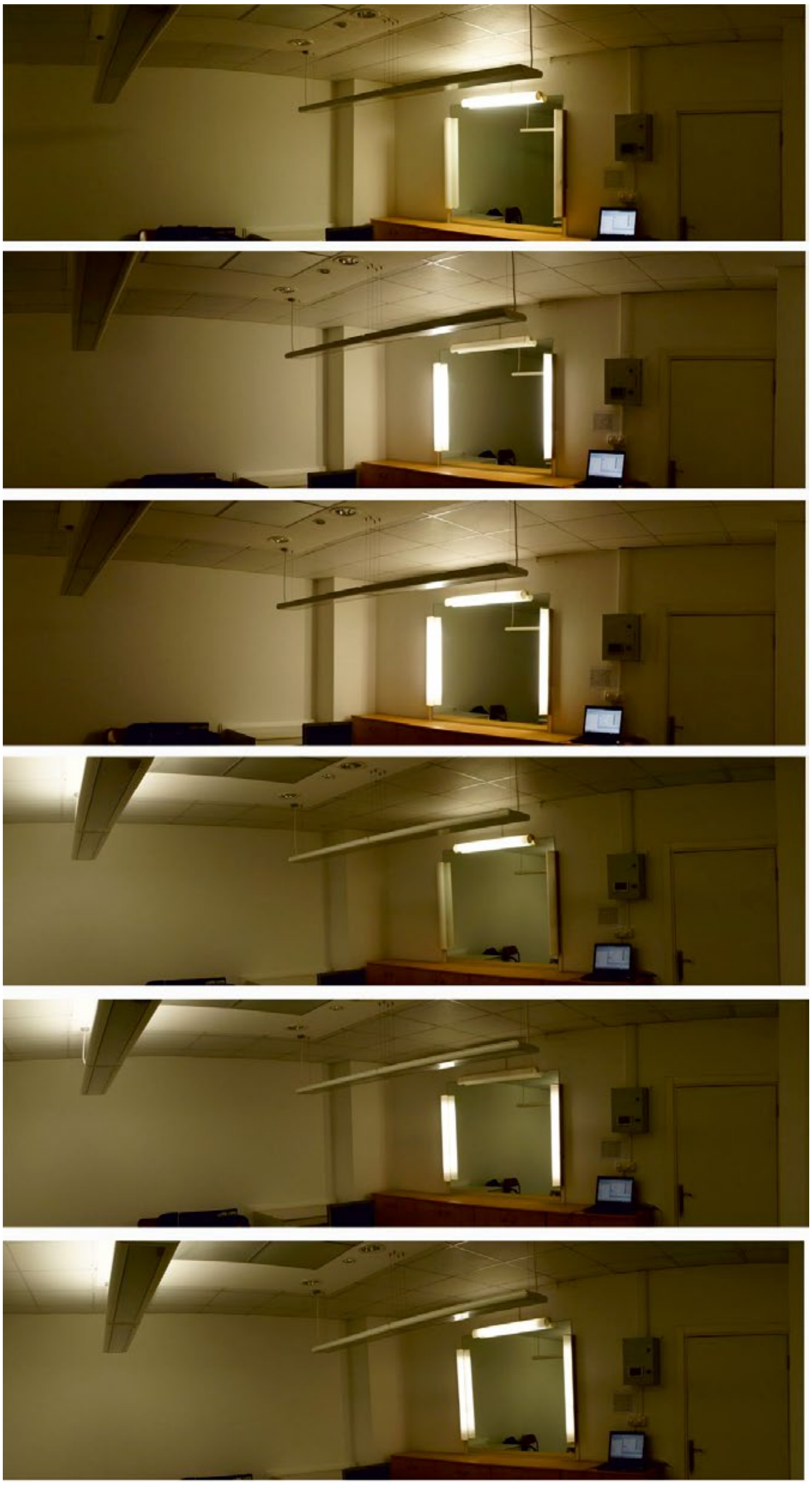


Fig. 3. Example luminance distributions on the road surface lighting fixtures a) with high pressure sodium lamp, b) LED for plane C0 – C180 and angle γ = 75 degrees



5a. Lighting Arrangement 1

5b. Lighting Arrangement 2

5c. Lighting Arrangement 3

5d. Lighting Arrangement 4

5e. Lighting Arrangement 5

5f. Lighting Arrangement 6

Fig. 5. Lighting arrangements

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SELECTED PROBLEMS IN MODERN METHODS OF LUMINANCE MEASUREMENT OF MULTISOURCE LED LUMINAIRES

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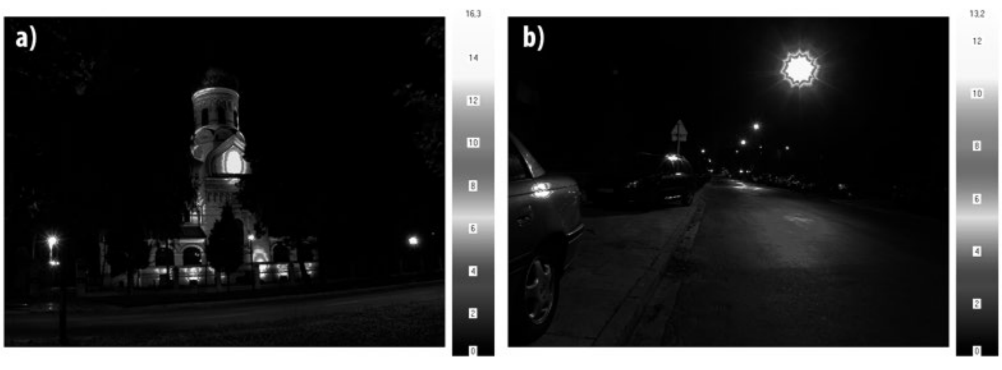
ABSTRACT

At the time of rapid development of LED technology, certain problems are associated with the measurement of the luminance distribution of multi-source LED luminaires. The construction features of luminaires which form luminous intensity distribution by means of lens systems causes problems in achieving high values of luminous intensity, at a level of 100.000 cd in particular directions, is associated with high values of the luminance, often getting levels higher than 10 million cd/m^2. Despite the rapid development of measurement techniques and the widespread use of imaging luminance measuring devices (ILMD), the appropriate luminance measurement of multi-source luminaires very often leads to errors. Technical problems substantially affecting the accuracy of the luminance measurement of small objects are presented in this paper. The problems are universal. Taking into account the rapid digitization of measurement methods in lighting technology, paying special attention to increasing measurement errors acquires a particular importance.

Keywords: lighting technology, glare, imaging luminance measuring devices (ILMD)

INTRODUCTION

The development of LED technology and common problems, which arise during design and implementation of the new solutions, necessitate the dynamic growth of measurement methods. High luminance values of LEDs, which are close to and many times higher than the luminance values of discharge lamps [1,2], provide huge opportunities while designing lighting fixtures featuring high luminous intensity amplification in specific directions. Luminous intensity amplification values are mostly more than 500-fold. The relative ease, with which luminous intensity distribution of high luminance light sources can be shaped by means of lens, reflector and hybrid systems equipped with optics, means a deluge



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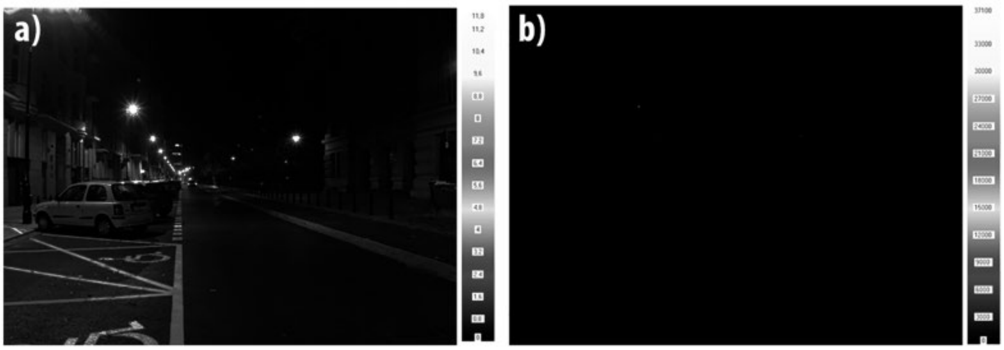

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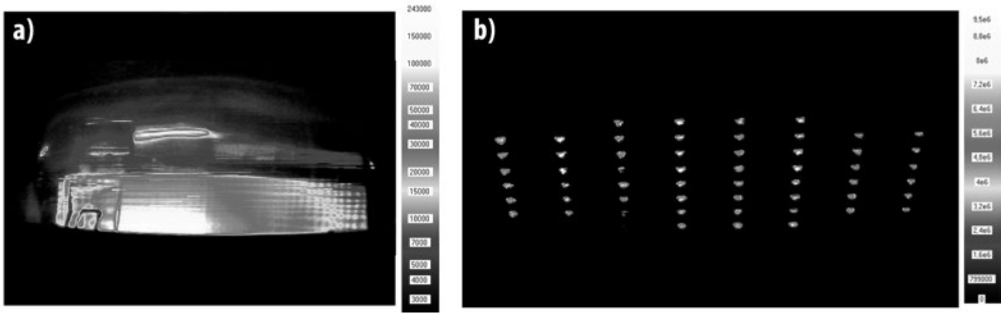


Fig. 3. Example luminance distributions on the road surface lighting fixtures a) with high pressure sodium lamp, b) LED for plane C0 – C180 and angle γ = 75 degrees

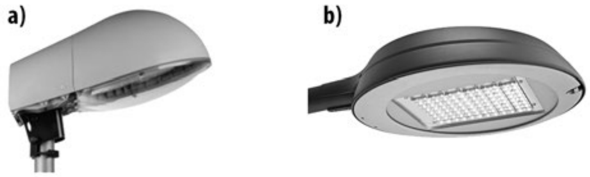


Fig. 4. Pictures of road lighting fixtures used in project

of luminaires have been created, with light sources based on new technologies. This also heralds a development in measurement methods. Unfortunately, the current rate of growth in photometry cannot match the pace at which new LED lighting solutions are designed.

This gives rise to some problems, which have to be controlled to avoid technology development becoming chaotic. Light sources of high luminance, exceeding 10^6 cd/m^2 in the observer's visual field can cause discomfort due to glare [3, 4, 5]. In some fields of application, such as road transport, it may cause a decrease in comfort and adversely affect road safety. Therefore, what is in fact a very good piece of technology, when applied in particular fields may lead to, for example, increased numbers of road accidents instead of improving safety and comfort.

CURRENT MEASUREMENT METHODS

At present there are no alternatives to digital imaging luminance measuring devices in the lighting technology. A single luminance measurement covers more information on luminance values in the field of view of the camera than has ever been possible before (Fig. 1) [6]. However, like every new technique, the digital luminance measurements require appropriate preparation from those taking them. Improperly selected measuring equipment and inattentive staff may be one reason for inaccurate and uncontrolled measurements (Fig. 2).

Fig. 2 shows the results of measuring street lighting parameters together with recording the luminance in order to apply further [7, 8, 9]. Figs. 2 a and 2 b illustrate the luminance distribution measurement ranges selected so that as many details in the road luminance range (between two and twenty cd/m^2, Fig. 2 a) as possible can be shown, or the luminaire luminance (Fig. 2 b). Simultaneously, Fig. 2 clearly proves that the measuring equipment rate allows us to catch the real luminance values of the street lighting fixtures as well as to measure the road surface luminance accurately. Two separate exposures, with

Table 1. Measuring equipment used in tests specifications

Imaging luminance measuring device (ILMD) from Technoteam (LMK) [10]		
Name of Sensor	CCD Sony ICX 285 AL: Diagonal 11 mm (Type 2/3)	Canon 550 D CMOS Canon APS-C Diagonal 27 mm (Type 3/2)
Sensor dimensions	8.8 mm x 6.6 mm	22,5 mm x 15 mm
Resolution	1030 pix x 1380 pix	5184 (H) x 3456 (V) 2592 (H) x 1728 (V) effective
Focal length	50 mm	Sigma 17–50 mm F2.8 EX DC OS HSM

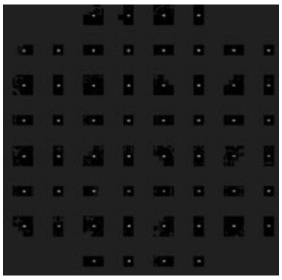
LED 70 W (original images resolution – each pixel has the same dimensions)	
a) 	$L_{max} = 12{,}1 \times 10^6$ cd / m^2
	$\gamma = 0^0$
	measuring distance: *0.33 m*
b) 	$L_{max} = 13 \times 10^6$ cd / m^2
	$\gamma = 0^0$
	measuring distance: *3,3 m*
c) 	$L_{max} = 2{,}71 \times 10^6$ cd / m^2
	$\gamma = 0^0$
	measuring distance: *8 m*

Fig. 5. Luminance distributions for single LED surface – 5 a and LED luminaire (C0 – C180) – 5 b, 5 c, recorded for the same observation direction from selected measurement distance (with aid of 50 mm lens)

differently set exposure times (first: 0.77 s and second: 0.039 s) enable recording the complete luminance in the measuring field of the camera.

For example, the measured street lighting luminance in both parts of Fig. 2 does not include accurate information on real luminance values. Even though, in the event of measurement (Fig. 2 b), the camera did not signal that the measurement range had been exceeded. Fig. 3 a presents the magnified luminance of road lighting fixtures installed over the examined road. Additionally, Fig. 3 b includes the magnified luminance distribution of a multiple light source luminaire with LED technology for street lighting, for the same observation angle.

The tests done at the Lighting Technology Division lab, Warsaw University of Technology, with the use of both types of luminaires explain why this is the case. The luminance distributions of luminaires and light sources were accurately measured, both for the ELGO road lighting fixture with a 250 W high pressure sodium lamp (Fig. 4 a), and for the Philips multiple light source road luminaire with 64 light emitting diodes, where every diode was equipped with an individual optical component (Fig. 4 b).

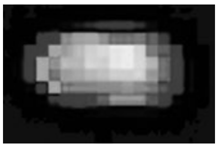
LED 70 W (LED image magnified to illustrate how the luminance values change with increasing distance on the same LED chip)	
	$L_{max} = 12.1\times10^6 \text{ cd} / m^2$
	$\gamma = 0^0$
	measuring distance: *0.33 m*
	$L_{max} = 13\times10^6 \text{ cd} / m^2$
	$\gamma = 0^0$
	measuring distance: *3,3 m*
	$L_{max} = 2.71\times10^6 \text{ cd} / m^2$
	$\gamma = 0^0$
	measuring distance: *8 m*

Fig. 6. Luminance distributions for single LED with optical system (C0 – C180), recorded for the same observation direction from selected measurement distance (using a 50 mm lens)

The tests showed that with an increasing measurement distance (from 33 cm to 8 meters), using the measuring equipment specified in Table 1, both recorded average and maximum luminance value of light sources decrease, for the same observation directions, using the same lens (Fig. 5).

The magnified image of the measurement result (Fig. 6) shows the reason for this result in terms of the digital luminance distribution measurements. A similar result was observed for this surface using high pressure sodium lamp burner.

ANALYSIS

The local magnification of the measurements showed that when the ratio of the camera viewing field (lens) and measurement distance to the size and number of pixels in the matrix improperly selected, the individual pixel of the measuring device could record the average value of luminance of a diode or its nearest surroundings.

$$K = 2\cdot\arctan(L/(2\cdot F)), \quad (1)$$

where:

K is the angle of view of lens/pixel,

L is the value of diagonal or length of matrix/pixel side,

F is the focal length of rectilinear lens.

When there is a high luminance variation gradient [11], i.e. when the recorded item of high luminance (approximately 10^8 cd/m^2) is surrounded by a luminance of between two and ten cd/m^2, the measured value drastically differs from the real average and maximum values (Fig. 2). A short analysis of the viewing field of the entire digital luminance camera and the viewing field of the individual pixel (formula 1), as for a rectilinear lens, enables us to effectively solve the problem of choosing the proper equipment and distance for the measurement (Tab. 2).

Table 2 shows the field of view of the digital camera used in the experiment with the 8 mm lens is (57.6 x 44.8 degrees), in this case, the field of view of the individual pixel is (0.045 x 0.045 degree). After changing the lens to the 50 mm rectilinear lens, the field of view of the digital camera is reduced to (10.06 x 7.55 degrees) and the field of view of the pixel is (0.0073 x 0.0073 degree). For the example measurement distance of 8 meters, it gives the field of view of the individual pixel equal to 1.05 mm^2, in the case of the 50 mm lens. The completed tests (Fig. 7) prove that to record the luminance distribution for a single diode correctly, its image should be recorded with more than 1,000 pixels. And this division should always be adapted to the luminance distribution at the measured item. The relationship describing this approach can be summarised as: the higher the luminance variation on the surface of the

Table 2. Example calculations for the field of view of the lens and individual pixels for selected measurement conditions

MATRIX	Number of pixels	"field of view" of matrix		"field of view" of pixel	
	MPix	Deg	w × h [m]	deg	w × h [mm]
Rectilinear lens, 8 mm – measurement distance 0.33 m					
2/3" 1380 × 1030	1.42	57.6 × 44.8	0.52 × 0.33	0.045 × 0.045	0.26 × 0.26
Rectilinear lens, 8 mm – measurement distance 3.3 m					
2/3" 1380 × 1030	1.42	57.6 × 44.8	5.20 × 3.28	0.045 × 0.045	2.6 × 2.6
Rectilinear lens, 8 mm – measurement distance 8 m					
2/3" 1380 × 1030	1.42	57.6 × 44.8	0.23 × 0.18	0.045 × 0.045	6.38 × 6.41
Rectilinear lens, 50 mm – measurement distance 0.33 m					
2/3" 1380 × 1030	1.42	10.06 × 7.55	0.06 × 0.04	0.0073 × 0.0073	0.04 × 0.04
Rectilinear lens, 50 mm – measurement distance 3.3 m					
2/3" 1380 × 1030	1.42	10.06 × 7.55	0.59 × 0.44	0.0073 × 0.0073	0.42 × 0.42
Rectilinear lens, 50 mm – measurement distance 8 m					
2/3" 1380 × 1030	1.42	10.06 × 7.55	1.42 × 1.06	0.0073 × 0.0073	1.02 × 1.03

light source/luminaire, the greater number of pixels should be used to record the luminance distribution.

With the surface of the chip together with the optical component of 10 mm^2, the individual pixel should measure the average luminance for the surface smaller than 0.1 mm^2.

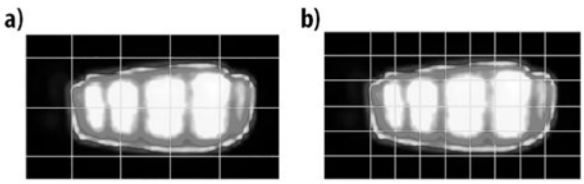


Fig. 7. Example diode chip division (with optical system) into a) 8 parts, b) 32 parts

SUMMARY

All the measurements, as well as their analysis, prove that the use of modern measuring equipment can lead to measurement mistakes and drawing of the wrong conclusions. It should not be ignored that most studies using this method relate to the human eye. For example, the measurements of luminance distribution related to glare discomfort studies, which require measurements of luminance distribution that match the resolution of the human eye. This can only be achieved by knowing the parameters of the luminance camera sensor and specifically choosing the lens and measurement distance. It would also be very helpful to add functionality to the ILMD software, which will indicate the possibility of measurement errors: for example, detecting local increase in luminance values within a single pixel or sensor part. The widespread use of ILMD in the lighting field causes frequent erroneous measurements, of which the person performing the measurements may not be aware. This stems largely from the fact that the measuring equipment only provides an indication of exceeded sensor dynamics, associated with too long an exposure time. There are no warning mechanisms for situations when there are light sources within the camera's field of view, the area is entirely contained within a single cell of the sensor. In this case, the recorded value is the average luminance of the light source and its immediate surroundings. Eliminating such errors is particularly important for measurements, which have health and safety implications.

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NEW APPROACH IN THE DETERMINATION OF QUALITATIVE CHARACTERISTICS OF OUTDOOR ILLUMINATION INSTALLATIONS

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ABSTRACT

An analysis of methods for determining necessary luminance levels in lighting installations of external illumination is carried out. A new method of calculating the visibility of traffic objects based on a statistical approach to the description of detection and identification of the objects by the human visual system is proposed.

Keywords: necessary luminance levels, threshold characteristics of visual system, theory of statistical solutions, optimum image detector

At present, assessment of lighting installations (LI) of outdoor illumination (OI) is based on their provision of necessary luminance (illuminance) levels regulated in Russia by the СП 52.13330.2011 Building Regulation [1].

The primary goal of any LI is the creation of such illumination conditions, which make it possible for a person to solve visual tasks of various complexities to a set level of reliability. The minimum illumination levels derived from a mass of experimental data on the thresholds and performance characteristics of human visual system, obtained from observations of everyday objects. With the evolution of, the number of such everyday objects constantly changes; in addition, their photometric characteristics change with time and strongly depend on the season, weather conditions, on the method of forming LIs themselves, etc. All this is either not taken into consideration in the standard-setting documents at all, or is partly accounted for by the introduction of admissible variation boundaries of normalised parameters. In this way, specific values of luminance or illuminance levels for LI design can only be determined approximately. Experimental methods of determining minimum luminance or illuminance levels require time and material costs, due to the multiple parameters comprising the problem, the solution of which depends not only on photometric object characteristics but also on road surfaces, weather conditions, etc. characteristics, which are generally changeable across field of sight.

Modern software packages for LI calculation (for example, *Lightskape*, *Dialux*, *Light-in-Night,* etc.) allow calculating luminance or illuminance levels to a high degree of accuracy, taking into consideration not only the photometric characteristics of the illumination devices but also the characteristics of illuminated objects. This means that a method is needed for calculating necessary luminance or illuminance levels, which takes into consideration the photometric characteristics of objects illuminated on the road, of road surface coating characteristics and atmospheric conditions, all of which can help to improve qualitative LI characteristics.

The proposed solution consists of the development of a mathematical method of calculating probability or threshold characteristics of visual organs (VO) of a person when solving the problems of detection and identification of the objects. This method will allow using the criterion of a necessary visibility level of objects in the road, which unambiguously determines the required luminance or illuminance levels when calculating EI LIs. As object visibility, i.e. relation of the visible contrast of an object with the background to its threshold value, takes into consideration spatial-angular luminance distribution upon the object and the background, as well as threshold human eye characteristics (for a selected reliability level of the task at hand), this approach can tangible improve traffic safety for vehicles and pedestrians.

Calculation of objects visibility is divided into two physically independent tasks: calculation of the threshold contrast of an object against its background, and the calculation of its "visible" value. In this work, a methodology for the first task is considered.

The most promising method so far for developing this mathematical calculation is based on physiological models describing the process of detection and identification of objects by a person. However, researches into these processes presenting enormous difficulties, and no usable results for LI calculation have yet been obtained. According to different evaluations, obtaining sufficient results based on physiological models may require tens or even hundreds of years of research.

The optimal solution to this problem is the maximum use of existing data on sight physiology and the structure of human eyes, bringing in results from other spheres of research. Physiological data about the structure of optical system (OS) of a human eye and of its retina are known in details; however, research onto the mechanism for processing visual information and the associated higher functions of the brain is in its infancy.

To solve this problem, we use the hypothesis that during evolution by natural selection, the human brain has reached the greatest possible perfection for solving visual tasks of object detection and identification. A precondition of this is the fact that during natural selection, carnivores with a less than perfect sight would die of hunger when competing with more adapted species and similar herbivores were eaten primarily without having time to reproduce. This formulated hypothesis allows using one of the results obtained in the theory of statistical solutions. This is the conclusion about the existence of an optimal radiation receiver (RR) [2]. It appears that among all the algorithms of signal extraction against interfering disturbance, there is one algorithm only, which can solve the problem of object detection or identification better than any other. This algorithm we will call the “optimum RR algorithm”, and algorithm for analysis of two-dimensional fields the “algorithm of an optimum image receiver”, or simply “algorithm of an optimum receiver”. There are various mathematical methods to describe this algorithm. The simplest description method from our point of view based on the function of likelihood and ratio. We don’t seek to assume that a calculation of this function occurs somewhere in the human brain. We only consider that as little is known about any specific nervous connections, the human brain implements some fort of algorithm close to the algorithm of the optimum receiver. The likelihood ratio function is simply a convenient method of describing this algorithm mathematically.

A block diagram of the mathematical VO model based on the optimum receiver is given in Fig. 1 [8]. The crystalline lens of an eye and all its optical elements are presented in the model as an OS. The eye’s retina is presented as a mosaic of n statistically independent RRs. In this case, independent RRs are either separate receivers, or receiver groups connected via intermediate neurons to one fibre of the ophthalmic nerve. A totality of random signals of the receiver mosaic (μ_i) arrives to the analysis device (AD) containing in its memory the antecedent information on the background and object. The AD calculates a one-dimensional function of the likelihood ratio Λ, which is equal to the relation of probability of emergence of random Y implementation in the detection (totality of signals μ_i) experiment, if the object is in field of vision of a person

(*P [Y/S]*), to the probability of emergence of the same implementation *Y*, if the object is absent (*P [Y/0]*):

$$\Lambda = \frac{p}{q}\frac{P[Y/S]}{P[Y/0]}, \tag{1}$$

where p and q are antecedent probabilities of the availability and non-availability of the object, $p + q = 1$.

As a matter of fact, the likelihood ratio, using the language of probability, shows how the image, which is seen by a person, looks like (random μ_i distribution): more like an image with an object or like an image without it.

According to the algorithm of the optimum receiver, the decision on the object availability in sight should be made in accordance with the decision rule:

$$\Lambda \geq \Lambda_{п}. \tag{2}$$

It is known from the statistical decision theory [2] that work according to the decision rule (2) allows accomplishing any criterion (algorithm) the decision making. Different criteria are only characterised by different numerical $\Lambda_{п}$ values. When developing a VO mathematical model, not a specific expression for $\Lambda_{п}$ using parameters of the signal processing algorithm is important (because this algorithm for human beings is not yet known), but the fact is important that whatever this algorithm would be, in the VO model, it will be characterised by a specific numerical $\Lambda_{п}$ value. Thus, taking as a working hypothesis the assumption about the constancy of the criterion decision making on the object's availability (on detection or identification), then determining $\Lambda_{п}$ value once for elementary experimental situations, the VO model can be used with this numerical $\Lambda_{п}$ value for all tasks (all types of objects, backgrounds, luminance levels etc.), where it remains constant.

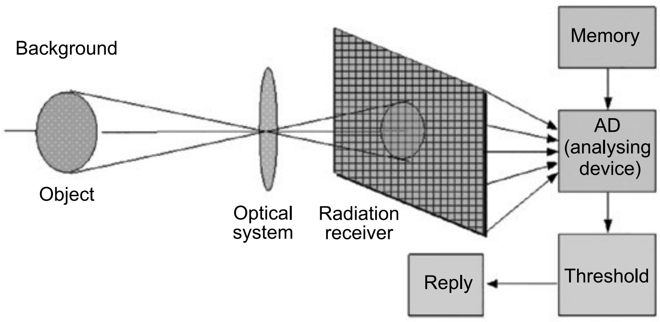

Fig. 1. A block diagram showing a model of the visual organ

It should be noted that although the VO mathematical model is based on the theory of the optimum receiver, represented as a block diagram is in Fig. 1, it does not completely coincide with the theory. Even if we do obtain expressions for the output characteristics of the optimum image receiver, we do not obtain the mathematical VO model. A difference of the VO mathematical model from the optimum image receiver is what the model requires to take into account the data of sight physiology about the structure of the retina and the features of transforming receptor signals within it.

Thus, to obtain design expressions for threshold and probability VO characteristics necessary for engineering calculations of object visibility, some specific problems need to be solved. Some of these are listed below:

1. To obtain a distribution law for receptor output signals proceeding from Poisson distribution law of incident radiation quanta, which is necessary to calculate the function of the relation of credibility;

2. To obtain design expressions for probability and threshold characteristics of the optimum receiver for areas of low and high luminance, where distribution laws of receptor signals vary;

3. To obtain an expression for calculation of the value $\Lambda_{п}$ from experimental research results, so that it would correspond to the decision making criterion on the availability or non-availability of an object in the viewer's field of vision;

4. To associate the design expressions for probabilities of the correct solution obtained by the mathematical model, with the results of experimental research using different methods (methods of minimum changes, constant stimulus etc.);

5. Proceeding from the optimum receiver theory, to obtain a design expression for "a correction for random success" similar to the correction introduced by Blackwell for its high-threshold model [7];

6. To determine the nature of nonlinear transformation law of radiation incident quanta flow into frequency of action current pulses being output signals of VO receptors, which is especially important for luminance area of 0.1–10 cd/m^2 characteristic for EI LIs;

7. To find a method of accounting for several receptors using one fibre of optic nerve with their removal from the sight axis in the mathematical model of group service;

8. To develop a technique of experimentally determining the distribution of sensitivity across the field of sight of an observer;

9. To obtain a design expression for the identification of two objects and to prove experimentally the correctness of the obtained expressions;

10. To obtain an expression to calculate the probability of identification of an object of an arbitrary set of objects when working according to the algorithm of the optimum RR;

11. To develop a theory of the optimum receiver in the event of external additive and multiplicative disturbances arising in sight of an observer under complex weather conditions;

12. To take into consideration the influence of eye optics aberration on the VO model, which are most essential with lowered luminance level.

The first problem, which will be considered in this article, is the determination of the law of distributing output receptor signals and of the expression for probability of object detection using the optimum receiver.

The initial law of distributing the quanta, which have incident on any RR, is well described by Poisson distribution [3]. As it is shown in [4], the error of this approximation does not exceed 1%, if condition (3) is met.

$$\frac{hc}{\lambda kT} > 4.15, \tag{3}$$

where h is Planck's constant ($6.626 \cdot 10^{-34}$ J/s), c is light speed in a vacuum ($2.998.10^8$ m/s), λ is radiation wave length, k is Boltzmann's constant ($1{,}38 \cdot 10^{-23}$ J/K), T is absolute temperature of the radiation source, K.

At the visible spectrum interval (λ < 0.78 μ), condition (3) is met at T < 6000 K. As the radiation transformation process in a VO retina is random, it can be characterised it using an effective transformation coefficient η, i.e. by relation of mathematical projection of action current pulse frequency to the radiation quanta flow, which fall onto the receiver. Taking into consideration that quantum efficiency of a visual pigment doesn't exceed 20% [5], and to form one action current pulse, disintegration of 5–7 molecules of photosensitive substance [6] is necessary, one can consider that within the whole interval of VO work, η is much less than 1. This assumption makes it possible to determine just enough the distribution law of action current pulses, i.e. of output RR signal in the model of vision organ.

In case $\eta \ll 1$, probability of emergence of two and more action current pulses due to one radiation quantum can be neglected. A conventional distribution law ($P[\mu / m]$) of output signal μ of any RR, will be determined using the binomial distribution law [3] provided that m quanta fell on the RR:

$$P[\mu / m] = C_m^{\mu} \eta^{\mu} (1-\eta)^{m-\mu}, \tag{4}$$

where $C_m^{\mu} = \dfrac{m!}{\mu!(m-\mu)!}$ are binomial coefficients.

Poisson distribution law for quanta falling on the RR is determined using the expression:

$$P[m] = \frac{X_0^1}{m!} \exp\left(-X_0^1\right), \tag{5}$$

where X_0^1 is the mathematical expectation of the radiation quanta number fallen during RR integration on its surface, m is random number of the fallen quanta.

Distribution law of the RR output signal will be determined under the formula of total probability [3] by summation across all possible m values:

$$P[\mu] = \sum_{m=\mu}^{\infty} C_m^{\mu} \eta^{\mu} (1-\eta)^{m-\mu} \frac{(X_0^1)^m}{m!} \exp\left(-X_0^1\right). \tag{6}$$

It is simple to show that the series (6) determines the density distribution function of the Poisson distribution law with the mathematical expectation $X_0 = \eta X_0^1$, i.e.

$$P[\mu] = \frac{(X_0)^{\mu}}{\mu!} \exp\left(-X_0\right). \tag{7}$$

The obtained expression for the law of RR output signal distribution allows finding *P [Y/S]* and *P [Y/0]* probabilities determining the likelihood ratio function.

For independent RRs

$$P[Y / S] = \prod_{i=1}^{N} \frac{(X_{0i})^{\mu_i}}{\mu_i!} \exp\left(-X_{0i}\right), \tag{8}$$

where X_{0i} is mathematical expectation of output signal of the i^{th} RR tracking an object against any background, N is RR number in the RR mosaic of VO model.

$$P[Y / 0] = \prod_{i=1}^{N} \frac{(X_{\phi i})^{\mu_i}}{\mu_i!} \exp\left(-X_{\phi i}\right), \tag{9}$$

where $X_{\phi i}$ are mathematical expectations of output signal of the same i^{th} RR tracking background image without objects.

Then the likelihood ratio function will be determined by the following expression:

$$\Lambda = \prod_{i=1}^{N} \left(\frac{X_{oi}}{X_{\phi i}}\right)^{\mu_i} \exp\left(-(X_{oi} - X_{\phi i})\right). \tag{10}$$

To determine the probability of correct detection of an object, it is necessary to integrate the conventional law of Λ distribution (under the condition that the object is in sight of the person) across area (2) determining algorithm of the optimum receiver operation. To obtain an analytical expression for the Λ distribution law is a complex problem, because Λ is connected with μ_i by complex power-law dependence. However, after taking the logarithm of expression (10), we obtain:

$$Z = \ln\Lambda = \sum_{i=1}^{N} \mu_i \ln\left(\frac{X_{oi}}{X_{\phi i}}\right) - \sum_{i=1}^{N}(X_{oi} - X_{\phi i}). \quad (11)$$

The law of Z distribution differs from the Poisson distribution law, at least because its dispersion isn't equal to the mathematical expectation; however, according to the central limit theorem [3] with big N, it tends to the normal distribution law:

$$P[Z] = \frac{1}{2\pi\sigma_\Lambda}\exp\left(-\frac{(Z-m_\Lambda)^2}{2\sigma_\Lambda^2}\right), \quad (12)$$

where m_Λ is the mathematical expectation of $\ln\Lambda$ provided that an object exists in the observer's field of sight;

σ_Λ^2 is dispersion of $\ln\Lambda$ under the similar condition.

As mathematical expectation μ_i is equal to X_{oi} provided that the object is in the observer's field of sight, it is easy to obtain expressions for $\ln\Lambda$ mathematical expectation and dispersion:

$$m_\Lambda = \sum_{i=1}^{N} X_{oi} \ln\left(\frac{X_{oi}}{X_{\phi i}}\right) - \sum_{i=1}^{N}(X_{oi} - X_{\phi i}), \quad (13)$$

$$\sigma_\Lambda^2 = \sum_{i=1}^{N} X_{oi} \ln^2\left(\frac{X_{oi}}{X_{\phi i}}\right). \quad (14)$$

The probability of detection of an object (P_{ob}) will be determined using function (12) integral across the area, where $\Lambda \geq \Lambda_п$. As a natural logarithm function monotonously increases, integration area (2) is equivalent to the area, where $\ln\Lambda \geq \ln\Lambda_п$. Then

$$P_{об} = \frac{1}{2\pi\sigma_\Lambda}\int_{\ln\Lambda_п}^{\infty}\exp\left(-\frac{(Z-m_\Lambda)^2}{2\sigma_\Lambda^2}\right)dZ = \Phi(y), \quad (15)$$

where $\Phi(y) = \frac{1}{2\pi}\int_{-\infty}^{y}\exp\left(-\frac{t^2}{2}\right)dt$ is probability integral [3],

$$y = \frac{m_\Lambda - \ln\Lambda_п}{\sigma_\Lambda}, \quad (16)$$

Proceeding from expressions (15) and (16), threshold conditions of object detection (P_{ob}=0.5, y=0) will be determined by the following equation:

$$m_\Lambda = \ln\Lambda_п. \quad (17)$$

The RR number forming the visual field of a person reaches hundreds of millions, therefore, using expressions (13) and (14) for the calculation of m_Λ and σ_Λ^2 is a complex task. In order to simplify the calculations, we move from reactions of mosaic separate RR to the sensitivity distribution function across the vision field of human eyes:

$$X(\varphi,\theta) = \frac{X_i}{\Delta\varphi\Delta\theta}, \quad (18)$$

where X_i is mathematical expectation of the reaction of the i^{th} RR tracking in space direction φ,θ; $\Delta\varphi\Delta\theta$ is solid angle of vision field of the i^{th} RR.

With such a representation of the sum, determining expressions (13) and (14) becomes integral, and expressions for m_Λ and σ_Λ^2 calculation take the shape of double integrals across the field of sight Ω:

$$m_\Lambda = \iint_\Omega \left[\begin{array}{l} X_o(\varphi,\theta)\ln\left(\frac{X_o(\varphi,\theta)}{X_\phi(\varphi,\theta)}\right) - \\ -X_o(\varphi,\theta) + X_\phi(\varphi,\theta)\end{array}\right] d\varphi d\theta, \quad (19)$$

$$\sigma_\Lambda^2 = \iint_\Omega X_o(\varphi,\theta)\ln^2\left(\frac{X_o(\varphi,\theta)}{X_\phi(\varphi,\theta)}\right) d\varphi d\theta. \quad (20)$$

Already at this development stage of the VO mathematical model based on the optimum receiver, we can obtain ratios, which are confirmed by analytical and experimental dependencies documented by other authors. In particular, A. Rose [5] using a single-channel RR model on the basis of the signal to noise threshold relation, obtained an expression experimentally confirmed at a low adaptation luminance, when VO receptors are linear RRs:

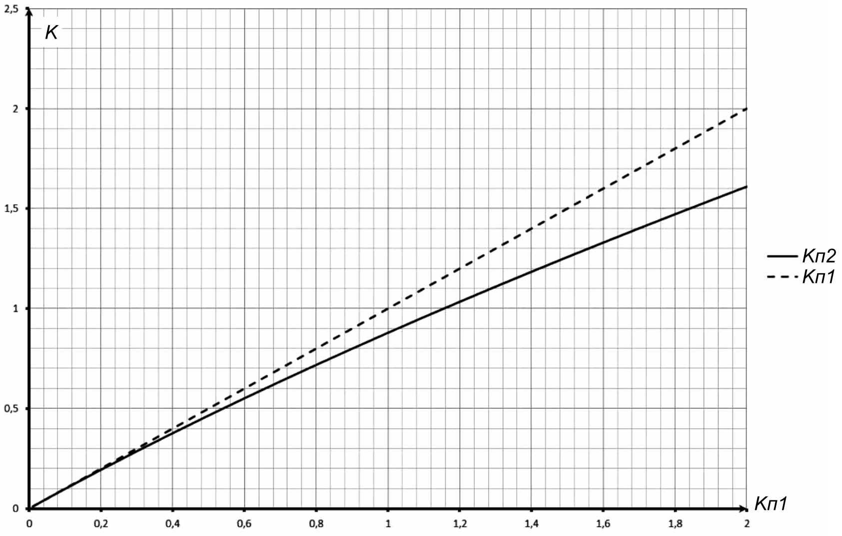

Fig. 2. Design dependencies of threshold contrasts

$$K_n^2 L_\phi \omega = m^2, \tag{21}$$

where K_n is the threshold contrast of an object with background, L_ϕ is luminance of a uniform background, ω is the object solid angle, m is the threshold signal to noise relation.

If the expression (19), a linear dependence between RR reaction and luminance ($X_\phi = cL_\phi$) tracked by it is assumed, then for an equally luminous object and background, it can be obtained as follows:

$$m_\Lambda = \left((1+K)\ln(1+K) - K\right) X_\phi \omega, \tag{22}$$

where $K = \dfrac{X_o - X_\phi}{X_\phi}$ is the contrast of an object against its background.

After expression (22) is substituted into expression (17) for threshold conditions of detection and for linear RRs, we obtain an expression of statistical model similar to (21):

$$\left((1+K_n)\ln(1+K_n) - K_n\right) L_\phi \omega = \frac{\ln \Lambda_\text{п}}{c}. \tag{23}$$

The calculations with expressions (21) and (23) essentially differ in the big threshold contrast area. This is connected with the fact that A. Rose accepted the RR output signal distribution law to be normal, instead of deducing it from the Poisson distribution law, which the radiation falling quanta statistic is subject to. If we consider a small contrast object area in expression (23) (which corresponds to big background luminance), when Puasson law is well approximated by the normal density function, then from (23), the expression $K_n^2 L_\phi \omega = \dfrac{2\ln \Lambda_\text{п}}{c}$ fully coinciding with expression (21) can be obtained.

In Fig. 2, design dependences of threshold contrasts Kp_1 and Kp_2 obtained according to design expressions (21) and (22) are given correspondingly.

The obtained expressions explain the reason for the difference between numerical values of positive and negative threshold contrasts. This phenomenon was found by many researchers [7] but there were no clear explanations of the reasons for this until now.

Both in threshold, and in exceeded threshold conditions, expression (17) does not depend on the contrast sign, therefore designating threshold value of positive contrast in (22) as K_+, and module of negative threshold contrast as $|K_-|$, we determine the interrelation between these contrasts when observing objects of equal angular size against the same background:

$$\begin{aligned}&(1+K_+)\ln(1+K_+) - K_+ = \\ &= (1-|K_-|)\ln(1-|K_-|) + |K_-|.\end{aligned} \tag{24}$$

Analysing expression (24) shows that to the maximum value of negative threshold contrast ($K_-= -1$), a positive threshold contrast value corresponds $K_+ = \exp(1) - 1 \approx 1{,}72$. The interrelation of K_- and K_+ obtained from expression (24) is given in Fig. 3.

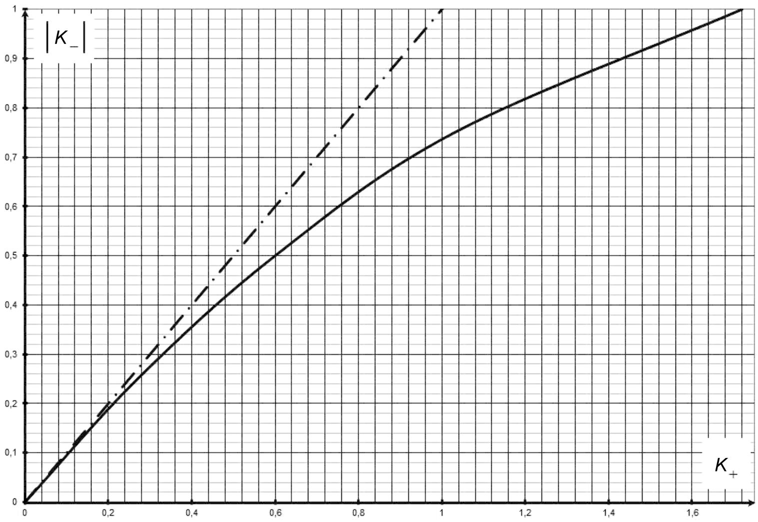

Fig. 3. Interrelation of positive and negative threshold contrasts

The presented examples confirm the importance of the sequential analysis of the deduced ratios, because unreasonable assumptions during their deduction can essentially raise errors in the mathematical simulation, which in turn reduces the efficiency of the mathematical method of EI LI optimisation.

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ENSURING THE SAFETY OF BALLAST COMPATIBLE LED, AS AN ALTERNATIVE TYPE OF FLUORESCENT LAMP, IN KOREA

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ABSTRACT

Products using LEDs are being actively developed, thus there has also been a great demand for LED products that can replace traditional lamps, such as fluorescent lamps and metal halide lamps. But so far there is no proper standard that a manufacturer can use to test their products. As a result manufacturers cannot develop retrofit LED lamps and sell them even if they have the technology. In this study, by analysing the control gear for a fluorescent lamp that is currently used in the market, which is a magnetic or electronic ballast, this study tries to develop a proper test method by investigating the compatibility between an all-type control gear and LED retrofit products.

Keywords: ballast compatible LED, LED luminaires, electrical appliances safety standards in Korea

1. INTRODUCTION

1.1. Background for the research

Currently, there are initiatives to replace existing lighting with LED lamps, and there is a growing trend among manufactures to develop a ballast compatible LED lamp, a so called G13 Cap type, that will replace the current lamps and use LED lamps, Fig. 1. In particular, the need to development the G13 double cap LED lamp for use in offices or factories is growing.

Thus, standards for product performance and safety are being discussed by an international standardization organization.

Recently, in 2014 CIE TC34 (Lighting Subcommittee) established the IEC:62776.

However, directly applying an international standards such as 62776 in Korea may not be appropriate, because each country's situation is different.

The goal of this study is to articulate the proper values and standards in order to prevent safety problems that might happen when the ballast-compatible LEDs enter the South Korean market.

When the ballast-compatible LEDs enter the South Korean market, the aspects expected to cause problems are as follows: weight, insulation performance, temperature rising, lamp variation, protection function of the safe operating area, compatibility (abnormal state). Thus, this study will address the safety standard according to the aforementioned problems.

Therefore, in this paper, we derive the appropriate values throughout the study to be operated suitably in Korea and results reflect to K10025.

2. THEORIES

2.1. Weight

A fluorescent lamp replacing LED lamp is currently subject to the international standard, IEC 60598–1: Luminaires Part 1: General requirements and tests, as well as Japan's national industry association JEL 801: L type and in an external converter type LED lamp standard, which is defined as less

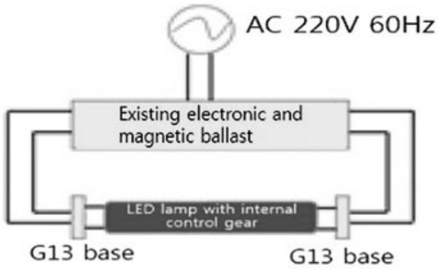


Fig1. Ballast compatible LED lamp wiring method and structure

than 500 g of in total weight for a LED lamp that uses a G13 cap [1,2].

The total G13 cap fluorescent lamp weight is on average 270 g (FLR 32 W), which are being sold in South Korea, whereas the weight of a LED lamp of the same length is about 400–450 g.

The weight of the LED lamp was determined to be acceptable, according to the international standards. However, when tested against the South Korean standard, the LED lamp degraded at a high temperature (50 °C: a movement condition when purchasing lamp equipment); and there was also a long-term aging condition (2,000 hours or more).

This is a direct problem linked to user safety. After an investigation into the causes, one result is that although the holder, which is used universally overseas, is an insert type holder and the connector type holder, Table 1, the lamp holder is a structure to sufficiently hold the LED lamp. However, the face-to-face type holder, which is most commonly used in South Korea, cannot sustain the LED pin and is structured to contact the holder on the surface, so the LED lamp weight cannot be sustained.

Therefore, in South Korea, it is recommended that the weight of an LED lamp to be less than 400 g to conform with the safety standard and also prevent accidents from falls due to the weight of a LED lamp, Fig. 2.

2.2. Insulation performance

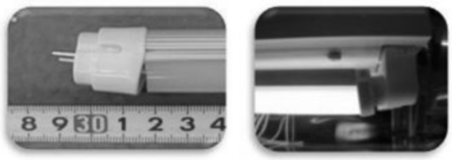
This test item is an additional item to prevent electric shock because of the insulation breakage of a fluorescent lamp replacing LED lamp, which concerns the test results of LEDs being sold in South Korea. The insulation performance item is applied with the aforementioned standard and is acceptable according to the international standard. The test method is applied and determined by the part accessible to the charging circuit of an LED lamp and by a user. The voltage applied at this time is 4 × U (maximum operating voltage) + 2000 V, and the allowed current of the test equipment is 100 mA.

Table 1. Lamp holder type

Insert type holder	Connector type holder	Face-to-Face type holder
	•	•
		

Table 2. Insulation performance test results

Test results	Remarks
1 st: 5 out of 6 are not acceptable	• Insulation breakage in the heat sink and charging circuit
• 2 nd: 5 out of 6 are not acceptable	



Test conditions: 50 °C, 2000 + hours aging
Test results: LED lamp equipment breakaway, fall

Fig. 2. Weight test results

The Kikusui TOS5051 A is used to measure the insulation performance. When an applied part is an injection (e.g., plastic material), the test is conducted by wrapping it in foil.

The application to U, operating voltage, is as follows. After connecting a LED lamp to the replacing KS C 8100 (electronic ballasts for fluorescent lamp) of a fluorescent lamp to an acceptable ballast, measure the input voltage of the instantaneous LED lamp at the moment of lighting the LED lamp by gradually increasing the input current (AC) of the reference ballast, and then applying the value of U, see Table 2.

2.3. Temperature rise test

The ballast compatible LED tubes are a structure of replacing the body with hands. If users touch

Table 3. Temperature rise test results

Types of lamp measured	Points measured (K)			
	• Cap	• Filament	Body center	Ballast surface
FLR32	• 16.2	• 26	• 11.3	• 3.1
• FHF32 SS	• 15.4	• 23.6	• 8.3	• 1
• FLR32 SS	• 20	• 28.3	• 15.3	• 4
• FLR 40	• 29.5	• 42.6	• 18.1	• 1.3
• FL40 SS	• 40.4	• 56.3	• 22.6	• 0.7
• FL40/36	• 35.3	• 61.6	• 21.1	• 0.7
• LED lamp	• 15.4	• -	• 16.7	• 3.6
	• 18.8	• -	• 40.8	• 6.8
	• 20.6	• -	• 45.6	• 4.6
	• 10.5	• -	• 50.8	• 4.5

an LED lamp in operation at a high temperature with their hands, then burns and accidents may occur. Hence, the temperature of an LED lamp body, cap, and fluorescent lamp is measured and compared when connecting the test ballast for fluorescent lamps (e.g., FLR32 W, FHF32 W, FL40 W) of the same length to the LED lamp being sold.

The Yokogawa uR1800 recorder was used in this test and temperature was measured in accordance with IEC 60598.

The corresponding ballast standard used for the test was the KS C 8100: electronic ballast standards for fluorescent lamp, see Table 3.

Table 4. International standard status

Standard name	Standard No	Measured parts	Temperature standard
Fluorescent lamp	• IEC 61195	• Cap	• 95 K (120°C)
• Holder	• IEC 60238	• Wiring part	• 45 K (75°C)
• Lamps	• IEC 60598–1	• Plug/holder interface	• 45 K (75°C)
• Converter	• IEC 61347–2-13	• Power code & wirings	• 45 K (75 °C)

The results show that a high temperature was measured in the body of an LED lamp with 42.5 K (67.5 °C) more than the fluorescent lamp. The investigation shows that because of the high current supply there was a mismatch with the internal converter of an LED lamp and ballast. Consequently, the already high temperature of an LED lamp charging part had increased further.

The permissible temperature rise of light and relevant international standards is 75 °C, Table 4.

It is only about 7.5 °C higher than the temperature measurement results of the LED lamp in this study.

However, this is not feasible to apply this to the light-emitting part (insulator) and heat sink, which are non-charging parts.

The CIE international standards for household electrical appliances recommendation is regulated the maximum temperature rise to 60 °C, with an ambient temperature of 23 °C, and when touched by hand.

Thus, this enhanced standard was applied to the lamp cover and the heat sink.

2.4. Thermal strain

A fluorescent lamp is structured by bonding a glass tube and metal cap with to withstand high heat,

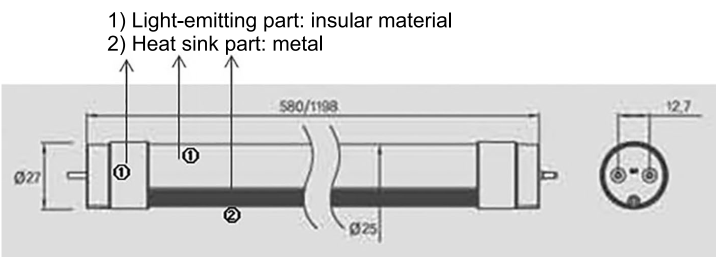


Fig. 3. LED tubes structure

Table 5. 32 W fluorescent lamp electrical characteristics standard value

Frequency	Evaluation Power	Voltage of lamp wiring (r.m.s.)V			Evaluation lamp current
kHz	• W	• Evaluation	• Min.	• Max.	A
20–26	• 32	• 128	• 118	• 138	• 0.255

but LED lamps are structured in a circular shape with a heat sink part and a light-emitting part of injection-diffusion material, Fig. 3.

Unlike the existing fluorescent lamp, if the LED lamp is used for long hours under high temperature, then it may cause accidents because of a breakdown and fall of lamp equipment through material strain, such as the cap. Thus, the related international standards were investigated and the products in the market were evaluated to incorporate them into the South Korean safety standard.

For the international fluorescent lamp standard, the following was used: IEC 61195, double-capped fluorescent lamps, Safety specifications. That is, after leaving the fluorescent lamp unlit for 2,000 hours in a 120 °C ± 5 °C chamber, when the cap and body rotated for 0.6 nm, the radius of rotation is specified as less than 6° [3].

Table 6. Matching test results

Electric characteristics of LED lamp						
Lamps applied		• Input power to ballast (W)	Input current to ballast (A)	Lamp power (W)	Lamp voltage (V)	Lamp current (A)
Fluorescent Lamp		• 33.2	• 0.2	• 27.4	• 139.1	• 0.3
• Ballast	• 1	• 23.8	• 0.1	• 21.3	• 102.7	• 0.2
	• 2	• 21.2	• 0.100	• 18.8	• 101.4	• 0.228
	• 3	• 21	• 0.100	• 18.7	• 101	• 0.228
	• 4	• 23.3	• 0.117	• 21.7	• 103	• 0.244
	• 5	• 34.0	• 0.170	• 30.2	• 67.4	• 0.430
	• 6	• 23.8	• 0.110	• 20.5	• 102	• 0.233
	• 7	• 24.6	• 0.114	• 21	• 102	• 0.236
	• 8	• 24.6	• 0.114	• 21	• 102	• 0.236

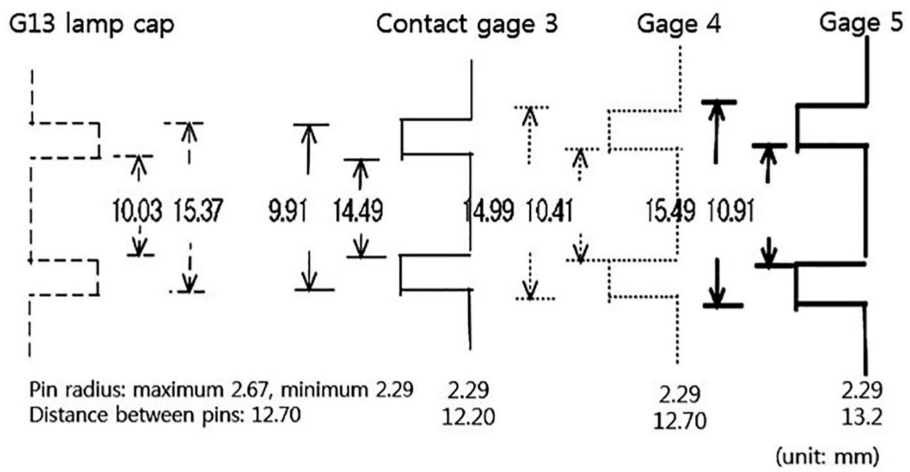


Fig 4. G13 cap dimensions review

Fig. 5. Thermal strain test results

Fig 6. Matching test results

And in the Japanese standards, section JEL 801:5.3 for the L-type cap external converter LED lamp, it specifies the change of a LED lamp length to be less than 2.0 mm in the ambient temperature of 75 °C, unlit; the bending of a LED lamp because of its weight is specified to be less than 10 mm in the central part [2].

After reviewing two standards, the CIE standard is the standard to certify the safety of a fluorescent lamp as mentioned above; however, is a bit too difficult to apply since its structure is different than the LED lamp. The Japanese standard for the external converter type LED lamp has no suitability hours and hence has no reproducibility, which is an important omission. This is because the measured value has different results, depending on the time of the test application.

Hence, because of the structural features of the LED lamp, the application hours for suitability were set at 24 hours to evaluate it at a test temperature of 125 °C + 5 °C which is applied to all existing lamp standards in order to evaluate the bonding power of the body with the cap.

The suitability standard for those conditions is applied when the rotation of the radius is less than 6°, when rotating with 0.6 nm, which is the international standard for the G13 cap, Fig. 4. The standard of LED lamp strain and bending is the international standard for the G13 lamp holder IEC 60400: fluorescent lamp holder; and IEC 60061–1, 60061–2, 60061–3, and 60061–4. Using the length standard of the LED lamp cap pin that can sustain G13 lamp holder from the gage and lamp can and holder stand-

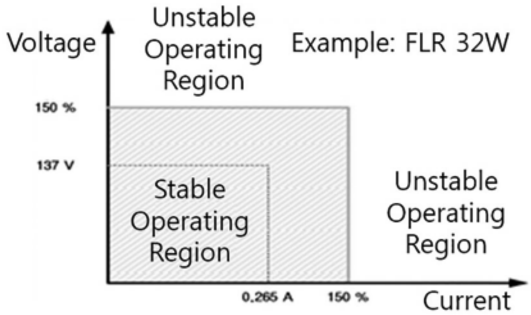


Fig. 7. Stable operating region area

ard for compatibility and safety control, the change of the length of the LED lamp is defined to be less than 2.0 mm. Thus, in brief, it shows that the LED lamp does not break away from the lamp holder, but only if the bending from the centre is defined to be less than 10 mm compared with its own weight.

The test results on the thermal strain for 2 products being sold in South Korea show, Fig. 5, that there was a degradation phenomenon of the LED lamp because of the strain, certain materials of the LED lamp cap, and the reduction in the thickness (to decrease the weight) of light-emitting part of the insulation material and heat sink. Thus, it directly affects the item and the safety of the user and is consequently reflected in the safety standard.

2.5. Safe operation area protection

The ballast compatible LED tubes must operate in the same operation area (e.g., lamp voltage, lamp current) as the fluorescent lamp. Under only that condition, the issue of consistency between the ballast compatible LED tube and ballast are resolved; so the issues of ballast damage, heat, and ignition are relatively minimised. The LED lamps presently being sold on the Korean market are of a type that replaces the fluorescent lamp FRL32 W and has the standard value of IEC 60081: Double-capped fluorescent lamps. Its performance specifications are shown in Table 5.

In this study, the electrical characteristics in operation are measured and the consistency characteristics that can occur are analysed by connecting the ballast compatible LED to the ballast for the fluorescent lamp being sold on the market.

In the fifth sample (Table 6), it was found that the ballast operates at a higher current than the movement area of the fluorescent lamp. Furthermore, that phenomenon can possibly lead to ballast damage, heat, and fire.

Table 7.Test results

Type	Input voltage, V	Reference current, A	Impedance, Ω	Frequency, kHz	Lamp voltage, V	Lamp current, A	Lamp power, W	Luminous flux, lm	Luminous efficiency, lm/W
LED lamp	• 213	• 0.266	• 450	• 25±1	• 97.37	• 0.256	• 22.9	• 2175	• 94.9
	• 210	• -	• 450		• 96.84	• 0.251	• 22.4	• 2139	• 95.5
	• 205	• -	• 450		• 96.01	• 0.242	• 21.4	• 2072	• 96.9
	• 210	• -	• 500		• 94.99	• 0.232	• 20.2	• 1979	• 97.8
	• 220	• -	• 500		• 96.28	• 0.249	• 22.0	• 2109	• 96.0
	• 256	• 0.255	• 500		• 100.54	• 0.315	• 28.7	• 2568	• 89.5

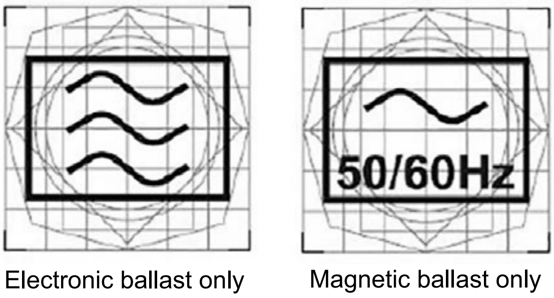


Fig. 8. LED lamp labelling

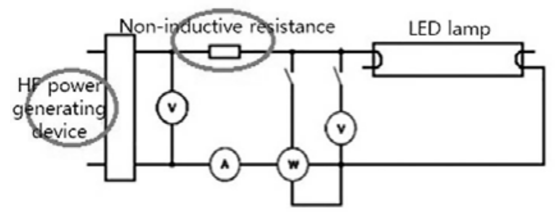
Analysing the corresponding ballasts shows that the self-oscillation, which is a frequency oscillation, is a phenomenon using negative pole pre-heated current. Hence, the cause is the increase of current because of the mismatch between the LED lamp and impedance.

There will not be a problem if the current supply is shut off with a smooth operation of the internal protection circuit of a ballast when the ballast and LED lamp are matched. However, when the protection circuit does not operate, it can lead to a fire, Fig. 6, hence the LED lamp's voltage and current are restricted to the characteristic value of a fluorescent lamp's voltage and current.

When the characteristic value of an LED lamp exceeds 150% of a fluorescent lamp's characteristic value, a LED lamp detects the movement by itself and operates the protection circuit in the LED lamp to prevent ballast damage, heat, and fire by maintaining consistency with the ballast, Fig. 7.

2.6. Compatibility test (at abnormal state)

In the international standard for the double cap LED lamp safety requirement (IEC 62776) for the LED lamp inserted to the electric ballast, the label must display that it is for the electric ballast only. However, if it is used for self-ballast, then the la-



*Measured by authorising voltage (V) and resistance (Ω) from the frequency of 25 kHz in HF power generating device

Type	Input voltage V	Reference current A	Impedance Ω	Frequency kHz	Power factor
32 W Fluorescent lamp	256	0.255	500	25 ± 1	More than 98%

Fig. 9. 32 W fluorescent lamp ballast test characteristics

bel must display that it is a self-ballasted LED lamp only, so that the users can fully understand and comply with the regulations, Fig. 8.

There is a safety issue when it is used incorrectly for the electrical and the self-style type. In order to prevent the problem of an erroneous insertion of a lamp, regardless different ballast types of the existing fluorescent lamp equipment, the South Korean standard promulgated a safety regulation that the LED lamps must operate with all types of ballast, electrical or self-ballast.

In this study about the measures and methods for the compatibility items, there have been many problem-solving methods. However, the paramount phenomenon to note is that when the LED lamps are installed into the existing ballasts (i.e., Table 7 test results), the input current of 32 W output of the existing ballast is decreased by 21 W–25 W. Consequently, the current of the LED lamp also shows the decrease.

This characteristic occurs because the ballast's operating principle detects an impedance of the existing load (e.g., fluorescent, LED lamp). The international standard of ballast for the fluorescent lamp specifies that the standard value for a 32 W fluorescent lamp impedance to be 500 Ω, Fig. 9. Hence, the blinking phenomenon was discovered because of the total impedance of the LED lamp IC Vcc, which is low in the oscillator circuit using the IC circuit.

The reference values of the input voltage, optical, and electrical characteristics were evaluated, according to the changes of LED lamp impedance, when connecting the LED lamps to the established ballasts and varying them.

As the test results show, the blinking phenomenon or non-lighting was not detected when the delay impedance maintains a certain value, even if the input voltage of LED lamp changed.

However further studies are required. The reason is that there are different ballast circuit methods for the U.S. and European ballasts versus those in China and Japan and, which have similar ballasts to those in South Korea. In order to develop and market LED lamps, it is desirable to better understand and design the standards and characteristics of ballast and fluorescent lamps. That is to check that they include the seven items mentioned earlier; in terms of the safety standard, that they includ the initial light speed, light efficiency (for reference), lamp power and light speed retention rate, as well as 15 additional items, such as the label, structure and assembly, dimensions of the LED lamp, insulation resistance, creep age distance and space clearance, failure conditions, heat-resistance, anti-flammability and fire-resistance, durability, etc.

The performance items are proposed as a minimum performance reference and it is suggested as a level that can replace the existing fluorescent lamp, Furthermore, it is presented as the same standard as the performance standard of the external converter LED lamp, on which the safety standard has been based.

3. CONCLUSION

In summary, this paper has elucidated the factors that can cause problems in LED lamps currently being sold on the international and South Korean markets. First, there was an analysis of a method to ensure the safety in the G13 intuitive double cap fluorescent lamp replacing LED lamp for the LED lamp using internal control gear that can replace the fluorescent lamp.

Next, this paper examined the prevalent international standard that is currently in becoming the accepted international standard, as well as a similar Japanese standard. Finally, a safety standard was proposed, which ensures the safety of users, and which will is also suitable for the South Korean situation.

The ballasts used in this study are expressed by sampling their representative values by analysing 100 ballasts being sold in South Korea; the LED lamp also applied the LED that has not obtained the South Korean safety certification (KC).

The LED lamp using internal control gear, which is sold mostly in South Korea, has not yet been approved by the international standard. That LED lamp replacing fluorescent lamp is expected to enter the international light market after meeting the international standard requirements in the near future.

Already, European lighting companies are gearing up for the development of the LED lamp; and they are currently selling well in countries where the compulsory certification is not being enforced.

Although the above research presents results for the G13 intuitive LED lamp, it can be applied to the safety standard to replace the LED lamp of the FPL (U type) fluorescent lamp. In order to develop the LED lamp to replace the fluorescent lamp, the following must be accomplished, to avoid loss of time and money: a prerequisite understanding of the characteristics of the existing fluorescent lamps and ballasts, as well as the corresponding national standards mentioned in this paper, and international safety standards. This research would be helpful to countries that wants to suggest new safety standarsd for ballast compatible LED.

In conclusion, the safety standards should be amended if there are additional needs after conducting a suitability assessment in accordance with the safety standard presented, and through continual testing and research.

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NEW SOLUTIONS FOR TRANSLUCENT STRUCTURES

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ABSTRACT

The authors propose new design principles for translucent elements of a building's shell, based on which it is possible to obtain energy efficiency and recover heat previously lost to the atmosphere, whilst aerating rooms through windows and facades without entailing power losses.

Keywords: energy effective construction, protective constructions, ventilated constructions,
translucent structures, energy saving active system, heat recovery

Translucent structures are the weakest element of the protective shell of a building in terms of heat insulation characteristics. Therefore, required minimum values for the reduced heat transmission resistance of walls, windows and balcony doors regulated by Moscow standards of 1995 [1], differ 2.94 times (1.0 and 0.34 m^2 •°C/W), and according to the most recent Russian national standard document of 2012 [2] they differ 5.80 times (3.13 and 0.54 m^2 •°C/W).

However, according to the Moscow standard documents [3] which are intended for the design of new buildings since 2016, this ratio slightly decreases: to 3.8 times (3.80 and 1.00 m^2 • °C/W).

From the point of view of thermal physics, to save energy during the building's operation, it would be better not to use translucent structures at all. The use of natural illumination, however, is still necessary according to wellbeing standards both in residential and public, as well as in most industrial buildings [4]. The inefficiency of constructing windowless buildings has already been proved in the 1940s and 1960s [5–8].

It is clear that the main real heat losses from rooms occur through translucent structures: between 30% and 60% of general heat is lost, depending on the structure of windows and facades, the environmental conditions, evaluation methods and on some other indicators.

In recent years, translucent structures and facades have developed significantly: both in terms of increases functionality and operational indicators, and by using advanced modern technologies. In Figs. 1 and 2, the improvement of light-transmission in filling and of wooden windows is shown using the reduced heat transmission resistance indicator.

So far, the biggest companies producing translucent structures, are able to manufacture windows and facades with reduced heat transmission resistance of 0.8–0.9 m^2 •°C/W [9] on a massive scale without considerable problems. However, to achieve values for this indicator which can be characterised as having heat-insulating efficiency greater than 1.0 m^2 •°C/W, it is necessary to apply new and expensive technological solutions.

This being said, there have been translucent structures developed in recent years [10, 11], the reduced heat transmission resistance of which reaches 1.5–2.0 m^2 • °C/W.

For improved functional indicators of traditional translucent structures and of their glass cover, various modern technological solutions are used, including the following:

– **Electrochromic glass.** This technology was developing over a long period of time, however today it is already being mass produced, and has shown its

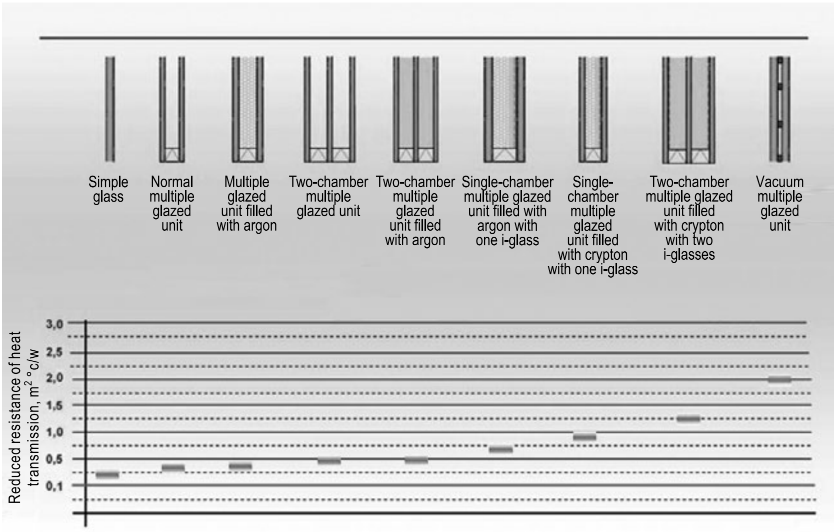

Fig. 1

efficiency when glazing window and facade structures, especially in regions with hot climates, as well as on southern and western facades of buildings. The essence of this technology is its ability to change the optical transmission of the glass cover because of a special coating influenced by electric current, which makes it possible to provide a comfortable microclimate in the rooms;

– **New generation heat-reflecting and multipurpose glass.** Such glass is manufactured using both traditional magnetron deposition of a special coatings on the glass, and with the application of “pouring” and other technologies, which allow improving heat engineering and lighting characteristics of multiple glazed unit windows, so that they work effectively in both winter and summer operation conditions;

– **Glass with a photo-electric effect.** Over the last several years, it has been possible to develop special effective translucent glass coatings, which can transform sunlight into electric energy, making facades part of the building engineering systems and to providing additional power efficiency to translucent and facade structures;

– **Vacuum multiple glazed units.** Such multiple glazed units appeared on the market for the first time in the early 1990s, however, they had some serious limitations to their use in most buildings. In recent years, a considerable progress has been made in bringing these structures to industrial production. Therefore, a sharp increase in the prodution of multiple glazed units can be expected in many countries: in the EU, USA, China, Japan and probably in Russia, which will allow for a substantial improvement in the heat engineering characteristics of the traditional window structures (Fig. 1);

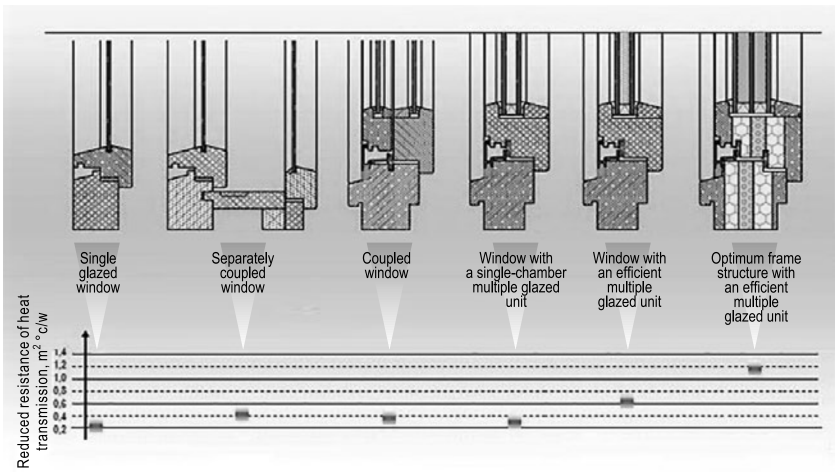

Fig. 2

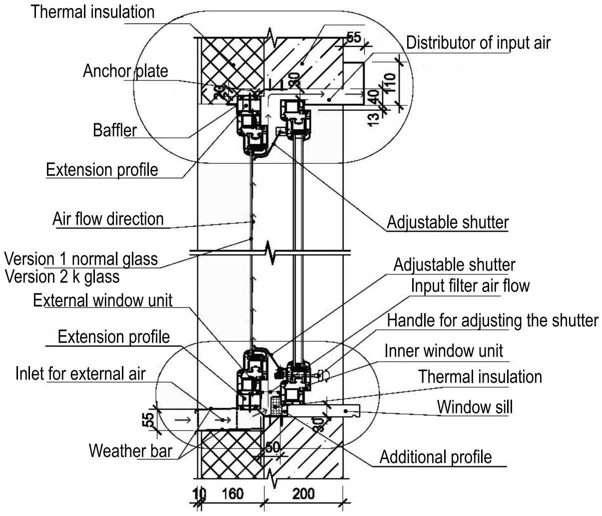

Fig. 3

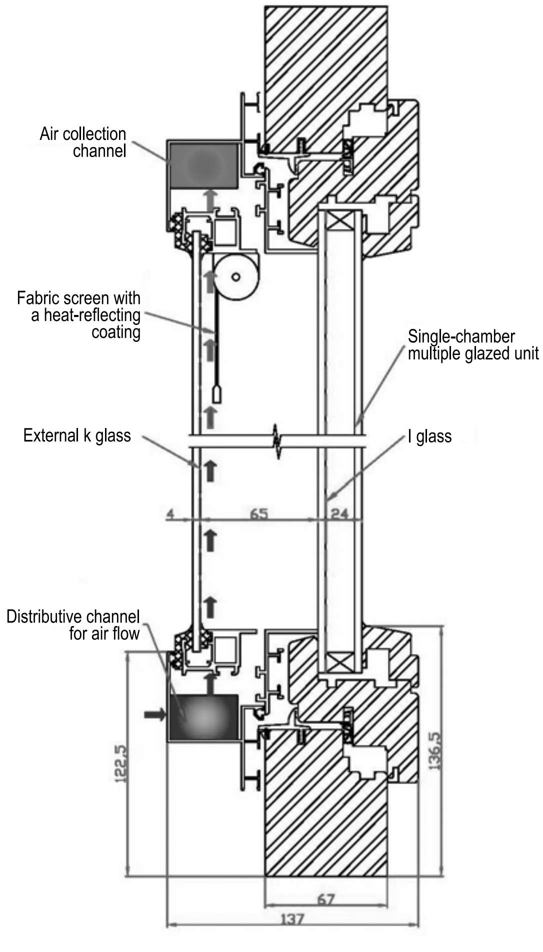

Fig. 4

– Multiple glazed units with electric heating. During the last decade, the use of translucent coatings on roofs, ceilings of atriums, glass canopies, etc. has become widespread. However, in weather conditions typical to Russia, they require frequent snow removal. For these such structures, as well as for the removal of condensate from swimming pool enclosures, multiple glazed units and glass with electric heating have become very popular. As a rule, these are made using glass with a solid heat-reflecting coating. As it is possible to deliver electric current to the heat-reflecting coating, a wide range of temperature adjustment of the glass is possible. The application of such multiple glazed units in the northern climate regions of Russia is effective in increasing the comfort of occupants in residential rooms and offices;

– Filling the space between panes of glass with aerogel. The first attempts to fill the space between panes of glass were made in the late 1970s. The unique heat engineering characteristics of this material, discovered by an American chemist Stephen Kistler in 1931, mak this possible. However, despite the very low heat conduction of aerogels and their high strength, a variety of technological problems appear during their practical use in multiple glazed units. These are caused by filling cavities between the glass panes, and by a high hygroscopicity of the aerogels. Besides, these materials are translucent and expensive, which also prevents their wide application. According to some sources, considerable progress in use of aerogels in the window industry has been made in recent years;

– Composite materials of frame structures. To increase strength, remove steel enforcers in standard PVC profiles, as well as to increase the heat engineering characteristics of windows as a whole, an entire generation of window profiles of various composite materials has been developed, which includes fibre glass, combinations of PVC and glass-reinforced plastic, a mixture of sawdust and PVC grains and many other things. Most of these have been little used up till now. At the same time, due to the increase of heat engineering and ecological requirements for windows in most developed countries, and with the need to recycle PVC and of other types of production waste, many large companies in recent years have paid closer attention to these materials. This provides hope for their increased application in the coming years.

It should be noted that the improvement in the heat engineering characteristics of translucent structures occurs mainly as a result of "passive" actions (increasing number of chambers in the multiple glazed unit, amount of glass with selective coating, the use of more effective inert gases, increase in the thickness of frames, etc.). However, as with mod-

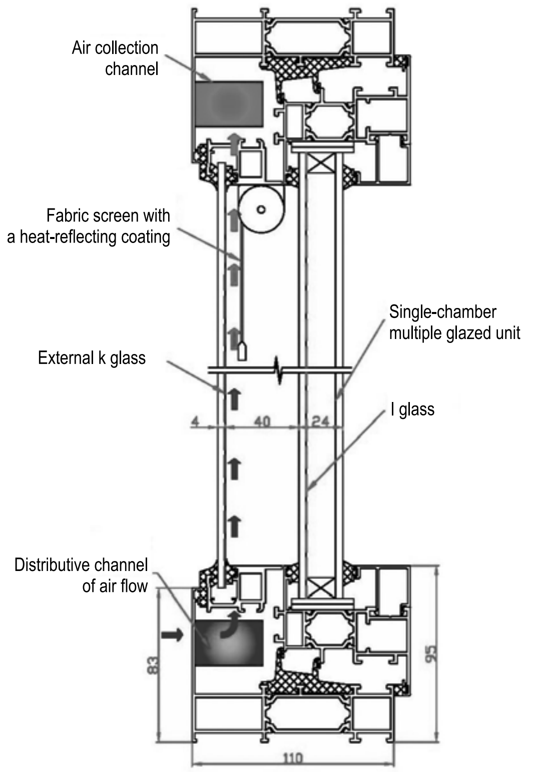

Fig. 5

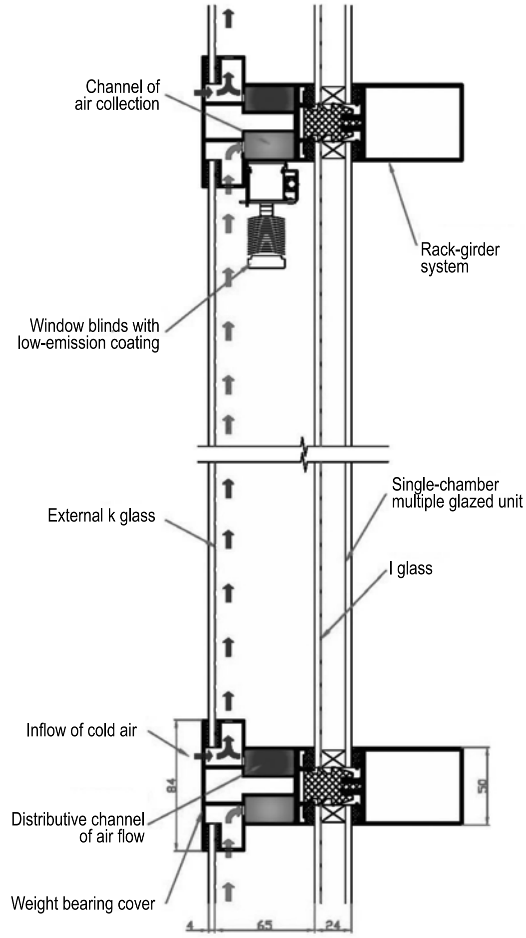

Fig. 6

els for opaque enclosures [12], such an approach to the increase of heat transmission resistance of translucent structures is in most cases inefficient from the economic point of view. Increasing the number of glass layers naturally reduces the light transmission coefficient of the structure.

The transition to the modern tight windows with multiple glazed units in multiple occupancy buildings had positive impacts, such as operational convenience, decrease in heat losses and improvement of acoustic characteristics, but led to a deterioration of the room air mode. Almost all window and facade structures of "the European type" do not provide standard air exchange in the rooms. This leads to unfavourable microclimate conditions and the growth of fungus and mould on the inner slopes and walls. "Salvo airing" of rooms proposed by many window manufacturer companies is uncomfortable and reverses all efforts to increase heat efficiency of translucent structures, completely negating the principles of energy saving policies. To improve the ventilation of rooms, (especially in multi storey buildings with natural ventilation, which practically never works) ventilation valves became popular [13]. However, these also increase the cost of the translucent structures.

Based on the new design principles for enclosing structures, proposed by the authors in [14], it became possible to develop energy saving ventilated translucent structures. It was possible to improve heat engineering characteristics and recover a considerable part of the thermal flow, which had previously been lost to the atmosphere. The ventilation of rooms by external air via windows and facades was improved with very little additional energy losses. A mechanism for the proposed operating principle for modern energy efficient and ventilated translucent enclosing structures (EVTES) is described previously in more detail in [12, 14, 15].

It should also be noted that a combined effect of the heat-reflecting screen in an air interval and ventilation via this interval with an active recovery of heat and moisture into a room using external cold air, **raises the thermal effect multiple times. This has been** proved experimentally during production experiments [15, 16].

The nature of these processes depends on the geometry of the layer, thermal characteristics of the

Fig. 7

materials, on the temperature of inner and external air, consumption of the filtered air, on structure of the input and output valves. For each specific module of energy-effective ventilated translucent enclosing structures (EVTES), these parameters can be optimised and adjusted by locating heat-reflecting screens and consumption of input air through recirculation of the ventilation discharge. All these processes will be described in more detail in the next article of the series, in which the results of the multiple research efforts into this new concept of enclosing structures (EVTES) carried out in the Scientific Research Institute of Building Physics in 2013–2014 will be provided.

Several versions of translucent enclosing structures (Figs. 3–6) were developed based on the new principles proposed by the authors. After passing through a layer of air, the heated external air enters the recovery mechanism.

The authors are grateful to ADITIM Company and Oleg Fomin for the help in preparing Figs. 4–6 for this article.

Fig. 3 shows the structure of EVTES, which requires barely any change to the window profile. PVC profile frames are combined (one frame is made with a single piece of glass, the other is manufactured with a multiple glazed unit). Between these frames, the main principles of twist-and-steer ventilation with active thermal flow recovery are implemented. This is a relatively simple the method for the modernisation of translucent structures, however the initial costs are significant. Nevertheless, this method has a short payback period due to the sharp improvement of the heat engineering characteristics of the windows.

To make popular wood-aluminium window units (Fig. 4) according to the principles proposed by the authors new external aluminium frames are necessary. In the space between the external glass and inner multiple glazed unit, there is a removable heat-reflecting screen (blind) and distributing devices for external air inlets and the collection of the heated air flow, which are necessary for the effective ventilation of the space between panes of glass and for the active recovery of the thermal flow.

Similarly to the modernisation of wood-aluminium windows (Fig. 4), thermal recovery improvements according to the design principles of EVTES principles, proposed by the authors, is also possible in warm aluminium windows (Fig. 5).

In modern aluminium rack-girder facade systems, multiple glazed units of a 75 mm thickness and and more can be installed. This allows for the modernisation of most modern facades according to the concept of energy-effective ventilated translucent enclosing structures developed by the authors. Implementation of the concept of energy-effective ventilated facade structures in this case is possible both with standard multiple glazed units, and with slightly modified aluminium profiles (Fig. 6). Applying these principles is especially interesting in the unitized facades, which are widely used, because it is possible to reduce the cosy for refurbishment as systems of air distribution and collection are used simultaneously across seevral floors.

It is difficult to refurbish residential buildings and public utilities which date from the period of rapid construction from the 1950s to the early 2000s, which have huge heat losses through external enclosing structures. The refurbishment is achieved through additional heat insulation of the facades and replacement of some engineering systems. Monitoring the costs for heating and ventilation between 2011 and 2013 for over 150 buildings in Moscow demonstrates both energy and economic inefficiency.

In recent years, a popular refurbishment method for old inefficient buildings, has involved the construction of an additional facade (Fig. 7). This has been dubbed the “double skin façade”. This method allows not only securing energy savings but also improved convenience of the façade. Certainly, this method is much more expensive than those usually applied in Russia. But the results of the additional

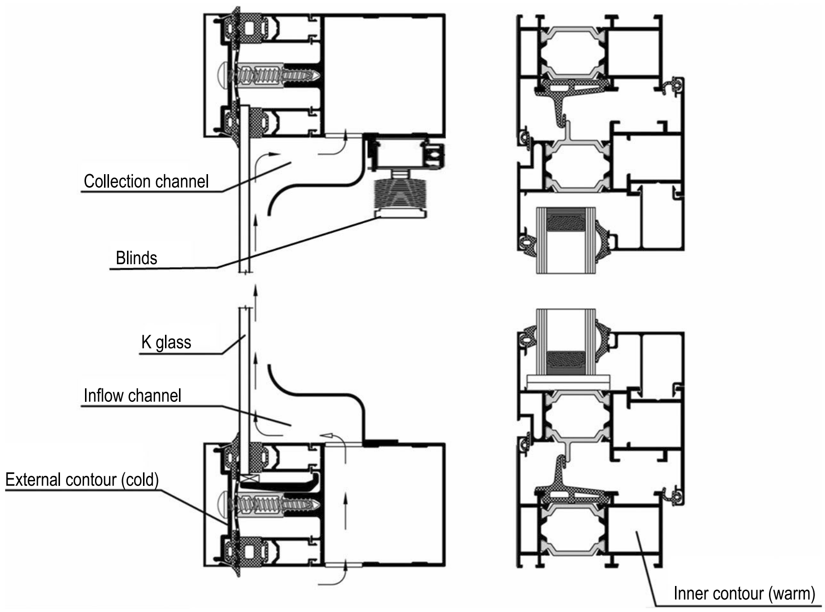

Fig. 8

heat insulation of facades obtained in Russia, are also disappointing.

The energy-efficient ventilated translucent enclosing structures proposed by the authors are ideally suited for double skin façades and for the refurbishment of old buildings (Fig. 8). Applying out methods, it is possible to provide not only additional heat insulation and reduce heat transmission resistance, (for which there are targets set in Russia for 2030) but also to provide a comfortable microclimate in rooms.

Besides, preliminary estimates show that when using EVTES, additional external thermal insulation can be minimised, leading to a reduced payback period for refurbishment costs.

It should be noted that enclosing structures with the active recovery of thermal flow and moisture based on the principles stated in this article, as well as in previous publications [12, 14], can provide not only considerably reduced resistance to heat transmission and less heat loss [15] but also work effectively in both winter (recovery of thermal output flows), and summer (reduced air-conditioning costs).

Besides, when improving the heat engineering characteristics of translucent structures through active energy saving, it becomes possible to increase the surface area of glass facades, improving the amount of natural illumination. It avoids the negative impacts of additional glass cover layers and heat-reflecting screens on natural illumination. It should be also noted that heat-reflecting screens can only be used at night time.

In conclusion, energy-efficient ventilated translucent enclosing structures (EVTES) proposed by the authors, can be implemented across almost all types of window systems and profiles. However, the implementation of our proposals is not so simple, as can be seen in the Figs. provided above (Figs. 3–6, 8). For each structure type, it is necessary to calculate EVTES modules, arrange ventilation systems for air layers, and create a system of replaceable/adjustable heat-reflecting screens. Nevertheless, the outcome in energy savings will make up for these costs.

The authors invite architects, contractors, investors, companies manufacturing window system profiles, translucent structures and hinged facade systems to cooperate in the implementation of these proposals.

The results of experimental research into EVTES performed at the Scientific Research Institute of the Building Physics in 2013 –2014, will be presented in the next article

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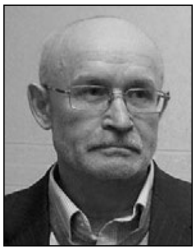

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AN EXPERIMENTAL INVESTIGATION OF MIRROR LIGHTING

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ABSTRACT

The aim of this study is to investigate the preferred vertical illuminance and luminaire placements for mirror lighting experimentally. For this purpose, a mirror is fixed on a wall of the mock-up room and three linear luminaires are placed around the mirror; one on each side and one above the mirror. Twenty-seven lighting scenarios have been designed by using three luminaires around the mirror for local lighting and four indirect suspended luminaires providing general lighting in the room. Lighting scenarios were based on different lighting arrangements and six vertical illuminance steps between 300 lx and 2000 lx. Surveys have been performed to determine the impressions and judgements of the participants in terms of illuminance provided, shadows produced and glare caused in each scenario. Findings obtained by means of the survey have been evaluated and guiding criteria for mirror lighting design are introduced.

Keywords: mirror lighting, vertical illuminance, glare, shadow

1. INTRODUCTION

Mirrors are essential interior architectural elements that people use for daily activities like shaving, putting on make-up, doing hair and checking their appearance. Although most of them serve a purpose, mirrors are also used widely as decorative elements in architecture. Due to their functional properties, mirrors are used extensively in bathrooms, bedrooms, entrance halls of residential buildings; in restrooms of all buildings; in dressing rooms, back stage, beauty salons, etc. It is important, especially for non-decorative mirrors, to produce complete true reflections. To get truthful images, the type, number and place of the luminaires around the mirror and the vertical illuminance provided are crucial.

The implementation of mirror lighting by linear luminaires placed vertically on two sides of the mirror is principally suggested in the literature [1–4]. Luminaires can cause direct glare depending on their position in the field of observer's view and direct light from the luminaires can create shadows on the face. The recommended angle between the line of view and the reflected image of the luminaire in the mirror lies between 30^0 and 60^0 to avoid direct glare [1–2, 4]. According to the European Standard (prEN 12464–1:2011) on interior lighting, UGR_L (*Unified Glare Rating*) should be ≤ 25 in spaces like cloakrooms, washrooms, and bathrooms [5]. The mentioned standard recommends 200 lx on the horizontal utilised plane in these types of spaces, but does not include any suggestions concerning the vertical illuminance on the facial plane. Öztürk and Sirel propose 500 lx on the vertical facial plane [1–2]. The Lighting Handbook published by IESNA recommends (100–200) lx, (200–400) lx, and (400–800) lx regarding the mean vertical illuminance on the facial plane for the age groups <25, 25–65, and >65, respectively [3].

Despite mirrors being indispensable, mirror lighting is often not given the consideration it deserves. Numerous inappropriate lighting applications can be seen in practice, popular literature, and product catalogues of luminaire and furniture com-

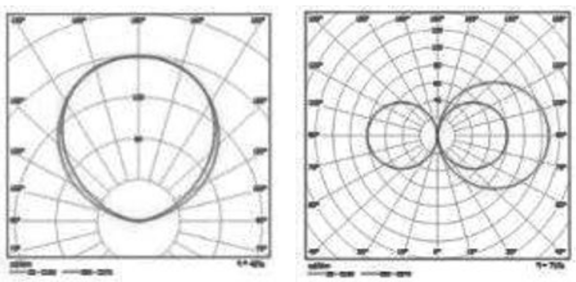
Fig. 1. Mock-up room

panies. The objective of this work is to investigate experimentally the most preferred luminaire position and the vertical illuminance for mirror lighting. For this purpose, different lighting scenarios have been applied in a mock-up room and surveys have been carried out to find out the preferences of the test subjects [6].

2. MOCK-UP ROOM AND LUMINAIRE POSITIONS

In the first stage of the study, different mirror lighting examples have been compiled by means of a literature review, internet searches, and on site investigation. A considerable number of examples, which differed by lamp types, luminaire types, and luminaire positions, have been collected and divided into eighteen groups. An example representing each group, eighteen examples in total, have been modelled in DIALux lighting software and the three most positive options regarding vertical illuminance on facial plane and/or glare are determined. These options refer to the use of linear light sources placed around the mirror.

Mirror lighting should be accompanied by general lighting. General lighting has to be diffuse in order to provide vertical illuminance required for both good visual communication in the whole room and also for activities like dressing, cleaning or bathing not specifically performed in front of the mirror. However, use of direct general lighting, especially by small recessed down light luminaires, is very common in almost every type of room where mirror lighting is used. This application is regarded as an economical option and also preferred because of its easy application. In this study, diffused general lighting is chosen to draw attention to the appropriate general lighting conditions particularly important in dressing rooms, back stage, and beauty salons, where avoidance of harsh shadows, sufficient vertical illuminance and consequently the sense of well-being is especially appreciated.



General lighting *Local lighting*

Fig. 2. Luminous intensity distributions of the used luminaires

An assessment of the lighting scenarios has been conducted in a mock-up room (5.55 m×5.35 m×2.55 m) that was previously furnished as an office for two users within the frame of another research study [7]. A mirror (1.50 m×1.30 m) was fixed on a wall of the room. Linear luminaires equipped with fluorescent lamps have been mounted on three sides of the mirror for local lighting. Sixteen luminaires were already present in the mock-up room; four of them have been used for general lighting. The four chosen luminaires could be adjusted for direct, semi-direct, direct-indirect, semi-indirect or indirect lighting. Indirect lighting is preferred for the reasons explained above.

The cabinets (h: 0.90 m) below the mirror have been assumed to be the vanity or dressing table surface plane (Fig. 1). Properties of the luminaires used for local and general lighting are as follows (Fig. 2):

- Local lighting: 3 surface mounted direct luminaires with diffuser, LOR (light output ratio): 0.70, 1×39 W fluorescent lamp in each luminaire (Fig. 1: M1, M2, M3).

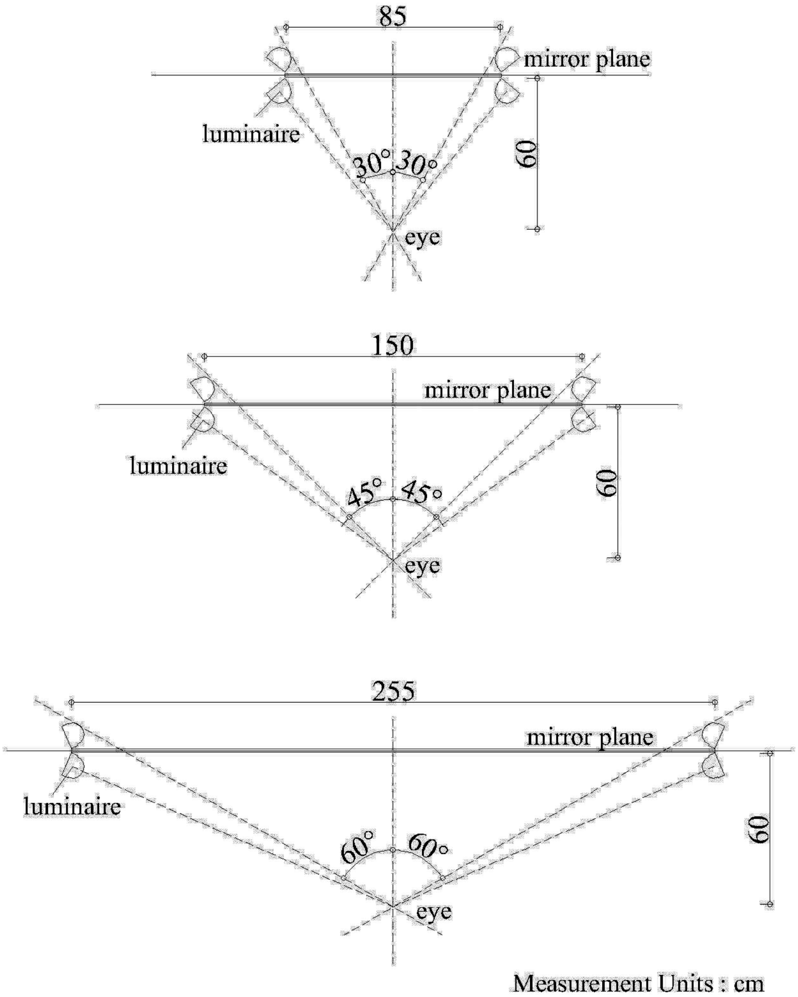


Fig. 3. Analysis of the position of luminaires for local lighting

• General lighting: 4 suspended indirect luminaires with diffuser, LOR: 0.61, 3 ×54 W fluorescent lamp in each luminaire (Fig. 1: ID-1, ID-2, ID-3, ID-4).

To decide on the angle between the line of view and the reflected image of the luminaire in the mirror, hence the luminaire position, initially the recommended 30^0–60^0 degrees were used (Fig. 3). The vertical and semi-cylindrical illuminance on facial plane as well as UGR_L values have been calculated by means of DIALux software considering three separate conditions of 30°, 45°, and 60° degrees in terms of the luminaire position. The results proved that the necessary distance between two vertical luminaires requires large spaces and the desired illuminance steps for the experiment cannot be achieved for the condition of 60°; additionally, UGR_L values are far above the acceptable limit for the condition of 30°. Consequently, it has been decided that the position of each luminaire around the mirror should ensure an angle of 45^0 between the line of sight and the reflected image of the luminaire in the mirror. Generated illuminance have been found to be insufficient when the luminaires were mounted parallel to the wall. In order to obtain higher illuminance, both horizontally and vertically placed luminaires have been rotated towards the observer (Figs. 3–4).

The position of an observer in front of a mirror over a vanity or dressing table depends on the dimensions of the furniture. The depth of vanity tables varries between 55 cm and 60 cm according to Neufert [8] and the depth of dressing tables are approximately 40–45 cm taking into account the dimensions provided by various furniture manufacturers. Although a standing observer can be very close to the table, the position of a sitting observer is naturally a bit further away from the table. Both, the distance of a standing observer's eye to the mirror over a vanity table and the distance of a sitting observer's eye to the mirror over a dressing table can be accepted as approximately 60 cm. So, the observer position was assumed to be 60 cm away from the

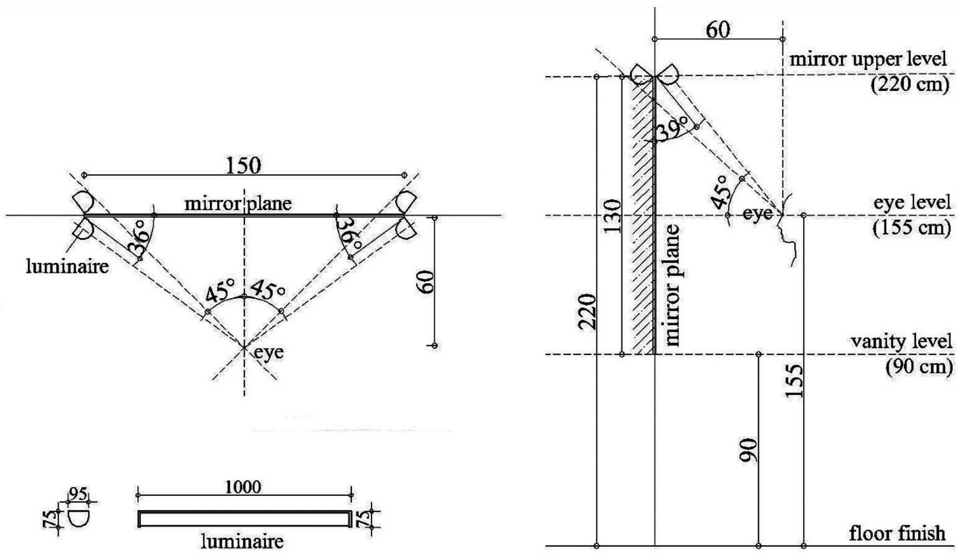


Fig. 4. Decided position of luminaires for local lighting

mirror. Eye level of the observer from the floor was approved as 1.55 m [4].

3. LIGHTING SCENARIOS

27 lighting scenarios were designed by using three luminaires around the mirror for local lighting and four suspended indirect luminaires providing general lighting in the room. Lighting scenarios were based on six different lighting arrangements (LA) specified as follows (Figs. 5–6):

- LA-1: Local lighting by one luminaire above the mirror (Fig. 5 a).
- LA-2: Local lighting by two luminaires on the sides of the mirror (Fig. 5 b).
- LA-3: Local lighting by three luminaires around the mirror (Fig. 5 c).
- LA-4: Local lighting by one luminaire above the mirror and general lighting (Fig. 5 d).
- LA-5: Local lighting by two luminaires on the sides of the mirror and general lighting (Fig. 5 e).
- LA-6: Local lighting by three luminaires around the mirror and general lighting (Fig. 5 f).

For each lighting arrangement the aim was to obtain a range of illuminance between 300 lx and 2000 lx on the 37 cm x 37 cm vertical plane, which was equidistant from two sides of the mirror and 60 cm away from the mirror. The dimensions of this vertical plane were based on top of head height for an average male and neck height for an average female [9–11]. The centre of the mentioned plane was 156.5 cm above the floor taking into account the average male and female heights.

At the first stage, the mock-up room was modelled in the DIALux lighting software to find out whether the intended range of illuminances could be produced and establish the dimming ratios regarding each illuminance step. It has been found that all intended illuminance steps could not be obtained for all lighting arrangements. The vertical illuminances obtained in 27 lighting scenarios are shown in Table 1 and Fig. 6. The illuminances on the mentioned vertical plane, provided separately by each luminaire used for mirror lighting and general lighting, have been recorded for each lighting scenario. At the second stage, the 27 defined lighting scenarios are implemented in the mock-up room. The records regarding the illuminances on the vertical plane were used to dim each luminaire in the mock-up room accordingly. The illuminances on the considered vertical plane were measured by the illuminance meter LMT Pocket-Lux.

Contribution of indirect general lighting to aimed mean vertical illuminance steps is adjusted to be 20% for each lighting scenario. This ratio was appropriate to ensure the recommended horizontal illuminance on the cabinets in the mock-up room, which were assumed to be vanity or dressing planes, while providing the recommended vertical illuminance on the facial plane [3]. It is deemed essential to keep direct to reflected light ratio equal for each lighting arrangement and illuminance step.

4. SURVEY ON MIRROR LIGHTING

A survey has been performed in the mock-up room to evaluate the 27 lighting scenarios creat-

5a. Lighting Arrangement 1

5b. Lighting Arrangement 2

5c. Lighting Arrangement 3

5d. Lighting Arrangement 4

5e. Lighting Arrangement 5

5f. Lighting Arrangement 6

Fig. 5. Lighting arrangements

ed. Lighting scenarios were shown to the subjects according to the order in Table 1, by regularly increasing illuminance. 51 people, consisting of 33 women and 18 men participated in the survey (Table 2). The average height of all subjects, women and men was 166.5 cm, or 162 cm, and 174 cm, respectively.

The impression of the subjects about their reflections in the mirror is analysed for each scenario. Sufficient illuminance without glare or shadows has been considered as appropriate mirror lighting. Therefore, the judgments and preferences of the subjects on illuminance, shadow, and glare were asked for separately to assess each scenario precisely according to the given three indicators (Table 3).

5. SUBJECTIVE EVALUATION OF LIGHTING SCENARIOS

Impressions of the subjects about illuminance on the facial plane, shadows produced, and direct glare can be summarised as follows:

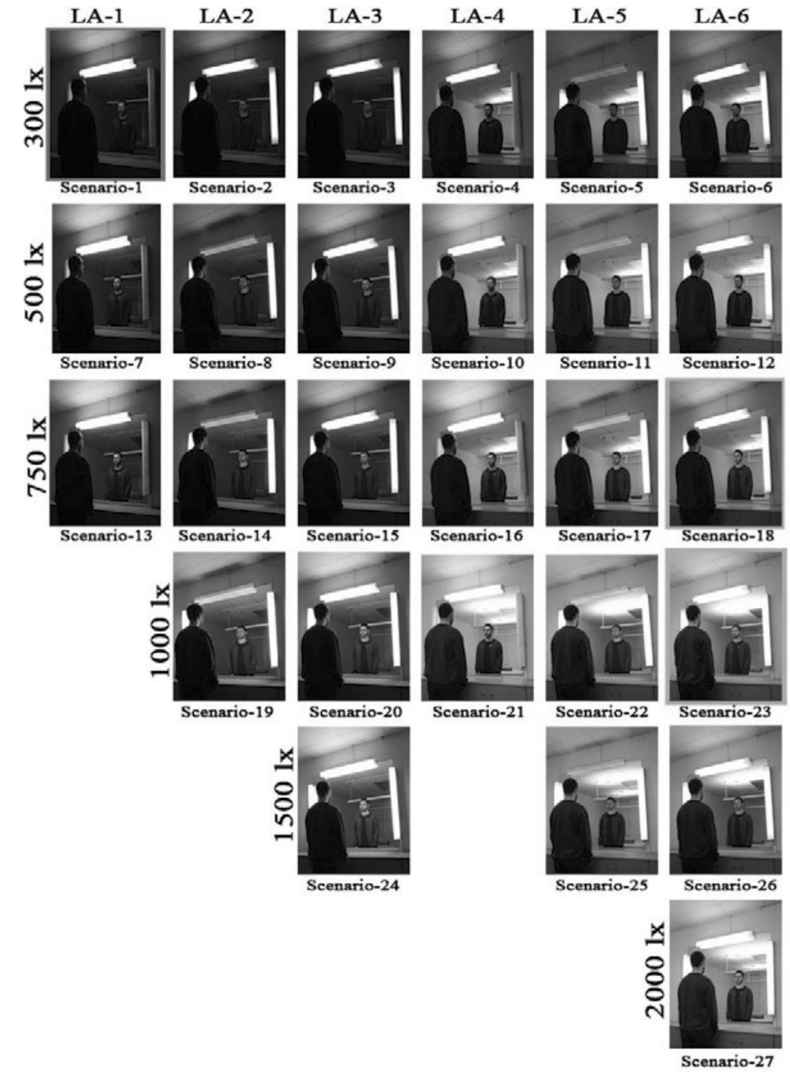


Fig. 6. Range order of the scenarios at the questionnaire

5.1. Illuminance

Regarding the responses of all subjects, lighting scenarios with 'the indirect general lighting additional to the local mirror lighting' were favoured more than the scenarios with 'only the local mirror lighting'. In other words, the lighting arrangements LA-6, LA-5, and LA-4 were preferred to the lighting arrangements LA-3, LA-2, and LA-1, respectively. The preference ranking of the subjects in terms of lighting arrangement was LA-6, LA-3, LA-5, LA-4, LA-2, and LA-1. Preferred vertical illuminance steps of the age groups 18–25 and 26–60 were (500–750 lx and (750–1000) lx, respectively. Preferred mean vertical illuminances obtained in this study are obviously higher than the preferences given in the literature. That is, ranges of preferred vertical illuminance in literature for the age groups <25, 25–65 and >65 are respectively (100–200) lx, (200–400) lx and (400–800) lx [3]. There is no significant difference according to gender in terms of illuminance as well as lighting arrangement preference.

5.2. Direct Glare

The negative sensation caused by direct glare increases as the illuminance increases without exception in each lighting arrangement. The preference ranking of the lighting arrangements with regard to direct glare was LA-4, LA-6, LA-5, LA-1, LA-3, and LA-2. Subjects were disturbed by direct glare most when vertical luminaires on two sides of the mirror were turned on. The impression of direct glare decreased when luminaires on three sides of the mirror were turned on. Mirror lighting by only the luminaire located horizontally above the mirror was

Table 1. Lighting scenarios and luminaires turned on for each scenario

Scenario		Turned on luminaires M1	M2	M3	ID	E_v (lx)
1	LA-1	+	-	-	-	300
2	LA-2	-	+	+	-	300
3	LA-3	+	+	+	-	300
4	LA-4	+	-	-	+	300
5	LA-5	-	+	+	+	300
6	LA-6	+	+	+	+	300
7	LA-1	+	-	-	-	500
8	LA-2	-	+	+	-	500
9	LA-3	+	+	+	-	500
10	LA-4	+	-	-	+	500
11	LA-5	-	+	+	+	500
12	LA-6	+	+	+	+	500
13	LA-1	+	-	-	-	750
14	LA-2	-	+	+	-	750
15	LA-3	+	+	+	-	750
16	LA-4	+	-	-	+	750
17	LA-5	-	+	+	+	750
18	LA-6	+	+	+	+	750
19	LA-2	-	+	+	-	1000
20	LA-3	+	+	+	-	1000
21	LA-4	+	-	-	+	1000
22	LA-5	-	+	+	+	1000
23	LA-6	+	+	+	+	1000
24	LA-3	+	+	+	-	1500
25	LA-5	-	+	+	+	1500
26	LA-6	+	+	+	+	1500
27	LA-6	+	+	+	+	2000

LA: Lighting arrangement
E_V: Mean vertical illuminance
M1: Luminaire over the mirror
M2, M3: Luminaires on two sides of the mirror
ID: Indirect luminaires

the most preferred condition. Direct glare decreased when local mirror lighting was accompanied by the indirect general lighting. No significant difference is noticed with regard to gender and age in respect of direct glare. The UGR_L value for the most preferred lighting arrangement (LA-6) and the vertical illuminances (750–1000) lx was ≤ 26 according to the responses of all subjects.

5.3. Shadow

The preference ranking of the lighting arrangements with respect to shadows was LA-5, LA-2, LA-6, LA-3, LA-4, and LA-1 when considering the responses of the subjects where they did not notice any shadows or did not feel disturbed by the produced shadows. Discomfort caused by shadows rose in lighting scenarios when only the luminaire above the mirror was turned on. Activation of three luminaires around the mirror was appraised positively in comparison to the use of a single luminaire. Participants did not indicate negative opinions when vertical luminaires on two sides of the mirror were turned on. Discomfort from shadow decreased slightly when local lighting was accompanied by general lighting. Differences in illuminance generally did not affect the rating of shadow conditions in all lighting arrangements. No remarkable difference is observed concerning gender and age.

5.4. Evaluation of the Results

As stated above, the preferred rank order of six evaluated lighting arrangements differs according to illuminance, glare, and shadows. In order to integrate the obtained results to derive guiding recommendations, the most distinctive response option has been chosen for each question given in Table 3 and the percentages of the responses received for these questions are given in Table 4. The fifth column of Table 4 shows the sum of the positive responses received for three different questions.

The three mentioned response options are:

- For the question ‘Is the illuminance sufficient for you to see details of your image in the mirror?’: ‘*Illuminance is sufficient*’.
- For the question ‘Do shadows occur on your image?’: ‘*No*’ and for the question ‘If shadows occur how does it affect you?’: ‘*Shadows do not disturb me*’.
- For the question ‘Do luminaires cause direct glare?’: ‘*No*’.

Table 2. Age, sex and education of subjects

<table>
<tr><th rowspan="2">Age</th><th colspan="2">Primary School</th><th colspan="2">High School</th><th colspan="2">Under Graduate</th><th colspan="2">Graduate</th><th colspan="2">Master's Degree</th><th colspan="2">Doctorate</th><th rowspan="2">Total</th></tr>
<tr><th>W*</th><th>M**</th><th>W</th><th>M</th><th>W</th><th>M</th><th>W</th><th>M</th><th>W</th><th>M</th><th>W</th><th>M</th></tr>
<tr><td>18–25</td><td></td><td></td><td></td><td>1</td><td></td><td></td><td>6</td><td>2</td><td>1</td><td>0</td><td>0</td><td></td><td>10</td></tr>
<tr><td>26–30</td><td></td><td></td><td></td><td></td><td></td><td>1</td><td>5</td><td>3</td><td>4</td><td>2</td><td>1</td><td></td><td>16</td></tr>
<tr><td>31–40</td><td></td><td></td><td></td><td></td><td></td><td></td><td>2</td><td></td><td>4</td><td></td><td></td><td></td><td>11</td></tr>
<tr><td>41–50</td><td></td><td>1</td><td></td><td></td><td></td><td></td><td></td><td>3</td><td>1</td><td></td><td>4</td><td>2</td><td>5</td></tr>
<tr><td>51–60</td><td></td><td></td><td></td><td></td><td></td><td>1</td><td>1</td><td></td><td></td><td>2</td><td>5</td><td></td><td>9</td></tr>
<tr><td>Total</td><td>0</td><td>1</td><td>0</td><td>1</td><td>0</td><td>2</td><td>14</td><td>8</td><td>10</td><td>4</td><td>9</td><td>2</td><td>51</td></tr>
</table>

*W: Woman, **M: Man

Table 3. Questionnaire

<table>
<tr><th>ILLUMINANCE</th><th colspan="2">SHADOW</th><th colspan="2">GLARE</th></tr>
<tr><td>Is the illuminance sufficient for you to see details of your image in the mirror?</td><td colspan="2">Do shadows occur on your image? If your reply is yes, where do shades occur?</td><td colspan="2">Do luminaires cause direct glare?</td></tr>
<tr><td rowspan="3">• Illuminance is much lower than I need
• Illuminance is lower than I need
• Illuminance is sufficient
• Illuminance is higher than I need
• Illuminance is much higher than I need</td><td>Yes
• Under the eyes • Under the nose
• Under the chin and neck</td><td>No</td><td rowspan="3">Yes
• Low glare
• Medium glare
• High glare</td><td rowspan="3">No</td></tr>
<tr><td colspan="2">If shadows occur how does it affect you?</td></tr>
<tr><td colspan="2">• I cannot see details on my image clearly because of the shadows.
• Shadows do not disturb me.</td></tr>
</table>

Participants most preferred the lighting arrangement, in which three luminaires were placed around the mirror and the mirror lighting was accompanied by the indirect general lighting (LA-6) according to the summarised results given in Table 4. The preference ranking of lighting arrangements was LA-6, LA-3, LA-5, LA-2, LA-4, and LA-1. There were differences between age groups regarding the preferred vertical illuminance on the facial plane. The age group 18–25 favoured 750 lx the most, followed by 500 lx. Older participants preferred 1000 lx in the first place, which was followed by 750 lx. 300 lx and 2000 lx illuminances were not preferred much by the subjects.

6. CONCLUSION

Mirrors are significant interior design elements people use often in daily life and special consideration should be given to the mirror lighting. The reason for this is the necessity to place luminaires on or near the mirror plane, which may cause direct glare or produce shadows. Sufficient vertical illuminance without glare and shadows should be provided for mirror lighting to be approved as successful. Nevertheless, guiding information regarding required illuminance on the facial plane and the appropriate luminaire positions is limited in the literature.

The aim of this research was to investigate the preferred vertical illuminance and the appropriate luminaire locations for mirror lighting. For this purpose, six different lighting arrangements and 27 lighting scenarios were designed by using three linear luminaires around the mirror for local lighting and four suspended indirect luminaires providing general lighting in a mock-up room. Lighting scenarios were based on six different lighting arrangements and a range of vertical illuminance between 300 and 2000 lx. Surveys were performed to determine the judgments and preferences of the subjects about which lighting scenarios cause glare or create shadows on the face and whether they provide sufficient illuminance. The results of the survey revealed the most preferred scenarios with respect to illuminance, glare and shadow separately.

Table 4. Integration of the survey responses

LA	Positive responses in percentage (%)			
	Illuminance	Glare	Shadow	Total
LA-1	12	28	9	49
LA-2	22	25	34	81
LA-3	35	28	33	96
LA-4	23	35	16	74
LA-5	24	29	35	88
LA-6	35	31	34	100

The interpretation of all responses indicated that the most favoured lighting arrangement was the one, in which three luminaires were placed around the mirror and the mirror lighting was supplemented by the indirect general lighting. In terms of the vertical illuminance on the facial plane, younger subjects most preferred 750 lx, while subjects older than 25 preferred 1000 lx. Therefore, mirror lighting should be dimmable to meet the needs of users of different ages and to prevent unnecessary energy consumption. It was predicted that women would be much more affected from the presence of shadows and they would need higher illuminance than men taking into account their diverse activities and the time they spend in front of the mirror. However, no notable differences were noticed between the preferences of the two genders.

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