LIGHT & ENGINEERING

With great sadness we inform our readers that Professor Janos Schanda,
big friend of our issue, passed away

Prof. Janos Schanda †
(16.05.1932–08.03.2015)
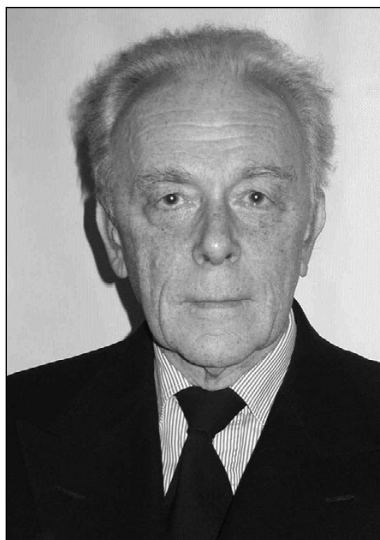
Dr. János Schanda was Professor Emeritus at the University of Pannonia, Hungary. He graduated in physics at the Loránd Eötvös University in Budapest. The Hungarian Academy of Sciences granted him the degree of "Doctor of Technical Sciences" for his thesis work on colour rendering.

After graduation he worked for three years at the Hungarian Office for Measures, then joined the Research Institute for Technical Physics of the Hungarian Academy of Sciences. He retired from the Institute as Head of the Department of Optics and Electronics and joined the University of Veszprém (now University of Pannonia) as professor of informatics. He headed there the Department of Image Processing and Neurocomputing. Since retirement, he was Professor Emeritus and heads up to death the "Virtual Environment and Imaging Technologies Laboratory".

During the nineteen eighties and nineteen nineties he worked also for the International Commission on Illumination (CIE). He was past Technical Vice President of the CIE, and on the editorial / international advisory board of Color Res. & Appl., USA, Light & Engineering, Russia, Lighting Research & Technology, UK, and Journal of Light & Visual Environment, Japan. Since 2010 he was a member of the Advisory Board of the Colour & Imaging Institute, Art & Science Research Centre, Tsinghua University, China, since 2011 – of the Centre for Colour Culture and Informatics (C3 I) of Taiwan.

Dr. Schanda was a member of the Optical Society of America, of The Society for Imaging Science and Technology and of several Hungarian Societies in the fields of light and lighting, and optical measurements. He also served as Vice-President on the Board of the International Colour Association (AIC). In 2010 the British Colour Group awarded him with the Newton Medal, in 2011 CIE presented him the "De Boer Pin". He is author of over 600 technical papers and conference lectures.

LIGHT & ENGINEERING
(Svetotekhnika)

СВЕТО ТЕХНИКА

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CONTENTS

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CLASSIFICATION OF DAYLIGHT CONDITIONS IN CLOUD COVER SITUATIONS

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ABSTRACT

Daylight is widely used for the illumination of workspaces and residential interiors the whole year round. Measurements of exterior illuminance at CIE IDMP stations show high variability of daylighting from sunrise to sunset. The changes of sun height, cloud type and cloud cover as well as the turbidity of the atmosphere influence levels of day light availability and daily illuminance sequences. To design and simulate daylighting in buildings the typical exterior conditions are needed. The cloud type, cloud cover and sunshine duration can determine various types of clear, cloudy and overcast days. The study of global and diffuse illuminance sequences based on measurements shows that six types of daily illuminance courses can be classified for daylighting and illuminating engineering calculations. This paper discusses the influence of cloudiness on daily illuminance sequences.

Keywords: daylighting, cloudy situations, daily illuminance sequences

1. INTRODUCTION

The human body and especially its visual organs have adapted to dynamic natural conditions over thousands of years of development. However, people nowadays spend more than 80% of their time inside buildings working, relaxing or doing various activities. More than 90% of information used by humans is obtained by the eyes. Therefore, it is imperative for lighting engineers to design and create indoor environments that are suitable for the comfortable performance of visual tasks and for satisfying healthy and safe occupation needs. Interiors can be illuminated by daylight and/or artificial light. While artificial light ensures stable luminous conditions during the whole operating time, daylight is permanently changing from sunrise to sunset every day across the year, which is its advantage.

In several countries like Slovakia, the Czech Republic, Russia, U.K and Germany, standards for daylighting design and evaluation of daylighting in buildings have been adopted and applied. Currently, the criteria for design rules are based on the CIE recommendations [1] presenting the worst luminous exterior conditions by sky luminance distribution of overcast sky after [2]. Kittler in [3] introduced a model of general sky describing a set of homogeneous sky luminance patterns adopted by ISO as the standard ISO 15469:2004, [4]. Several authors [5 - 12] realised that a lot of cloudy and sunny skies with various types of cloud cover and atmospheric turbidity can occur in all climatic zones on the Earth, and they affect irradiance and illuminance availability.

The classification of cloud types for meteorological purposes has long been established and elaborated upon, e.g. in [13 - 15]. Since computer techniques were not available the influence of various cloud types on the levels of daylighting were studied based on a sporadic measurement base [16 - 19]. Detailed information about occurrence of daylight during various cloudy daily conditions were obtained recently from regular measurements at the CIE IDMP stations [20].

Results of illuminance measurements in IDMP Bratislava show that no two same daily courses of global and diffuse illuminance have been identified. With regard to daylight and the design of artificial lighting systems, no specific/original daily illuminance sequences are often repeated during the life span of a building and thus representative. This can be explained by the permanent changes in solar altitudes, varying aerosol and particulate matter content in the atmosphere, as well as movements of various types of clouds with varying thickness and cover. However, the classification of daily sequences can serve as a basis for technical studies and applications, e.g. for the daylight design and design of lighting control systems. Darula and Kittler in [21 and 22] proposed four types of daily illuminance courses for determination of reference daylight sequences in a location. Later studies noted that clouds in the sky can significantly change daily illuminance courses [23] and the availability of daylight in orientation to cardinal points [7 and 24].

2. DEFINITION OF HOMOGENEITY AND NON-HOMOGENEITY OF SKIES WITH REGARD TO THEIR LUMINANCE PATTERNS

Homogeneity is generally defined as the uniformity of structure characterising the mass or media properties of the same kind or origin. In the case of the atmosphere and sky luminance patterns, there seems to be only one occasion when a true homogeneous atmospheric environment exists resulting in an absolute uniformity in sky luminance over the space of the sky vault. This is caused by dense layers of stratus clouds or turbid fog and the multiple diffusion, scattering and inter-reflection of sunrays. Such a uniform luminance over the whole sky hemisphere coincides with the Lambert′s assumption used in theoretical photometry since the 18th century, sometimes termed as Lambert′s sky [25]. In nature such circumstances happen when a dense fog close to ground level and sometimes combined a with stratus cloud layer above it form an overall translucent and quite diffused environment. More often overcast skies covered by stratus cloud layers create quasi-homogeneous conditions due to the different optical thickness of the cloud layer with respect to the horizontal ground plane, the

gradual increase of its transmittance is resulting in the luminance decrease from the sky zenith to its horizon. However, besides this vertical gradation the horizontally extended homogeneity and uniformity in luminance on sky almucantar circles is quite constant with almost no variations in different azimuth directions. Such an overcast sky type was adopted as a CIE standard [1].

On the other extreme, completely cloudless skies with only slight turbidity content spread smoothly all over the atmospheric space has the character of symmetry to the sun meridian. However, the presence of direct sunlight scattered and reflected within the atmosphere influences the distribution of luminance on different elements of the sky vault combined with the effects of the simultaneous gradation influence of the relative optical air mass. Therefore, in spite of the rather homogeneous atmospheric content, the cloudless sky luminance patterns seem also to be quasi-homogeneous, with only the luminance pattern symmetry with respect to the position of the sun.

All partly cloudy or more or less cloudy skies, due to differences in cloud cover and cloud type, in their combinations form a large family of non-homogeneous skies with many irregular sky luminance patterns due to:

• Different placement of clouds in various patches on the sky vault;

• Different cloud type in the overlapping combinations of their layers;

• Occasional or constant shading of the sun position by different clouds;

• Different turbidity resulting from water vapour, smoke, dust or other pollution.

All these circumstances form non-homogeneous skies, often unstable in time, driven by airflow and winds of various velocities and directions. Thus a trial has to be made to identify the most prevailing situations or locally exceptional cases, which can have for different reasons some importance for practical purposes e.g. in window size and shade design, in building façade design or maintenance of buildings.

Another possible approach to solve this quite complicated problem of the non-homogenous sky patterns is to assume the existence of simpler cases, e.g.:

• For simplicity, presume a regular placement of cloud patches over the sky vault which could identify roughly stable conditions, check-

ing the more or less equal illuminance on measured horizontal or vertical planes with different orientations;

• Or model the unstable inflow of the cloud masses from a certain direction, as for instance is frequent for the air current from NW in Europe, which brings the cloud, humidity and rain from the Atlantic. Such directional changes in time steps could be checked by very remarkable differences measured on differently orientated vertical planes in time sequences on days when weather changes take place;

• Study the collected fish-eye photo images of cloudy skies to find the most prevailing luminance patterns and cloud formations in a specific location.

3. THE INFLUENCE OF CLOUDINESS AND ATMOSPHERIC TURBIDITY ON SKY LUMINANCE PATTERNS

Two of the main factors determining luminance distribution on the sky vault are turbidity of atmosphere and cloud cover conditions influenced in a locality under particular weather situations. Although overall air temperature is affecting the whole building envelope or solar collectors on it, all surfaces are exposed by the directional sunlight and skylight due to their orientation and slope. Thus, for instance vertical facades oriented to cardinal points are exposed to luminances from the sun and sky within their solid angles in their "view", which can change in time during any day.

Within the high pressure region the prevailing content of mostly unpolluted air molecules are usually influenced by turbidity resulting from the overall temperature of water vapour particles. The lower the overall temperature the less its water vapour absorption and content. Therefore, during the winter months, especially in the countryside and on mountains are the smallest turbidities during cloudless clear days with luminous turbidity factor $T_V = 1,5$ to 3. In summertime and especially during noon in subtropical and equatorial zones the turbidity is quite high, e.g. $T_V = 3$ to 5. These quasi-homogeneous skies are modelled by ISO/CIE standard sky types 11 to 15, while type 12 represents the extremely clear cloudless type with the lowest turbidity, i.e. $T_V \approx 2.5$.

On the depression margins of a moving air mass the following cloud formations are typically formed:

• Plumes of whitish tread-like clouds popularly known as mare´s tails termed as scattered cirrus patches (Ci 1/10 – 3/10 cloudiness);

• In changeable windy drifts cirrus clouds are sometimes seen in quite irregular parallel bands;

• Wind flows are carrying smaller cloudlets like fleecy cotton wool patches irregularly distributed on the sky vault in different cover extent.

Further, approaching the low pressure region the water vapour is cooled and carried upwards, even more chilled and condensed. Tiny ice particles in high altitudes (e.g. circa 6 km above ground) develop white stratus layers or thicker cumulus formations. Even in summertime such cumulus clouds in quite fair weather might be snowy white sometimes fringed with cirrus-like wisps.

Many possible cloudiness types and cloud covers are found in non-homogeneous sky types. After a previous research project assessing the year-round cloudiness occurrence frequencies in Bratislava, [26] a shorter summary of results was published by Kittler and Pulpitlova in [27]. In the original study the measured cloudiness data gathered at Bratislava airport were chosen after daily reports from four years (1970 - 1974) specifying cloud cover in the range 0/10 – 10/10 compared with sunshine duration in three hour steps (at 7, 10, 13, 16 and 19 o´clock). These were compared with thirty-year monthly averages (1930 – 1960) and representative months were chosen from the 1970 – 1974 data as relevant and typical in the long term. Such months formed a typical cloudiness year summarising 1825 measured cloud type and cover situations within one reference year. The results of this older study are summarised in Figs. IV.2 and IV.3 in [27] respectively. Some lessons about occurrence frequency can help to characterise the non-homogeneous sky luminance patterns too, as e.g.:

• Under clear skies especially in the summertime, cloudless skies are prevalent, with arbitrary turbidity, secondly Ci 1/10 and thirdly Cu 1/10 sparsely distributed clouds;

• In Central Europe, cirrostratus (Cs) and cirrocumulus (Cc) as well as cumulonimbus (Cb) cloud types occur rarely with direct sunlight;

• Cumulus (Cu) and altocumulus (Ac) clouds are quite frequent in almost all cover possibilities,

while the more spacious is the cover, the rarer are these linked with direct sunlight, which is true also for the stratocumulus type (Sc);

• Very numerous is the group of overcast skies without sunshine and very frequent in wintertime when almost equally occur altocumulus Ac 9/10 and stratus St 10/10 seconded by altostratus As 10/10;

• When cloud masses are saturated and their temperature falls the surplus vapour has to condense in liquid form as rain associated with some cumulus and dark nimbostratus (Ns) clouds lower to ground;

• Strato-cumulus without sunshine (Sc 2/10 – 10/10) and sometimes with fog often form a special category of perfectly diffuse homogeneous cases with Lambert uniform luminance patterns.

In the case of a stable overcast day, the vertical illuminance on all four cardinally oriented planes is almost the same and roughly half of the diffuse horizontal level, not accounting for small gains from the ground's reflection. A classic documented example was a typical 11th day November 1995 [7].

Unfortunately, the CIE IDMP general observatory on the roof of ICA SAS does not record simultaneously cloud cover and cloud types. However, the project partner, the Natural Science Faculty of the Comenius University (NSF KU) at Bratislava is roughly two kilometres away and has data on cloudiness in the same period of ICA SAS illuminance measurements [28]. In this way the ICA illuminance data set can serve reliably for comparison with the NSF cloudiness information. As ICA records instantaneous minute-by-minute measurements over a long period from 1994, any cloud type and cover data in an exact date or time can be found from the data set to be compared with the calculated result of the theoretical model. For simplicity, the choice can be concentrated on four specific cloud types that are occurring roughly in 1351 out of the total 1825 cases in a reference year, i.e. in 74% probability as follows:

• Ac cloud type was present in 43.5 %;
• Ci cloud type was present in 20.5 %;
• Cu cloud type was present in 19.6 %;
• St cloud type was present in 16.4 %.

Of course these cloud types summarise all covers and also can occur with or without sunshine. However, for instance St 10/10 cloudiness occurs in an overwhelming probability 79 % without sunlight as well as Ac 9/10 and 10/10 with a 40% probability. On the other extreme, absolutely cloudless skies with sunshine were found yearly only in 108 cases within the 1825 set, i.e. in 6 %, but sunshine was frequently associated with low covers in Ci and Cu types with roughly 50 % probability [27]. In accordance with the cloudiness observation time in meteorological cloud reports measured only at 7, 10, 13 and 16 o´clock daily only these can be chosen as cases for a meaningful comparison, but seldom can serve as cloudiness characteristic for the whole day without suspecting momentary changes and cloud movement consequences.

So it is true that many possible cloud cover types and their location in different parts of the sky vault there create countless transitory cases that are specific in time, locality and configurational arrangement. Thus usually partly cloudy skies are considered as so scarce and unreliable with no importance for daylight design and evaluation.

4. CLASSIFICATION OF CLOUDY DAILY ILLUMINANCE COURSES

Availability of daylight during a day can be studied and analysed statistically by calculations or levels of measured data in consecutive using graphical evaluation methods. The first method was applied for finding out the parameters of some characteristic four daily courses based on the half-day sunshine duration [21 and 29]. The second was used to identify characteristics of illuminance courses affected by specific cloud types. The iluminances measured on the CIE IDMP station Bratislava were plotted in the daily sequences while cloud covers and cloud types taken from NSF KU in Bratislava and SHMI (Slovak Hydrometeorological Institute) in Bratislava were associated with these sequences. The parameters of the selected days from achieved results are documented in Table 1. The relative sunshine duration in the last column in Table 1 indicates the duration of sunlight presence during a day. This can be equal to 0 % during any overcast day (February 4, 1994, December 21 1994, March 2 1995) and can reach to 94,6% during ideally clear day (July 4, 1996). Values of the relative sunshine duration were calculated from irradiance measured simultaneously at the CIE

Table 1. Cloudiness [32] and sunshine parameterisation of characteristic daily illuminance conditions

Day	Cloud level	Cloud observation detection						Relative sunshine duration, s
		7	10	13	14	19	20	
February 4, 1994	High							0.000
	Medium							
	Low	StFs 10	St 10	St 10		ScFs 8	Sc 6	
February 22, 1994	High					Cs 10	Cs 10	0.174
	Medium	Ac 6	Ac 6	As 10	As 10			
	Low	Sc 4	Sc 4		Cu 1			
March 2, 1994	High			Ci 1	Ci 1			0.108
	Medium	As 10	As 10	Ac 5	Ac 2	Sc 3	Sc 4	
	Low	Sc 2	ScCu 5	CuSc 6	CuSc 6			
March 28, 1994	High			Cs 1	Cs 3	Ci 3	Ci 3	0.784
	Medium					Ac 2	Ac 2	
	Low	Cu 1	Cu 1	Cu 2				
April 29, 1994	High					Ci 4	Ci 2	0.536
	Medium							
	Low		CuFc 3	CuFc 5	CuFc 5			
May 7, 1994	High							0.469
	Medium							
	Low	Sc 9	ScCu 3	Cu7	CuFc 6		Sc 2	
May 8, 1994	High	Ci 2		Cs 1				0.922
	Medium					Ac 4	Ac 3	
	Low	Cu 1	Cu 3	Cu 3	Cu 3	Cu 1	Cu 1	
December 21, 1994	High							0.000
	Medium	As 10	As 10	Ns 10	Ns 8	Ns 10	Ns 10	
	Low	Sc 8	Sc 8	ScSt 8	ScSt 8	St 4	St 4	
February 11, 1995	High	Ci 9		Cs 10	CiCs 9			0.166
	Medium	Ac 4	AcAs 10	Ac 4	Ac 5	Ac 8	Ac 4	
	Low	Sc 3	Sc 3	Cu 1				
March 2, 1995	High							0.000
	Medium	AcAs 7	Ac 10	Ns 10	Ns 10	Ns 10	Ns 10	
	Low	Sc 1	Sc 8	Sc 5	Sc 7	Sc 6	Sc 5	
March 12, 1995	High							0.932
	Medium							
	Low							

Table 1. Continued

Day	Cloud level	Cloud observation detection						Relative sunshine duration, s
		7	10	13	14	19	20	
May 2, 1995	High							0.939
	Medium							
	Low							
May 14, 1995	High					Ci 3	Ci 3	0.004
	Medium	Ns 10	Ns 10	AcAs 10	AcAs 10	Ac5	Ac 4	
	Low	FsFc 10	FcFc 8	ScFc 8	ScFc 8	Sc 8	Sc 7	
November 18, 1995	High				Ci 7			0.138
	Medium	AcAs 9	AcAs 9	AcAs 9		Ac 3		
	Low		Cu3	CuSc 3	Cu 2		Sc 1	
April 21, 1996	High							0.940
	Medium							
	Low							
July 4, 1996	High	Ci 1	Ci 1	Ci 1	Ci 1			0.946
	Medium			Ac 1			Ac 1	
	Low	St 3	Cu 1	Cu 1	Cu 1			
July 12, 1996	High							0.008
	Medium		As 8	As 8	AcAs 7	Ac 2	Ac 1	
	Low	St 8	St 6	St 7	StSc 5	Sc 2	Sc 3	
July 16, 1996	High							0.696
	Medium	Ac 3	Ac 3					
	Low	CuSc ¼	Cu 6	Cu 4	Cu 2	Sc 1	Sc 1	

IDMP station Bratislava respecting the condition 2.4.4 of [30 or 31] as:

$$E_{es} \le 120 \text{ W/m}^2, \tag{1}$$

where E_{es} is a normal solar irradiance.

Comparison of consecutive measured data of global illuminances E_{vg} and diffuse illuminances E_{vd}, results similarity of illuminance levels and sequence shapes. The specific influence of the sun's position, cloud type and cloud cover and duration of sunlight exposition expressed by relative sunshine duration s on daily illuminance changes was found. Six characteristic daily illuminance courses were identified, with specific sequence shape of global illuminance E_{vg} and diffuse illuminance E_{vd}, Table 2. In the diagrams the global illumi-nance courses were plotted by solid lines while diffuse illuminance by dashed lines, time in hours is displayed on the x - axis and the scale of illumi-nance in klx is placed on the y - axis.

Type **CC – Clear, cloudless** sequence repre-sents ideally clear day without clouds on the sky. During such a day only changes in the sun's posi-tion and the sunlight reduction due to the turbidi-ty of the atmosphere influence the values of direct and diffuse skylight sequences respectively. Sun-shine duration is continually registered from sun-rise to sunset. Situation CC is occurs quite rarely in Central European climate.

Type **QC - Quasi-Clear non-homogeneous** sequence is very similar to the clear cloudless type. Global illuminance can slightly decrease from an ideal curve with reduction of sunlight due

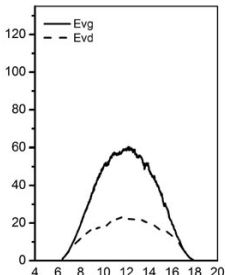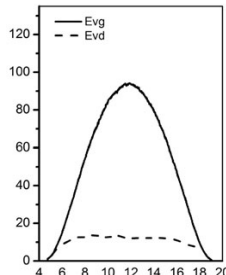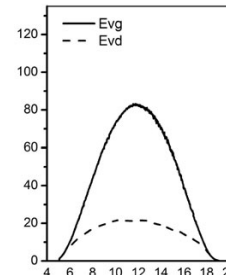**Table 2. Classification of daily exterior illuminance sequences.**
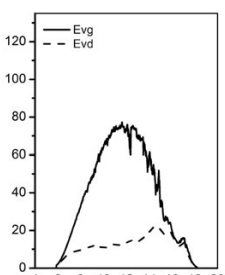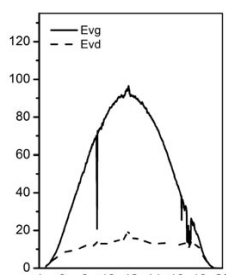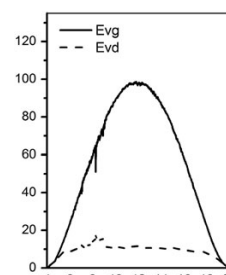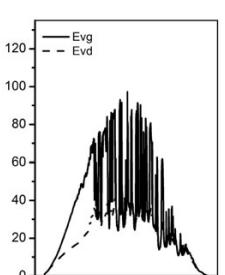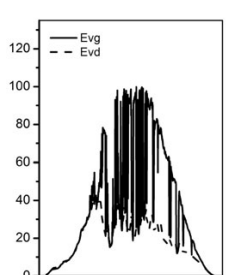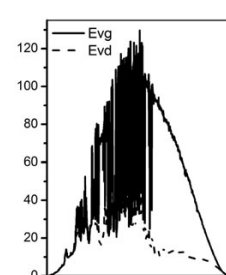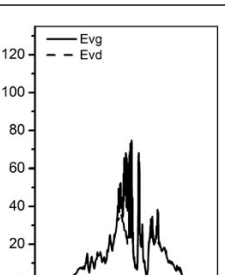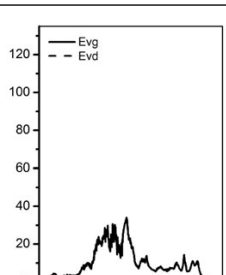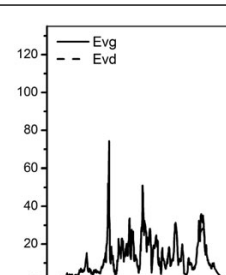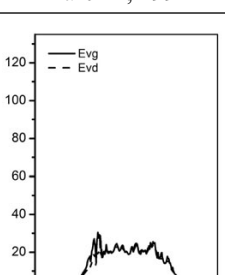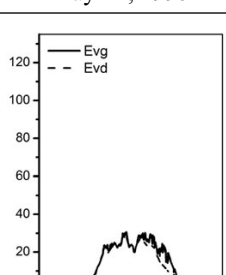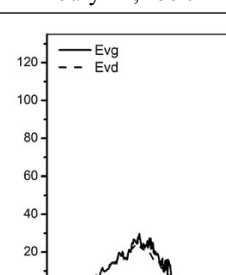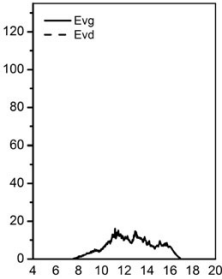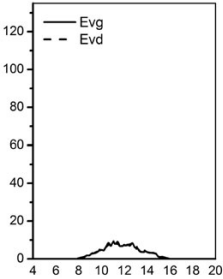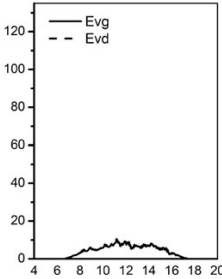
Code/Description		Examples		
CC	**Clear cloudless**			
Strong dependence on the solar altitude. Whole day sunshine duration.				
$S = 0.932 - 0.940$		March 12, 1995	May 2, 1995	April 21, 1996
QC	**Quasi-Clear nonhomogeneous**			
Direct sunlight is -- reduced by Ci, Cs or -- shaded by moving clouds Cu, Ac. Very high daily sunshine duration				
$s = 0.784 - 0.946$		March 28, 1994	May 8, 1994	July 4, 1996
CD	**Cloudy dynamic**			
Frequent changes of the sun disk shading and levels of direct sunlight. Dependence E_{vg} banding on the solar altitude. Higher daily sunshine duration.				
$S = 0.469 - 0.696$		April 29, 1994	May 7, 1994	July 16, 1996
CN	**Cloudy nonhomogeneous**			
Independence on the solar altitude. Low daily sunshine duration.				
$S = 0.004 - 0.108$		March 2, 1994	May 14, 1995	July 12, 1996
OQ	**Overcast quasi-homogeneous**			
Dependence on the solar latitude. Higher diffuse illuminance. Very low daily sunshine duration.				
$S = 0.138 - 0.176$		February 22, 1994	February 11, 1995	November 18, 1995

10

Table 2. Continued

Code/Description		Examples		
OH	**Overcast homogeneous**			
Strong dependence on the solar altitude. Low diffuse illuminance. Zero daily sunshine duration.				
$s = 0.000$		February 4, 1994	December 21, 1994	March 2, 1995

to a thin layer of cirrus or cirrostratus clouds covering 1/10 – 3/10 or dropping occasionally to the level of diffuse illuminance (dashed line) and even lower when effecting by cumulus or altocumulus clouds, which shade the sun disk. The curve of global illuminance is not smooth because of these troughs. Local increases of diffuse illuminance indicate the occurrence of a larger cloud covering. Sunshine durations can be comparable with those in clear cloudless days if clouds are located out of the sun's position, or when sun is occasionally shaded by clouds Cu or Ac can be lower.

Type **CD – Cloudy dynamic** sequence is very often occurring during summer, transitional spring and autumn periods in the Central European climate [22]. Global illuminance rapidly and frequent changes during a short time with the upper limit equal to sunny days and lower limit equal to sunless days, i.e. in the second case, global and diffuse illuminances are the same. Due to higher covers of the sky vault by scattered and faster moving Cu, Ac and Sc clouds often cause sun disk obstruction happens. The virtual bounding curve of global illuminance during sunshine follows the shape of sunny cases influenced by changes of the sun's heights. The relative sunshine duration during daytime dynamic days is quite high in the wide range 0.40 – 0.75.

Type **CN - Cloudy non-homogeneous** daily sequence is caused by the increase of cloud cover decreasing periods of sunshine. The cloudiness on the CN type hemisphere consists of Ci, As, Sc, Ns, Ac, Sc, ScCu, St, Sc clouds moving usually in all tree cloud levels. Due to various cloud thickness, cover, form of clouds and their random location in all levels simultaneously were found very unstable illuminance courses. Global and diffuse values are independent on changes in solar altitude. Global illuminance can reach much higher levels during sunny spells as measured on March 2, 1994, or can be low and relatively stable, as was the case on May 14, 1995. Observations of cloudiness on July 12, 1996 show the influence on illuminance variations due to combined effect of denser As, St Ac, Sc clouds moving in lower parts of the atmosphere. Changes of relative sunshine duration were registered lower and often in the range 0 – 0.45.

Type **OQ - Overcast quasi-homogeneous** sequence shows the whole day availability of skylight illuminance during almost overcast situations determined by clouds Ac, As, Sc, Cu located in the lower parts of the atmosphere with high cover increased to 10/10. In this case, cloud layers are more compact resulting in higher diffuse illuminances and dependence on solar altitude changes, as is documented in sequences measured on February 22, 1004, February 11, 1995 and November 18, 1995. Values of the relative sunshine duration are very low in the range 0 – 0.2 and very often equal to zero.

Type **OH - Overcast homogeneous** sequence represents days with occurrence of the lowest skylight illuminance values without any sunshine, as is demonstrated by courses on February 4, 1994, December 21, 1994 and March 2, 1995. Values of global illuminances are equal to diffuse illuminances due to the absence of direct sunlight. Overall, the atmosphere is fully overcast by the combination or one type dense clouds Ac, Ns, As, St, Sc in low levels without any clouds in the highest level. Resulting cloud cover is 10/10 without any blue sky background patches. Relative sunshine duration during overcast homogeneous days is equal to zero.

Table 3. Summary of estimated quantification of cloud and sunshine descriptors causing typical daily illuminance courses

Code/Description		Cloud level	Cloud type	Cloud cover	Relative sunshine duration, *s*
CC	**Clear cloudless**	High	-	-	0.93 – 0.95
		Medium	-	-	
		Low	-	-	
QC	**Quasi-Clear Non-homogeneous**	High	Ci, Cs	1 – 3	0.70 – 0.95
		Medium	Ac	1 - 4	
		Low	Cu	1 – 2	
CD	**Cloudy dynamic**	High	Ci	2 – 4	0.40 – 0.75
		Medium	Ac	3	
		Low	Sc, Cu, Ac, ScCu, CuFc	1 - 9	
CN	**Cloudy non-homogeneous**	High	Ci	1 – 3	0.00 – 0.45
		Medium	As, Sc, Ns, Ac	1 - 10	
		Low	Sc, ScCu,St	2 - 7	
OQ	**Overcast quasi-homogeneous**	High	Cs, Ci, CiCs	3 – 10	0.00 – 0.20
		Medium	Ac, As, AcAs	3 – 10	
		Low	Sc, Cu, CuSc	4 – 10	
OH	**Overcast homogeneous**	High	-		0.00
		Medium	AcAs, Ac, Ns,As	7 - 10	
		Low	St, Sc, ScSt	4 - 10	

5. CONCLUSIONS

The presented study shows that there is a correlation between daily illuminance coursed and the occurrence of cloud types. The different results were obtained when illuminance sequences of clear days were evaluated. Observation of cloud type occurrence documents, that also clouds Ci, Cs and Cu can disturb symmetry of sky luminance distribution typical for cloudless situations but daily illuminance sequences look like similar. Clouds Ci or Cs is effecting only the reduction of direct sunlight but not its full elimination. Different effects resulted by moving clouds Cu, Sc, Ac. Due to changes in the random scattering on the sky, shape and dimension of these clouds the direct sunlight is often eliminated producing dynamic luminous environment. If the cloud cover is higher and occurrence of As, Ns clouds are combined with Cu, Sc, Ac ones the daily illuminance sequence is losing its dynamic character and is transformed to continual illuminance changes independent on the solar altitude. Illuminance sequences on overcast days can be classified in two types with very low or no sunshine. The first type is the product of clouds moving in all levels of the atmosphere with higher exterior illuminances. The second represents influences of dense St, Sc, Ns As clouds moving in low levels of the atmosphere. Exterior illuminances during these days are the lowest and conditions for daylighting of building interiors are the worst.

Therefore, the classification of outdoor daily courses characterising daylight availability as influenced by cloudiness and sunshine duration, can be summarised in six daytime situations, as is shown in Table 3.

The presented classification can serve lighting engineers, specialists and researchers as a tool for the prediction and simulation of typical daily illu-

minance courses and for the determination of daily and seasonal conditions for daylighting and energy saving design in buildings.

ACKNOWLEDGEMENT

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ASSESMENT OF DAYLIGHTING PERFORMANCES OF CLASSROOMS: A CASE STUDY IN KIRKLARELI UNIVERSITY, TURKEY

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ABSTRACT

This study was conducted to evaluate the daylighting performances of classrooms. For this study, a classroom in Kayali Campus and two classrooms in Kavakli Campus of Kirklareli University have been selected. In these buildings, the illuminance levels have been measured and standards and design rules have been investigated. Modelling in the Velux Daylight Visualiar simulation program, the classrooms have been evaluated in terms of daylighting parameters. Consequently, window properties that can provide better natural lighting in the classroom have been identified. According to the measurements and the results of the simulation, daylight illuminance levels in these environments has been found to vary by directions. The buildings' orientation, the window openings on the facade of buildings and the shading elements should be designed at the point of the natural lighting idea by expert designers in the field.

Keywords: energy efficiency, daylighting, illuminance, classroom, school lighting, Turkey

INTRODUCTION

Energy is one of the most important parameters in understanding development and welfare level of countries. Furthermore, as in other countries, in Turkey it is the most important parameter that increases living standards besides economic and social development. The increase in energy consumption affects the balance of supply and demand and countries search for alternative ways to meet energy demands. Countries mostly use conventional energy sources to supply energy demands and this leads to environmental problems. In order to address this problem, renewable and alternative energy sources are sought. The usage of renewable and alternative energy sources prevents environmental pollution and plays an important role in preventing the dependence on other countries for energy resources. The usage of renewable and alternative energy sources contributes to an increase in labour force potential and mobilisation of a countries' internal resources due to the transfer of technology [1].

Buildings intensively consume energy and always need it. The energy consumption of buildings in the use stage differ from the construction stage and include warming, lighting, air-conditioning, hot water supply and the usage of electrical devices. The usage rates of these consumption methods differ depeding on the service type of the building. This variability in the buildings of educational institutions occurs as lighting, air-conditioning and supplying the energy demand of machines and devices in labs. Artificial lighting constitutes a high amount of energy demand in educational institutions [2]. So there is potential to generate energy savings through rehabilitations in lighting and its systems and their related energy supply. The

natural lighting systems are considered as the best solutions to this issue.

Daylighting is often cited as a key component of green building and a type of lighting carried out by using daylight [3]. The term 'daylight' is used to refer to the totality of illumination provided by the sun and the sky [4]. Daylighting is the main lighting source used to enlighten the interiors of buildings from past to present. When daylighting is used correctly and appropriately, the users of the buildings can work and act easily and efficiently in a comfortable environemnt [5]. By using natural lighting systems, the lighting system load can be decreased by a significant amount. However, natural lighting can only be used when there is daylight. In educational facilities, especially in those that give dual-educational systems, there must be an alternative solution to carry out energy continuity because of the absence of daylighting. In this situation, engaging artificial lighting systems or hybrid renewable energy sources can be a solution.

This study firstly describes the components of lighting systems and investigates the usage of natural lighting equipment in buildings. For the transfer of daylight into the building, the sizes of windows, the position of windows and the orientation of buildings; for uniform light distribution in the interior environment, variables such as colour and reflection properties of spaces have been investigated. Later, the daylighting performances of a classroom in Kofcaz Campus and two classrooms in Kavakli Campus have been evaluated. In these places, the lighting levels have been measured and standards and design rules have been investigated. The classrooms have been evaluated in terms of daylighting parameters using the modelling capabilities within the Velux Daylight Visualiar simulation program. Consequently, window properties that provide better natural lighting in the classroom have been identified.

2. BENEFITS OF USING NATURAL LIGHTING IN EDUCATIONAL BUILDINGS

It is known that illumination affects the mood and motivation level of people. The proper design and selection of daylighting systems can significantly help in improving energy efficiency and reducing environmental pollution. It creates healthier learning environments that may result in increased attendance and improved grades in the case of school design [2,6,7]. When properly designed, windows, clerestories, and roof monitors can provide a large portion of the lighting needs without undesirable heat gain or glare. And therefore, electric lights can be turned off or dimmed in daylit spaces when the target illuminance is achieved by daylighting. Energy savings can only be achieved by implementing light controls, sensors and light dimmers for the lighting system of those daylit spaces [2,8,9].

The International Energy Agency (IEA) reports that 19% of electricity worldwide is used for lighting [10]. The usage of daylight in buildings significantly decreases the electric energy consumption [11,12]. For instance, it has been shown that artificial lighting of non-domestic buildings represents 50% of the energy consumption in Europe. It also has been shown that it is possible to reduce this consumption by between 30 to 70 percent by combining the use of artificial and natural lighting. Potential savings dependend on orientation, the size and shape of the window, and the shape and surface reflectance of the room. [8,11].

The use of natural lighting is an important element in modern architecture as it aids in creating a pleasant visual environment. Natural lighting is considered the best source of light for colour rendering [2,13]. The visual comfort related to the quantitative and qualitative aspects of the daylight significantly contributes to the well-being of pupils and thus leads to better school performances. A survey of more than 20,000 elementary school students and 100 schools in the USA confirmed this statement. It has been proved that students with the most natural lighting in their classroom progressed 26% faster in reading and 20% faster in mathematics [14].

3. ARCHITECTURAL DESIGN PARAMETERS OD BUILDINGS WHICH TAKE ADVANTAGE OF NATURAL LIGHTING

3.1. Windows

Classrooms are designed to receive light on a two facing facade. In this way, a more uniform distribution of daylight can be achieved in the classroom. Large window areas may provide good amounts of daylight and pleasant views [2]. Keeping the depth of rooms within 1,5–2,0 times of window head height provides adequate illumination levels

and balanced distribution. With a reflective light shelf, this zone may be extended up to 2.5 times the head height. Keep window area to a 30–40% window-to-wall ratio. Band windows application which provide a more uniform spread of daylight in the classroom should be preferred. A vertical form of east and west windows should be chosen. For example, vertical fins or recessed windows. It is also useful to block early morning and late afternoon low sun on the north [14].

3.2. Lighting

Lighting is one of the most important of all building systems. Every school relies on lighting to provide an effective learning environment, which is one of the most critical physical characteristics of the classroom. The modern classroom is a space where a wide range of teaching/learning activities take place. These include traditional blackboard tasks, individual desk work, computer work, audio-visual presentations, fine arts, sewing, the use of visual aids on the walls and more. Adequate lighting is vital for sight-impaired students or for students who use dangerous equipment such as lathes or saws in shop classes. Key issues are visual comfort and providing appropriate horizontal illuminance for all the various tasks and activities that take place in the classroom [12].

Classroom lighting needs to provide teachers with the ability to change the lighting in response to the visual needs of each type of activity. Indoor lighting should achieve the desired appearance and ambience in the space as well as meet many other important functional and psychological needs. Educators have noticed how lighting affects students' behaviour, alertness and ability to learn. Classroom lighting plays a particular role because of the direct relationship between good lighting and students' performance. Bad lighting leads to discomfort and hyperactivity, while better lighting produces greater productivity. Teachers have also noted that lighting affected their own effectiveness in the classroom and their ability to handle the stress of the teaching profession. Lighting can have a significant impact both on student and teacher productivity [15]. One approach to classroom lighting that has gained wide acceptance in recent years is creating instructional spaces that rely on daylight for illumination. While natural illumination from windows and skylights is a preferred standard, most learning environments

will require supplemental electric lighting. The Illumination Engineering Society recommends a minimum of one window per instructional space because it increases the quality of the educational environment [15]. It is evident that lighting and windows play a significant role in the achievements of students; however, daylight in some poorly designed instructional spaces may enter the room too directly and create glare, which can hinder learning.

Generally, when people sense the lighting system is causing visual discomfort, the problem is poor lighting quality. Integrating a building's daylight strategy with the electrical lighting system is critical to achieving energy savings. The type of lighting equipment selected for a school can increase energy efficiency. Other methods of enhancing the use of daylight while increasing the effectiveness of a daylight plan are: skylights, clerestory windows, roof monitors and a roof design that diffuses light throughout an area [16].

3.3. Colour of exterior and interior surfaces

In order to increase daylight's entrance into the building, light colours should be used on for windows' wings that direct the light and light shelves. Moreover, the elements used to reflect light must be made in a position to reflect the light to the ceiling. Wall and ceiling surfaces must be light coloured so that the light can be spread [14].

3.4. Recommended surface reflectances

Desirable reflectance according to Illuminating Engineering Society's recommendations: ceilings >80%; walls 50–70% (higher if wall contains window); floors 20–40%; furniture 25–45%. Use light-transmitting materials for partitions where possible. Use clear or translucent materials in the upper portion of full-height partitions. If this approach is taken in corridor walls, corridors may be adequately lit just by this spill light [14,15].

3.5. Building orientation

The most suitable direction for natural lighting are south and north. The north direction is not exposed to radiation, but can always get daylight in the same quality. In the west and east directions, the sun radiates in horizontally and makes it difficult to control. In the south direction, the effect of the sun
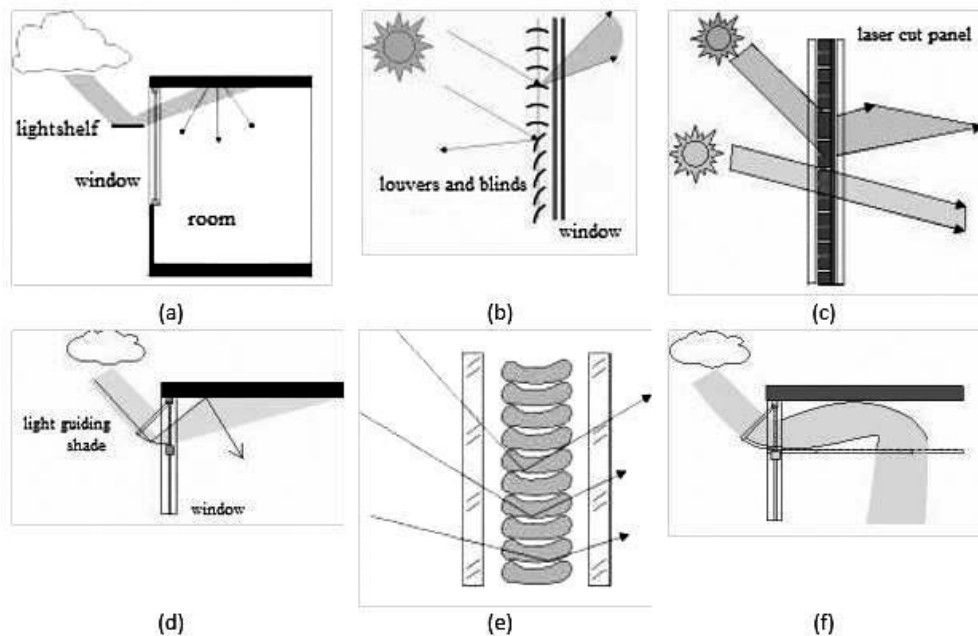
Fig 1. Daylighting systems using direct sunlight
(a) Light shelf system (b) Window shade and blind system (c) Laser cut panels (d) Light guiding shade
(e) Light guiding glass (f) Anidolic ceiling

is permanent and sun rises at a right angle compared to the west and east directions. Therefore, it is easy to control.

3.6. Building form

In order to benefit from natural lighting, the rate of surface size should be decreased. More exterior front areas leads to more opened windows. However, the decrease in the rate of surface size will increase the heat loss and earnings via the building's shell. It is necessary to strike a balance between both parameters. Moreover, while designing the plan of construction block actions supplying self-shadow to east and west directions can be made, fronts can be deepened. If this cannot be carried out, unwanted sun penetration and shadowing elements (blinds, light shelves and solar cutters) can be decreased. It is preferable that the shadowing elements are openable and closable.

3.7. Use north facing monitors

In case the design did not permit south-facing roof monitors, north-facing roof monitors were used. Due to their orientation, the glazing area required was more than the south-facing monitors, thus this design costs more. On the energy side, in our climate, there was the concern of heat losses through the north glazing, leading to an increase in building energy use. North monitor design was maximized by using the back-side (south-facing) to mount solar collectors, wherever applicable. This combined approach helped cut down on overall costs, while providing adequate daylighting [17].

3.8. Daylighting systems

Daylight is defined as ''the combination of the diffused light from the sky and sunlight''. A daylighting system is a device located near or in the openings of building envelope, whose primary function is to redirect a significant part of the incoming natural light flux to improve interior lighting conditions. There are two simple daylighting systems, namely, side-lighting and top-lighting. Side-lighting, which is more commonly observed, is simply a window opening. Top-lighting is an opening in the ceiling or roof element of the building [2].

3.8.1. Using light shelves

The light shelf is a classic daylighting system. This system has been designed to prevent light reflection, shadowing and direct rays from the sky. The light shelf is usually placed horizontally to the interior or exterior of the window front. The light
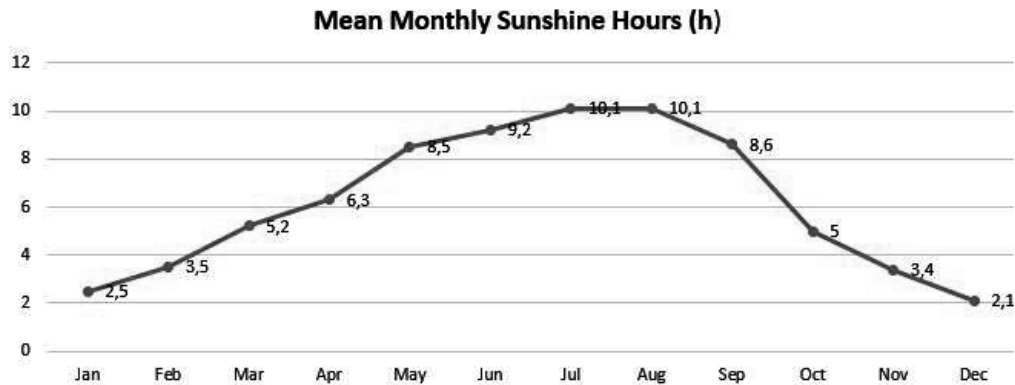
Mean Monthly Sunshine Hours (h)

Fig 2. Mean monthly sunshine hours of Kirklareli city

shelves divide the window as the scenery part is below and upper part points upwards (Fig. 1-a). Their placements are selected according to the direction of window, position of room, ceiling height and the eyes level of people in room. They can be applied to deep places to the south direction in the north hemisphere. They do not work in the east and west directions and in cloudy weather [16,18].

3.8.2. The use of louvers and blinds

The blind system is a classic daylighting system to prevent shining and daylighting and enable shadowing. They consist of multiple horizontal and vertical slats (Fig. 1-b). The exterior blinds are usually made of stainless steel, anodize, painted aluminum or PVC which is low costing and highly resistant. The slats can be smooth or curved. The size of slats can differ according o the size of blind [16,18].

3.8.3. The use of a laser cut panel

The laser cut panel is a thin transparent acrylic panel with parallel cuts made using a laser cutting machine (Fig. 1-c). A LCP makes an array of cuts at an angle perpendicular to the surface. Each surface of laser cut turns acts like small mirrors that deflect the light passing through the panel. The panels direct the light upwards. These cuts are usually made through the panel because this method requires less control of the cutting speed and laser power than other methods. Therefore, the panel should have a 10- to 20-mm-long solid part to support the cut sections. The acrylic panel is usually fixed between two glass panes to form a double glazed window. They are placed above the eye level to prevent shining [18].

3.8.4. The use of light guiding shade

The light guiding shade is an exterior shadowing system that direct sky and sun light to the ceiling. The light guiding shade consists of distributive glass space and two reflectors made for directing the light sprawling from building space with angles in the significant angular range (Fig 1-d). The light guiding shades are more complex that traditional shadowing systems. Highly reflectant materials must be used in interior areas. The light guiding shade systems are placed on the upper half of the window or upper one-third of part [16,18].

3.8.5. The use of light guiding glass

These are made of concave acrylic material placed vertically between two panes of glass (Fig. 1-e). They reflect the daylight coming in directed or direct from all angles to the ceiling. The other important part of the system is the ceiling that conveys the directed light to the work space by reflecting it. This system is placed to eye level to prevent shining and other visual effects [16,18].

3.8.6. The use of an anidolic ceiling

The first aim of anidolic ceiling system is to supply enough daylight to rooms in cloudy weather condition. The anidolic ceiling consists of daylight collecting optics attached to a light canal on the hanged ceiling (Fig. 1-f). The system is designed to be placed on the window. Since the system is designed to collect the light sprawling from the sky, it can be used in every latitude. On sunny days, the shining that stems from the sun light affecting directly and the excessive heat can be prevented by the protecting entrance glass [16,18].
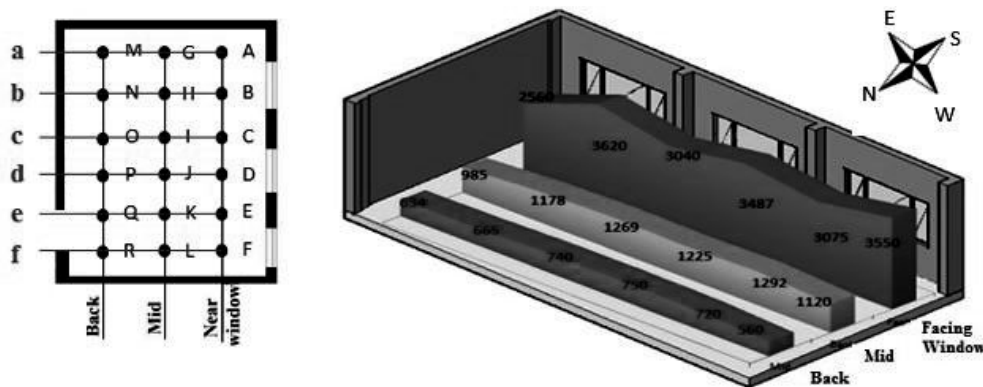
Fig. 3. The daylight chart for the south facing classroom (TEF-201)

4. THE COMPARATIVE ASSESMENT OF DAYLIGHTING PERFORMANCES OF CLASSROOMS

A number of daylight simulation techniques, have been developed over the past 50 years, making use of simulated or artificial skies and building models. These simulation techniques also have the advantage of allowing for unique buildings shapes and room configurations [19]. One of the most important daylighting simulation programs is Velux Daylight Visualiar. In this study, the classrooms in Kavakli and Kayali Campuses of Kirklareli University are simulated using Velux Daylight Visualiar.

Illumination performances of classrooms were assessed by the daylighting measurements made. Kirklareli is located in the northwest of Turkey, at 41° 44' N latitude and 27° 13' E longitude. Fig. 2 shows the mean monthly sunshine hours of Kirklareli city. In March, when the experimental measurements were made, Kirklareli has 5.2 hours of sunshine time.

4.1. Daylighting measurements of classrooms

The layout of the existing classrooms of Kirklareli University in Kayali and Kavakli Campus is introduced in the sense of the general daylighting performance.

A classroom in the south and north direction on Kavakli Campus and a classroom on Kayali Campus have been chosen. The schematics and measurements of the chosen classrooms have been taken and the window size and position have been placed in the drawing program. The measurement points at 2 meters intervals have been drawn according to the middle axle of the classroom plan and measurements have been carried out with a lux meter at the 85 cm work height. The measurements have been put into graphics using Excel.

The classroom seen in Fig. 3 is located on the second floor of the Technical Education Faculty building and faces south. The classroom has three windows. Each windows has two double pane glass with the following characteristics: external and internal glass is 4 mm thick, the air filled insulation gap is 12 mm thick.

Illuminance measurements have been taken between 12:30–12:50 pm on the 21st March. As can be seen from the Fig 3, the illuminance in regions close to the window is excessively high in the measurements that have been taken when the sun directly affects the interior of the classroom. Since the glaring and reflecting will increase depending on the daylighting, the sunlight must be prevented. Therefore, the curtains are used in the classrooms. However, the curtains entirely block the daylight. Instead of this a simple blind system can be used.

The classroom seen in Fig. 4 is also located on the second floor of Technical Education Faculty building, but is north facing. The classroom has four windows. Each windows has two double panes of glass with the following characteristics: external and internal glass is 4 mm thick, the air filled insulation gap is 12 mm thick. According to the measurements taken between 12:50–13:20 pm in the north-facing classroom in the same building the illuminance values are higher, but it is not at a disturbing level.

The classes in Kavakli Technical Education Faculty buildings are rectangular in size and positioned in parallel to the facade of the building. The windows are on the long side of the classroom. Therefore, the required window intervals can be easily obtained for natural illumination of the classroom.
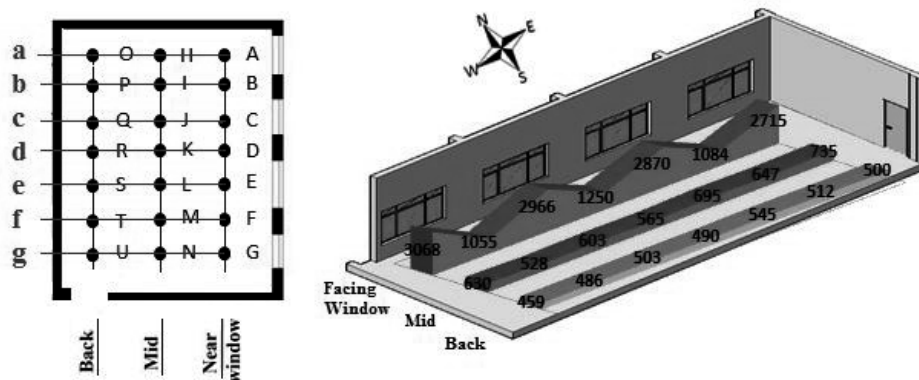
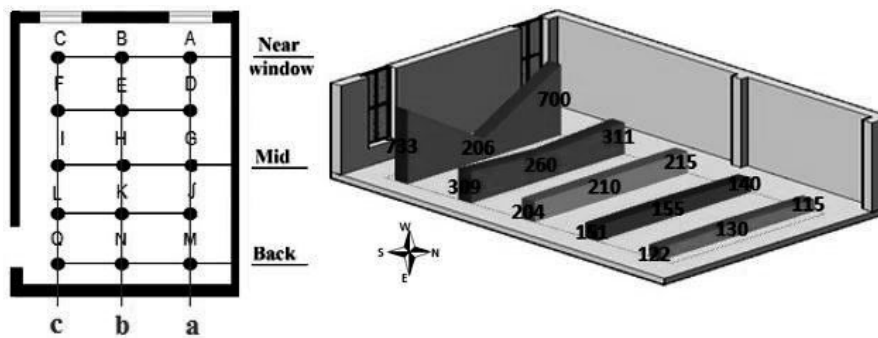Fig. 4. Daylight chart for the north facing classroom (TEF-208)

Fig. 5. Daylight chart for the south-west facing classroom (Central classroom building, Z-42)

The last measurement has been taken from an existing classroom on the ground floor of the newly built building in Kayali Campus of Kirklareli University between 11:30–12:00 pm on the 21st March. The classroom is also rectangular in size, but the layout of this classroom is different. The windows are on short side of the classroom. So, a deeper distance has been created and narrow and long windows have been designed.

According to the measurements, it can be seen that the illuminance is insufficient in all parts of the room except from the windowsills. The main reason for this is that the entire window area is insufficient. Two windows (0.90x3.60 m) have 6.28 cm² areas and a lower 10 percentage rate than the total area of the class. Although the windows have 3.60 meter height, they are insufficient because of their narrowness and number. It is necessary to increase the windows that prevent glaring and reflecting since they face in north direction. The classes in Kayali center have been placed vertically to the front. In order to reach the wanted illuminance level, the necessary window area can be supplied by dividing the entire front area with window interval.

4.2. Daylighting simulation results for the classrooms

In this study the natural lighting simulation of an existing classroom in Kayali Campus and two classrooms in a building belonging to the Technical Educational Faculty in Kavakli Campus of Kirklareli University has been carried out usuing the Velux Daylight Visualizer program. The results of simulation are given below.

As can be seen from Figs. 6–7, the illuminance in regions close to the window is high the same as in the measurements. In Fig. 8, the classroom's illuminance level is insufficient at all points apart from the windowsills. The main reason of this is that the whole window area is insufficient. Illuminances shown in the following Figs are in foot-candle.

5. RESULTS AND DISCUSSIONS

The results of simulation made on the natural lighting in the educational institutions support the literature information presented above. The illuminance levels of the classerooms facing in the south direction in Kavakli Campus is higher
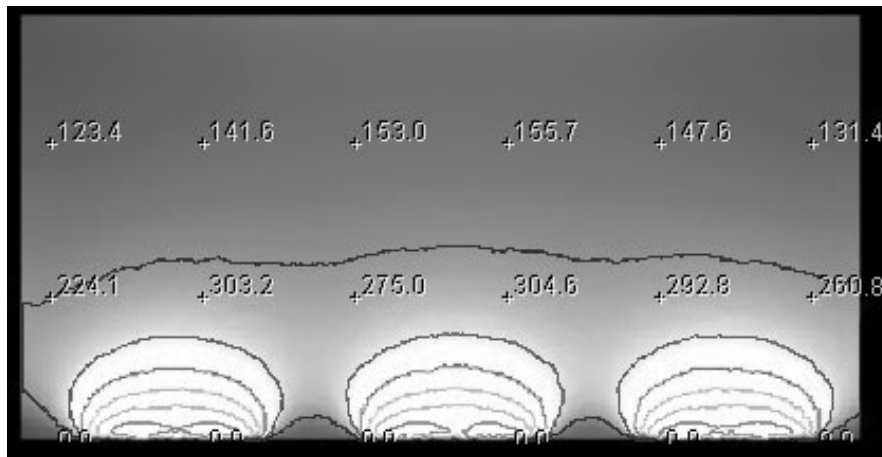
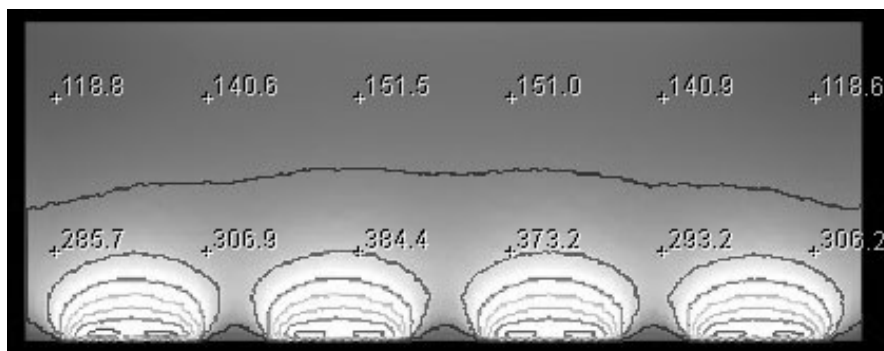Fig. 6. The lighting simulation of the TEF-201 classroom in Kavakli Campus

Fig. 7. The lighting simulation of the TEF-208 classroom in Kavakli Campus

depending on window interval, but it leads to luminance and glare. Therefore, if a uniform illumination is desired, the designs that don't directly take the daylight into the space must be made. The interval in the upper limit must be done for the lighting if it is possible. If this does not work, light shelves, lightpipes and lightwells should be preferred.

The window intervals and sizes in the class existing in Kayali Campus are insufficient for natural lighting. The window intervals must be horizontal instead of vertical, by in way much more daylight can be benefited from by using a light shelf. When the simulation results of the classerooms in both buildings are evaluated, it becomes clear that the buildings were designed before the natural lighting design for classroom usage had been considered.

6. CONCLUSIONS

Although the daylighting level of spaces differs in terms of directions, the measurements taken from the north direction has displayed that

if a sufficient enough window interval is used, the wanted illuminance in the spaces facing north can be obtained. The minimum net glazed (window) area should not be less than 1/3 or 1/5 of the floor area of the room served [20]. Therefore, in Kavakli Campus classrooms, the floor area ratio of windows are respectively 1/5,54 and 1/5,58. But, in Kayali Campus classroom, the floor area ratio of window is 1/10,54. In this classroom, sufficient illuminance can not be obtained with the existing windows and building orientation, as has been observed by the results of the simulation and measurement. So, in order to increase the illuminance level, a suitable daylighting system (light shelf, anidolic, ceiling etc.) must be chosen. The light pipes must be chosen for classes near the roof. The appropriate selection of wall colour, ceiling and ground covering will be helpful to obtain sufficient illuminance levels.

As it is known, the use of daylight helps energy saving. Furthermore, it contributes to the success of students by affecting their psychology in a positive way. Therefore, when desgning educational buildings, in cooperation with architects and installation engineers, buildings that will supply
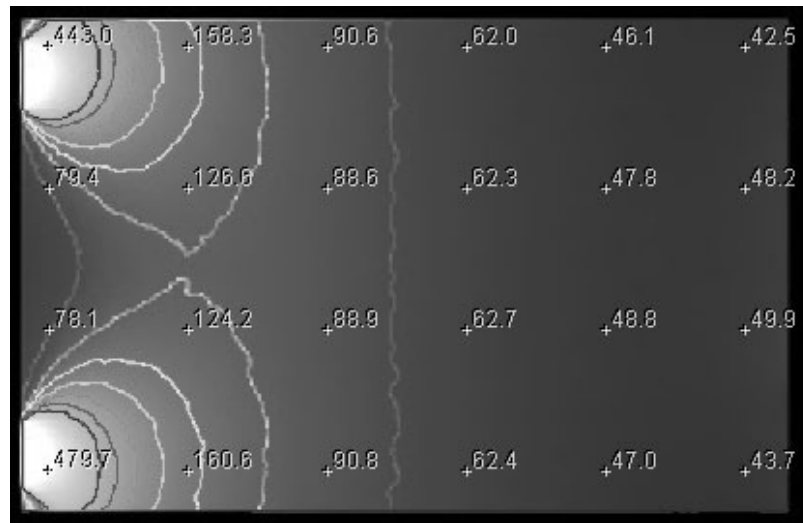
Fig 8. The lighting simulation of the Z-42 classroom in Kayali Campus

more efficient work places must be constructed with an interdisciplinary effort from the beginning and to the end of the project.

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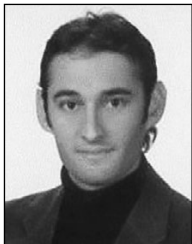
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A LIGHT TRAP IN THE LOBBY OF THE EQHO TOWER
IN PARIS LA DÉFENSE

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ABSTRACT

The paper is devoted to the short description of the light design part of skyscraper modernisation project in Paris La Défense.

Keywords: solar light trap, tower "Eqho", lobby, natural light, sun's rays

Built in 1988 in the business district of La Défense in Paris, this 130-metre high-rise, originally called the Descartes Tower, Fig.1, underwent a renewal of its façades and a complete restructuring of its lobby in 2011 to allow for the entry of natural light and to open it up visually to the bridge-type structure supporting the tower.

This is the background to the request from the French architect studio, Hubert & Roy, to Concepto lighting design studio to work with them in totally rethinking the daytime and nocturnal images of the lobby.

A SOLAR LIGHT TRAP THAT ADDS COLOUR AND MARKS THE PASSAGE OF TIME

In addition to wide openings out into its urban environment, the lobby has a large glass roof 12 metres above floor level. It is suffused in natural light, which changes the space as time goes by, throughout the days and seasons.

At certain times of the year, and depending on the sun's course, sunbeams shine into the lobby beneath the bridge-type structure, projecting onto the walls and floor the shadowy spans of the metal mesh like structure above.

To breathe life into these projected lights, to highlight the size of the lobby and reveal the sun's courses in the changing seasons, a glass installation, consisting of coloured tinted dichroic glass (integrated directly into the laminated panels in the glass roof) and reflective panels made of mirror-

Fig.1. "Eqho" tower in Paris La Défense
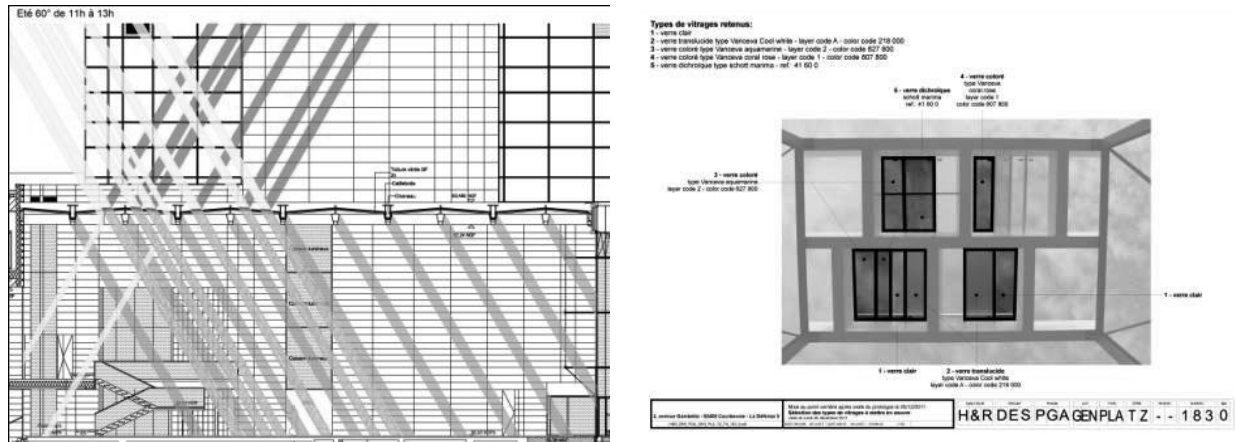
Fig.2. Principle of reflection / transparency / refraction of the various glass elements – Prototype for the glass roof
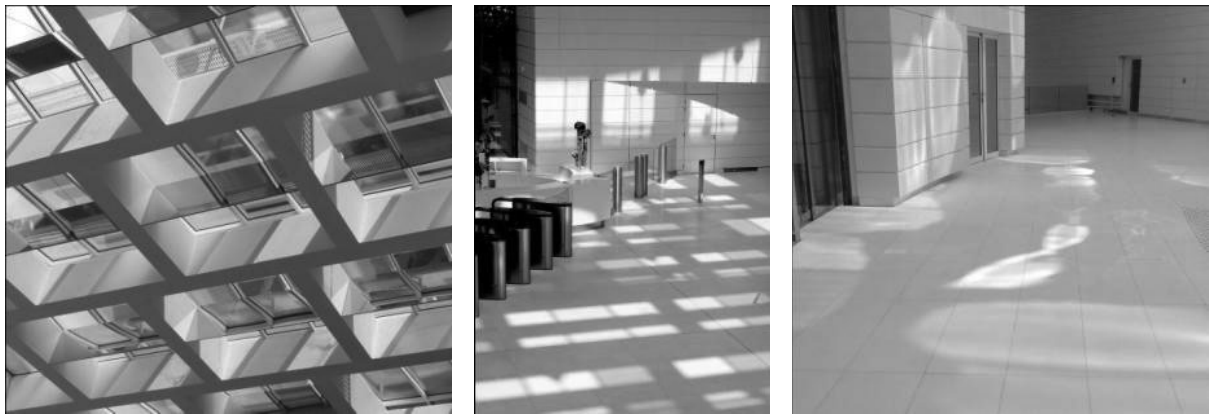

Fig.3. Left to right: system of vertical mirrored panels – Direct coloured projections – Deformation of the light by the mirrored panels on the mezzanine
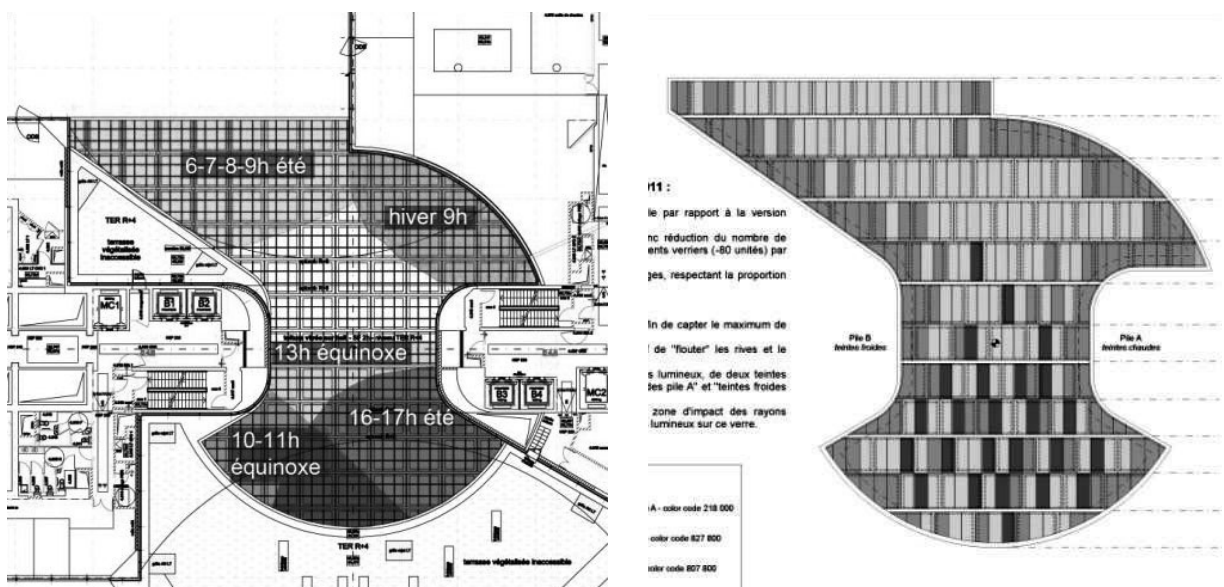

Fig.4. An analytical summary of the heliodon on the glass roof determined the positioning of the glass panels
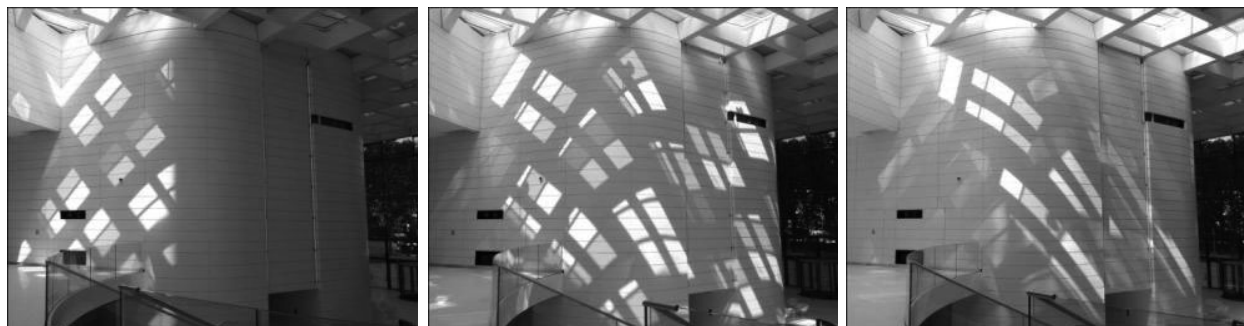
Fig.5. The course of the sun on the west gable on 3 September 2013: 11.30am – 12.20pm – 3pm
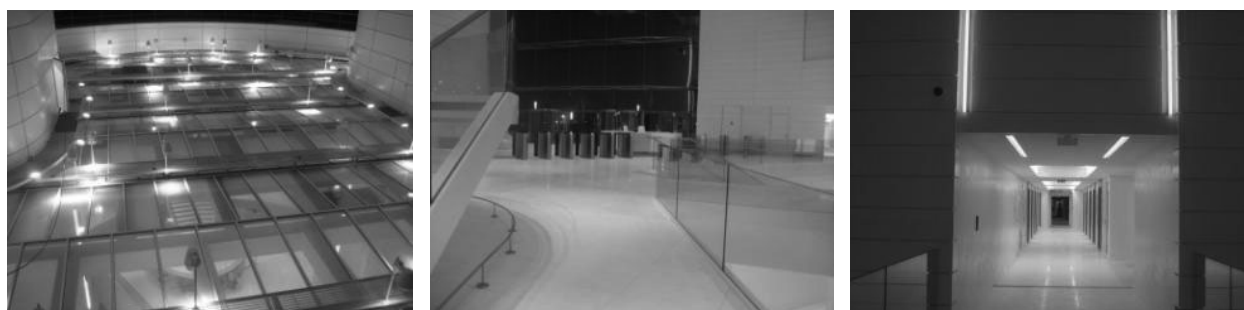

Fig.6. Installation of floodlights above the glass roof – Pastel shades on the ground floor, in the lobby – Coloured vertical lines in the lobby and access corridor.

polished stainless steel suspended vertically, was created and incorporated into the mesh.

Dichroic glass has the ability to colour rays of light passing through it, changing the colour within a predefined range (in this case, from blue-green to purple) depending on the variations in the angle of incident sunbeams. Dichroic glass also reflects sunbeams by colouring them differently from the rays being transmitted.

Thus the sun's rays are projected onto the floor and white walls of the lobby, generating spots of colour that slowly move and change tone throughout the day and the seasons.

The mirrored panels hung vertically within the metal mesh allow certain coloured rays to be deviated and projected onto the inner wall of the north-facing auditorium, which never receives direct sunlight.

The chromatic density of the various panels of coloured glass is increased in the southern portion of the glass roof to reduce the light and heat produced by the sun's rays in the middle of the day in summer, Fig.2. The sun's rays, which strike the building at a more acute angle in winter at the beginning and end of the day, flood the lobby with light from the large vertical glass walls built entirely of clear glass.

Thanks to this optical device, the lobby has become a light trap offering occupants and visitors interesting, moving, changing images during the day throughout the year, Figs.3,4.

ARTIFICIAL DOWN LIGHT THAT MAGNIFIES AND INCREASES THE DRAMATIC EFFECT OF THE LOBBY

At night, the entire volume of the lobby is lit by floodlights (equipped with various optics and 150W ceramic metal halide lamps, T: 3000K, IRC 80) mounted above the glass roof, on the exterior along the metal duckboard required for maintenance work, Figs.5,6.

This lighting system makes it possible to use the metallic mesh like a huge stage grid, concealing the lighting fixtures from view. The beams of light shine vertically down into the lobby, lighting the floor of the ground floor, the openings into the basement, the stairs and the walls. The average illuminance in the lobby is 150 lx, with additional light picking out certain areas or meeting specific use requirements when necessary.

The coloured glass panels play an active role in the nocturnal lighting system. The beams of light form an irregular pattern above the pink or blue transparent, translucent panels then take on colour as they pass through the glass roof. These hues combine

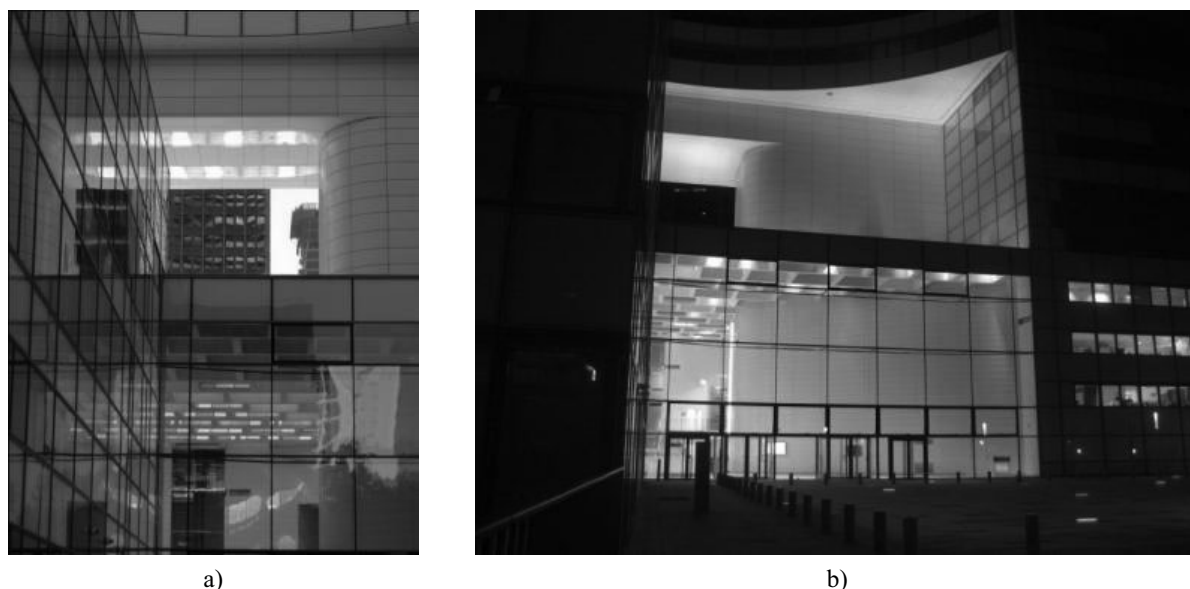a)   b)

Fig.7. Daytime view from the north square: a) the sun's rays are reflected in gold by the blue dichroic panels mounted under the bridge structure; b) night-time view from the north square, showing the illuminated bridge structure above the lobby

in space, suffusing the visitors in delicate variations of pastel shades.

In the centre of the lobby, two large vertical panels are flanked by two lines of LED lights (8 metres tall). These four vertical lines are brought to life by colour variations in complementary shades (emerald green to deep blue on the west side; pale orange to reddish-pink on the east).

The transparent lift shaft running up to the auditorium and business centre is also lit by coloured LEDs.

A colourful nocturnal effect with uplighting outlining the bridge-like support for the Tower

Visible from the lobby and from the wide public esplanades in Courbevoie and La Défense, the bridge-like support structure is an emblematic sight. The Tower is now free of its previously cumbersome volumes and is clearly identifiable by pedestrians close by and from a distance.

At night, the image reverses the daytime perception of the building, emphasising the open space created beneath the Tower by means of dynamic blue uplighting that accentuates the underside of the structure, its side walls and its recesses, Fig.7.

It is the empty space created by the bridge-like structure, which is flanked and bounded by the coloured light, giving pedestrians a mysterious, unusual view from the lobby up through the glass roof and from the square in front of the building.

The coloured lighting varies very slowly in tone from deep blue to cyan, thanks to variable colour LED floodlights mounted along the walls above the glass roof and on the roof terraces.

Roger Narboni, light designer, Director of *Concepto Studio* organised in 1987, author of term "consepteur lumier", master in city illumination and author of some books in this field. More than 80 well known and awarded projects were realised by him and his studio. Roger Narboni is a lecture in field of light design at the special schools in France

Virgine Nicolas, light engineer, manager of architecture and indoor illumination projects and projects of public places illumination in *Concepto Studio*

Roger Narboni and Virginie Nicolas

A Light Trap in the Lobby of the Eqho Tower in Paris La Défense

Fig.1. "Eqho" tower in Paris La Défense
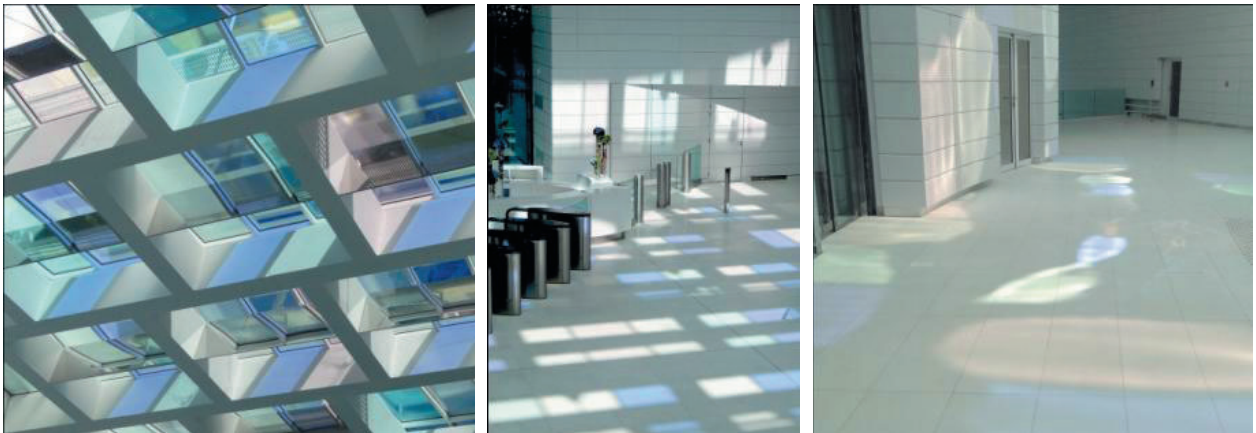
Fig.3. Left to right: system of vertical mirrored panels – Direct coloured projections – Deformation of the light by the mirrored panels on the mezzanine

Fig.6. Installation of floodlights above the glass roof – Pastel shades on the ground floor, in the lobby – Coloured vertical lines in the lobby and access corridor.

Eugene Kh. Allash, Dmitry S.Varga, and Leonid G. Novakovsky
Modernisation of Lighting Devices for Underground Rolling Stock

a)   b)
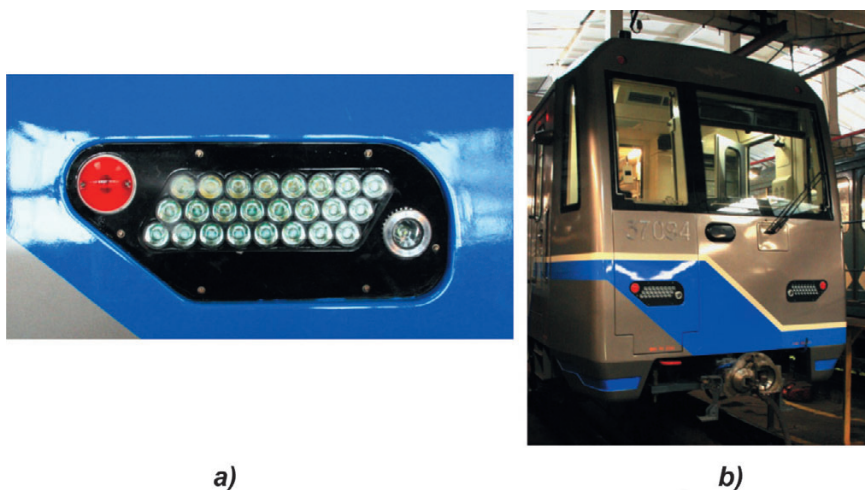
Fig. 2. Appearance of the light-emitting diode headlamp unit

Fig. 3. A retrotrain of A series

a)

b)

Fig. 4. Headlights of A series underground car: a) – before modernisation: b) – after modernisation

Fig. 5. Light distribution of a «retroheadlight» with car xenon MHL

30

Fig. 6. Location of the traditional and modernised headlights on the cars of models 81–717, 81–717.5, 81–717.5 M: a – on the 81–717 car; b – on the 81–717.5 car; c – on the 81–717.5 M car; a', b'and b' – the correspondent modernised versions
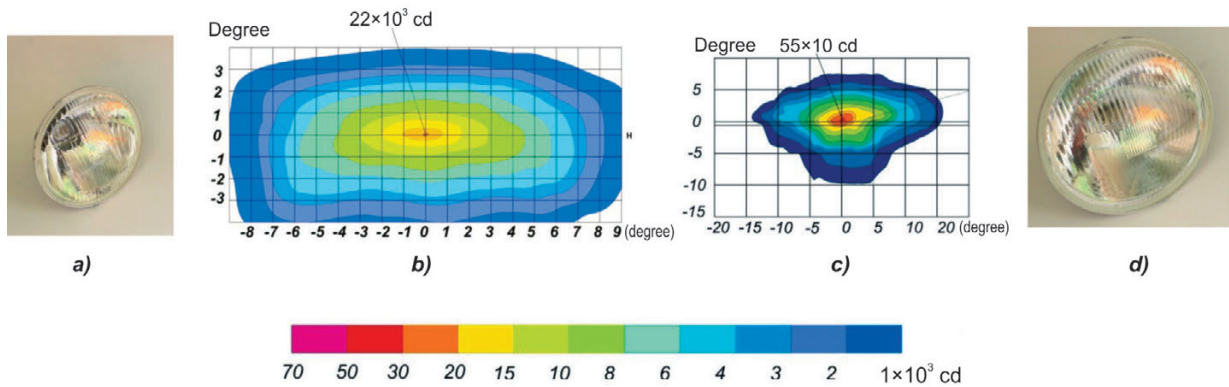
Fig. 7. Headlights of cars 81–717.5 and 81–717.5 M: a – appearance of headlight ФГ145 (0145 mm); b – light distribution of headlight ФГ145, c – light distribution of headlight ФГ122; d – appearance of headlight ФГ122 (0170 mm)

Fig. 8. Modernised headlight Аlf cars of models 81–717, 81–717.5 and Ми 81–718: a – appearance of headlight of cars 81–717 and 81–717.5 M; b – light distribution of one headlight; c – total light distribution from six headlights; d – appearance of headlight of cars 81–717.5

Valery V. Aurov, Mariya D. Bausheva, and Nikolai I. Shchepetkov

The Light Image of High-Rise Buildings
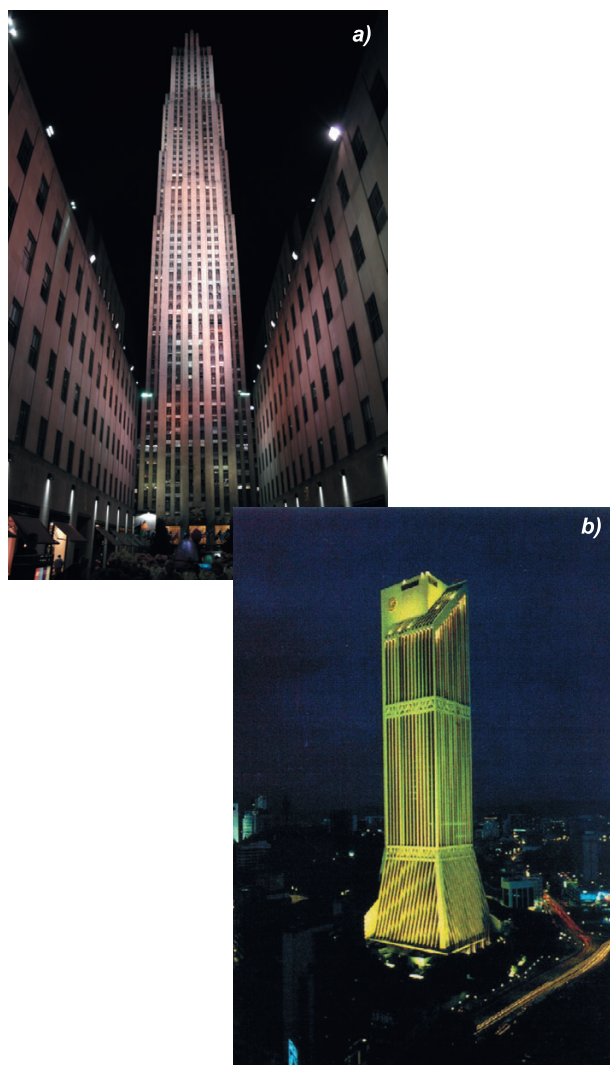
Fig. 2. Floodlight illumination:
a) – a building in the Rockefeller-center ensemble (light devices since 1984); b) – an office building of the Bank of Malaysia, Kuala Lumpur (end of the XXth – beginning of the XXIth centuries)

Fig. 6. Luminant facade:
a) – an office building of the Sony-center in the Potsdamer Platz ensemble, Berlin (2000); b) – the Agbar Tower office building in Barcelona (2005)

Fig. 4. Local illumination:
A light view of Manhattan, New York, with illuminated silhouette finials of some skyscrapers (the Empire State Building, the Chrysler building, etc.)

THE LIGHT IMAGE OF HIGH-RISE BUILDINGS

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ABSTRACT

The light image of city architectural objects observed in daylight dramatically changes at night with artificial illumi nation. The formation of an expressive light image is the creative task of a light designer, and it is especially important in the case of high-rise buildings and constructions, which usually serve the dominant structures in lit views and perspectives of a night city. The principal methods and ways of a light-and-colour composition of facades are considered with different interpretations of the set task using the example of one of Moscow skyscrapers. A short review of the global experience of architectural illumination of high-rise buildings is given.

Keywords: light image, high-rise building, skyscraper, architectural illumination, light silhouette, lighting parameters

Creating images is one of the greatest demonstrations and properties of perceiving works of art, including architectural objects. As they are created, interpretive and informative perceptions of forms and material impact the observer. In architecture, these images reflect the spatial characteristics of the object, in other genres they can be pictorial, musical, literary, etc. These effects are characterised by their strong first impression, and remain in the memory finding generalised features, and sometimes also a symbolical sense through engaging the imagination, experience, associations and so on. Historically, architectural styles were governed mostly be a certain specific style of image solutions reflecting the inherent spirits of each era. In the process of perception of architectural constructions the light information seen by an observer's eye produces the main impact of the visual impression. This information is "transmitted" by architectural forms into the natural environment under conditions of natural or artificial illumination. Without light these forms are emotionally dead: the light transforms architecture into an imaginative art.

High-rise buildings are increasing in number in cities around the world and their architectural image is dominated by the perception of the vertical, which has always attracted attention, from the times of ancient menhirs and Egyptian obelisks. Therefore, in urban architectural compositions, high-rise buildings usually play a dominant role. According to the theory of a Spanish sociologist M. Kastels, high-rise buildings and constructions designate architectural space as "space of a place". Probably because of the fact that "vertical is the main axis of a human body" [1], a high-rise construction symbolically expresses the greatness of a person using architectural and artistic images on a grand scale. It is obvious in daytime, when the vertical of such a construction dominates over the neighborhood against the light sky as, for example a skyscraper in Montparnasse, Paris, and it is less expressed, when this vertical is built into a group of other high-rise buildings such as the Empire State Building in Manhattan, New York. But everything changes at night, with an arti-
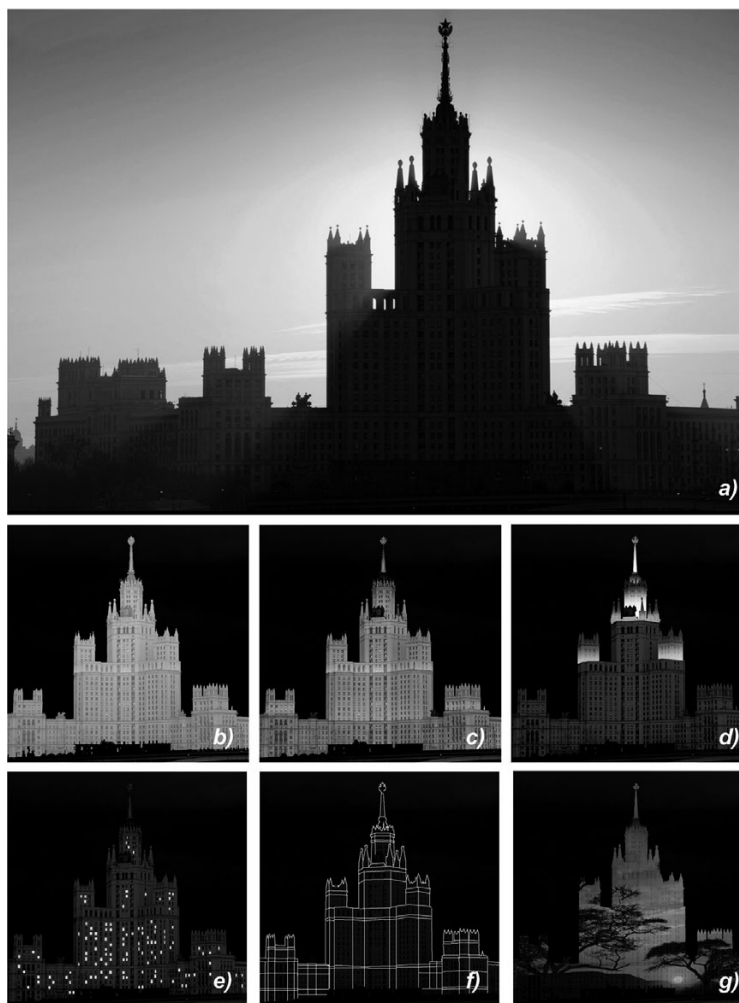
Fig. 1. Schematic versions of illumination of a stepped high-rise buildings:
a) – light (negative by luminance contrast) image of a "skyscraper" at daytime (sunset) illumination; b) – floodlight (luminance positive, reverse) simulating a daytime prototype, with a gradient luminance increase and chromaticity change of light from the bottom upwards all over the height of a building for its mass (weight) to be illusory lighten; c) – local floodlight with gradient change of luminance and chromaticity within each step, but with retention of a constancy inherent in daytime illumination of an average luminance on the all steps; d) – local illumination of the crowning silhouette part; e) – "light graphics" of lines tracing contours of the basic volume-plastic elements of a building; f) – spontaneous "punching" of luminant windows; g) – projective "light painting" on facades not connected in any way with architecture of the building

ficial illumination. An unilluminated skyscraper can lose its compositional role completely, and quite often, an illuminated but minor object of a less height will visually dominate in this context. In the city environment, skyscrapers, which are too tall to be perceived into heir entirely by people, even in daytime, because of distortions in perspective and shielding by other buildings. From a distance they are perceived as "silhouette images" in panoramas.

To assume a dominance in the illuminated environment, the important parameters are important for a building: the height and dimensions in daytime illumination, silhouettes, tectonic characteristics, volume and shape, façade colour. Any of these features

by the will of the lighting designer can present (or not, as the case may be) the buildings original interpretation under artificial illumination conditions. As a result, an evening light image, which is similar by association to the daytime image, will be easily recognised. Decorative illumination methods, which drastically change the visual parameters of an object, will make the building difficult to recognise, going as far as its illusory disintegration, more often found in light video-mapping shows. When selecting the methods, means and characteristics of a dominant illumination, the main aspects of its perception as existing in a real urban setting must be considered. These aspects are as follows: its land-
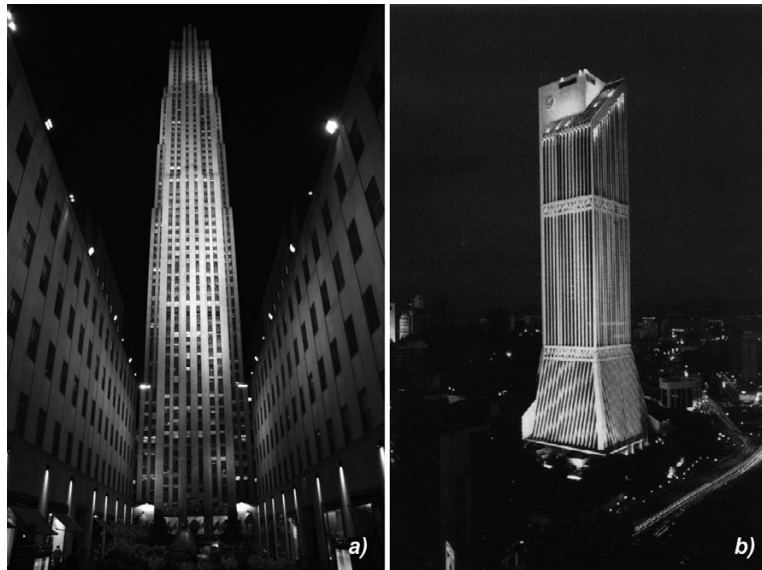
Fig. 2. Floodlight illumination:
a) – a building in the Rockefeller-center ensemble (light devices since 1984); b) – an office building of the Bank of Malaysia, Kuala Lumpur (end of the XXth – beginning of the XXIth centuries)

Fig. 3. Locally- fllodlight illumination:
a) – the highest for today Burj Khalifa skyscraper, Dubai (2013); b) – a high-rise apartment house on Kudrinskaya square in Moscow (light devices since 1995)

scape scale (light views and deep perspectives, as well as a significant distance of an observer from the object), an ensemble scale (average distances and anticipation of "immersing" a person into the light ensemble medium), or a chamber scale (small distances, expressive foreshortenings, some general sensations of a pedestrian who is in a general light space with the dominant feature). These aspects should be determined when developing the general light plan of a city or of a light ensemble and taken into consideration when carrying out bespoke illu-mination projects. In all such cases, the basic ques-tion arises: how should different parts of the façade, or a harmonised light ensemble be illuminated? This is a complex question, which requires imaginative consideration of each object's optimum visibility, starting with the dominant object, from the selected observation points, taking into account foreshort-enings, observation distances and adaptation lumi-nance of the observer's visual field at these points. The standards prescribed in Russia give a rather ap-proximate answer to this complex question. Further

Fig. 4. Local illumination:

a) – a light view of Manhattan, New York, with illuminated silhouette finials of some skyscrapers (the Empire State Building, the Chrysler building, etc.); b) – the Eiffel Tower, Paris (light devices since 1986)

questions follow on from this main issue, concerning method selection, chromaticity and dynamics of architectural illumination, gradients of luminance and chromaticity, as well as of the light pattern. Usually the lighting designer finds answers to many of these questions in the process of empirical light simulations. Today he/she can do thi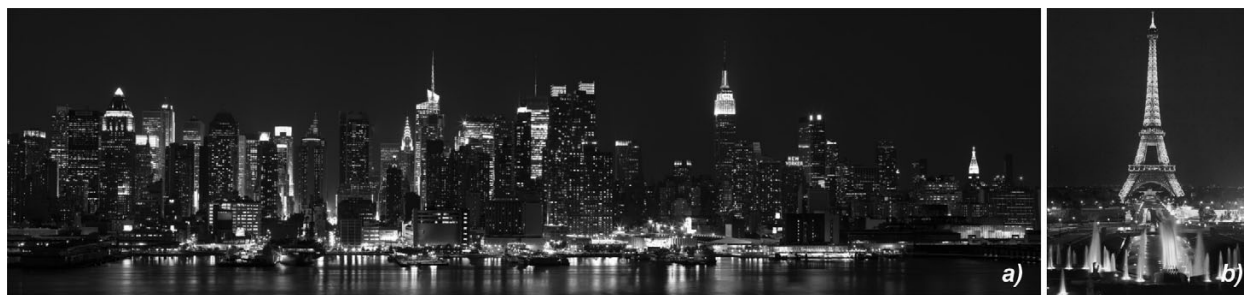s with computer visualisations. 15 or 20 years ago he/she had to resort to a much more labour-intensive method: with paper, brushes and paints, pastel, ink and other traditional materials of fine art or by light simulation on a projection screen, or using a model. Whether the most successful light image of this object can be found depends on the skill, talent and competence of the light designer. There are two "pitfalls" here: firstly all lighting designers in Russia are self-taught persons, because such a profession has not been recognised in Russia until recently. Secondly, the finished light image is not necessarily similar to the one drawn and not always fully co-ordinated.

The conceptual project of architectural illumination of the Moscow-city ensemble, which was quite an expense for the city budget, was widely promoted and exhibited, receiving multiple awards from 2005 until 2007, and the project of the colour solutions, came down to just a book graphics; a design fiction, far from any real capabilities or results, which was clear to the professionals at first sight. The project was completed by Svetoservis and Mosproject-3 companies under the general management of the chief artist of Moscow I.N.Voskresensky. Many people fouled up with illumination projects of similar objects, because it is impossible to predict how a high-rise building will look at night without participating directly in the development of its facades and systems of inner and external illumination, as well as without the experience of an analytical work connected with observations, photometric measurements and analysis of the implemented projects. One

should at least study photographic materials of light-scapes of global cities, specially in the USA, where every big city has its own Downtown. Spontaneously developed light views of these cities often present impressing pictures (especially against a sunset sky) including the chaos of luminous windows. There are plenty such materials available on the internet and in printed publications. Rare "touches" of a special (architectural) light on some buildings supplement this light punching, but essentially do not change its nature. The authors of the Moscow-city ensemble illumination system completely ignored this feature. As it could be expected, in reality, one more night mini-Manhattan was created, and it was far from its best copy. Besides, unfortunately it "absorbed" a high-rise business center office building by the light design near the Bagration bridge.

Due to the fact that many skyscrapers were constructed in Moscow during the last 20 years, or are currently in design and construction, naturally the question arises of their role in the modern light view of the capital and about their individual light image. The Research and Design Institute of the General plan of Moscow determined the total number of the skyscrapers in 1995–96 using the Comprehensive programme of high-rise building up to 2020. According to this programme, their would be 228 objects, of which 92 exist already. This programme is not mentioned today, but construction of high-rise buildings continues. In 2004 within Mosproject-3[2], we accomplished a conceptual project "Proposals on formation of a light silhouette of the designed high-rise buildings and of large-scale public ensembles". By doing this we tried to solve the problem of the creative coexistence of the light silhouette of Mos-

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[2] The conceptual projects are developed in Mosproect-2 and Mosproect-3 accordingly under author's management of N.I. Shchepetkov.

Fig. 5. "Light graphics":
a) – Dubai Marina district in Dubai with the Infinity tower and others, including illuminated as in Manhattan;
b) – the Downtown Burj office building, Dubai: a combination of the light graphics and local lighting

cow formed by the end of the XXth century, with that being formed today, which is more large-scale and massive. The new one being brighter, colourful and dynamic in both day and night time effectively destroyed and "knock down" the visual historic silhouette, which is smaller in size and more has more honest lighting parameters. By that time, the visual reconstruction of Moscow's historical silhouette was almost completed. Based on old engravings, the historical Moscow silhouette was typically "spikey" with its spires, angular roofs, domes, crosses and towers, which were illuminated according to our concept of 1993, with a gold-ish light from sodium lamps reviving the symbol of the gold-domed Moscow[3].

Unfortunately, the Moscow City Architecture Committee did not understand and were not interested in options of a light and colour zoning of highrise buildings within the night silhouette of Moscow, which would enable recognition in the light views and images the history of Moscow's extensive buildings, as well as facilitating spatial orientation of a person in the city. It is obvious that this problem still remains important, especially in the context of the prospective development of the "Big Moscow".

Illumination of stand-alone high-rise buildings, taken out of the typical historical light context, can be methodologically classified by the methods used into several groups. The oldest methods are from the American practice of turn of the 20th century, when skyscrapers and electric light appeared: a) floodlight searchlight illumination of a facade all over its height or local floodlight illumination of its crowning part. Sometimes coloured light filters were used on different steps of the skyscraper [2], because only incandescent lamps and arc candle lamps existed at the time; b) contour illumination, which is simplest from the technical point of view, using garlands of low-power lamps. This was followed by light graphics method; using various light patterns on the facades of solid lines, dotted lines, points, grids based on modern discharge lamps and of light-emitting diode cords operated in different dynamic modes; c) facades of glazed skyscrapers illuminated with a programmed standby interior light, the symbol of which in the 1950 s was the Lever-house (architect G. Banshaft) and the Seagrem-building (architects L. Mies van der Rohe and F. Johnson, as well as light engineer R. Kelly), New York.

With the development of light engineering texhnologies the method of light painting was added to the methods above as powerful light projections onto facades. Recently this method was followed with the video-mapping animation style of light shows (N. Shoffer in the 1960s and Jean Michel Jarre in the 1990s–2000s on building facades of La Defense ensemble in Paris, of the Moscow State University buildings in Moscow, etc.). One should also note the method of a self-luminating façade acting like a TV screen with different solutions of a media facade, including interactive ones. Obviously, this approach is of a far-reaching importance [3].

Fig. 6. Luminant facade:
a) – an office building of the Sony-center in the Potsdam Platz ensemble, Berlin (2000);
b) – the Agbar Tower office building in Barcelona (2005)

The effect of these vanguard light-design facilities used on high-rise building facades is doubled due to the dominance of these objects in the evening city surroundings.

Whilst classifying light-composition methods of illumination for high-rise buildings, several basic variations on the known methods of architectural illumination can be proposed, versions of which already exist in cities around the world (Fig. 1).

In these cities interpretation of their dominating vertical and sensations of gravitation connected with it, of static and dynamic forms, their stability and instability, mass and weightlessness, whether intentionally or not, is expressed or should be expressed in their light image ascreated by lighting designers. Floodlight illumination (Fig. 2)[3] dominated the world practice of architectural illumination, including in Moscow, on the so-called Stalin's skyscrapers during public holidays from the 1960 s to the 1980 s, and had high energy consumption (it used searchlights with powerful incandescent lamps). This created a prominent, easily recognised image of buildings, which closely resembles the daytime image under the direct sunlight. This type of illumination can be relatively uniform all over the height of a building, as it is over the 160 meters of the Washington monument in the US capital, or non-uniform as a gradient on many buildings, with luminance increase from the top to down or in reverse. The impression of its dynamism and mass depends on the all these factors. It is yet to be empirically determined what luminance levels and vertical luminance distribution, as well as what gradient provide an optimal effect of visual dynamics of an object and sense of its solidity or lightness in comparison with the daytime perception. In many constructions stepped in structure (such as Moscow's skyscrapers or Gothic cathedrals), their mass becomes visually lighter higher up, creating an illusory dynamic in daylight. This illusion can be made stronger or fade under artificial illumination at night. This means a change in the average luminance at each step and its change over the building whole height, the luminance value gradient within each step, as well as on the whole over the height of the skyscraper, and changes in light chromaticity at different steps have the most important significance, which became obvious due to our experience during the 1990 s on the skyscrapers of Moscow.

Some examples of local floodlight are given in Fig. 3.

The local illumination of some fragments of a high-rise building, most often of its crowning part (Fig. 4), can be termed American. Only one building of the Rockefeller-center in New York, which is not the highest in the city, is floodlit through the height. Some other skyscrapers of Manhattan are only illuminated at the top, which is typical for light silhouettes of other cities of the USA as well, or for example, for Dubai in the United Arab Emirates.

The light graphics method (Fig. 5) is decorative, because it does not reveal in any way building structure, but it can clearly trace the silhouette of a building and so effectively express its vertical component, even its anti-gravitational dynamics. As an example, one can remember colour light lines running from the bottom upwards at the corners of the Infinity office building in Dubai twirled a la Calatrava [4].

Though the number of completely glazed skyscrapers in the world is growing, they are seldom luminant as the new Seagrem-building, the original illumination of which does not function as well nowadays.

Obviously, "splashing out" such a quantities of light into space and "polluting" atmosphere over a city, has become unfashionable, uneconomical and energy-inefficient. In the event of using the luminant façade method (Fig. 6), certainly effective, a "light-emitting" building visually loses its mass, becomes weightless though its inner structural-tectonic basis, which is not visible in daytime, is appeared to be rather truthful, informative but applicative. This method exactly, a century before had generated the universal term "light architecture", which is now more and more replaced with the separate term "light design" for artificial illumination conditions.

The huge expressive potential of high-rise building and construction light design is far from being exhausted neither in creative, nor in technological relations. It is a pity that quite often, people of little skills and experience but self confidence undertake the development and approval of these projects. As a result, we are where we are. Try to name a new skyscraper in Moscow, the illumination of which would be pleasant to many people. Sometimes passions ran high within professional discussions concerning imaginative qualities of skyscrapers, but traditionally (and intuitively) at daytime illumination! Architect authors without doubting for a moment, give complete control of the second man-made shape of the night-time image to God knows whom, or do not remember it at all. And this is apathy.

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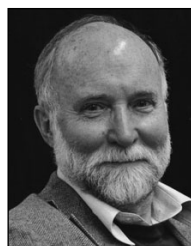
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[4] The "twirled" or "spiral" shape of a high-rise residential building for the first time was created by a Spanish architect S. Kalatrava in Malmë, Sweden. Then its "doubles" began to appear in different cities including the Moscow-city ensemble.

LIGHT AS AN INSTRUMENT FOR CREATING VIRTUAL IMAGES IN ARCHITECTURE

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ABSTRACT

Light as a construction "material" has been used for a long time as the main component of a visual image. The architectural music, set in stone, can be only seen in the presence of light. But light does not only make the real world visible, it can also simulate a virtual world. This use of light was first explored four hundred years ago, during the baroque era, when devices like the microscope, telescope and magic lantern were first invented, and images were first projected by means of the latter. Today we can create static and dynamic illusory images in architecture, which are capable of beginning a visual dialogue with the observers.

The key characteristics of such illusory spaces are their temporal nature, multi-variance and sense of spectacle.

Keywords: light, architecture, virtual space, visual illusions, illusory images, epoch of the baroque, innovations in architecture, light design, *3 D* video-mapping, media facade, holography

Architecture, as an art form, has always kept up with technological progress. This is also true today. The development of digital technologies allows exploring methods in architecture, which previously weren't connected with it. Modern computer and light technologies make it possible to introduce static and dynamic virtual images into a physical space, which can begin a visual dialogue with the observers. It becomes especially interesting to track the origin and development of methods for simulating virtual space in architecture, which use light as their main instrument and material.

A well-known statement from the outstanding architect Konstantin Melnikov says: an architect should be able to use the features of a human eye, "to play on the eye of a spectator as on an instrument", just as a composer accounts for the peculiarities of a human ear – "plays on ear". Problems of human sight have worried people for a long time. According to Euclid's writings, ancient optics tried to express a connection between real objects and sensations combining visual images of an observer. Euclid postulated that a person feels objects, when linear rays emitting from them converge on the eye, and consequently that the system for sight rays can be imagined as a pyramid, the vertex of which is located in the eye, and the objects observed as its base [1].

Over time, understandings of visual perception changed. Galen, the court physician of emperor Mark Aurelius, is known to have said that rays go out from the eyes, which touch objects as though with a thin invisible stick to feel their shape. Then, in the tenth century, a famous Arabian mathematician and physician Ibn al-Haisam (965–1039) known in medieval Europe as Alhazen, asserted that eyes do not radiate any rays. Rather, on the contrary objects send rays to the eyes from each of their particles, and each ray excites a correspondent point in the eye's crystalline lens [2]. Here again many rays are gathered into one pupil. The wealthy Italian Giambattista della Porta (1535–1615) improved the camera obscura, which he compared with an eye. A little later, it became possible to design complex optical devic-

Fig. 1. St. Paul's Cathedral in London, 1675–1708

es: the telescope and the microscope[1] based on the principle of the eye, as well as a magic lantern – a light device used as the first projection camera. This last invention can be considered as the origin of cinema, which later exerted the strongest influence on architecture.

The structure of the eye represents a hollow sphere with a pupil lens on the one side and a concave inner retina surface on the other. Light fluxes reflected from objects arrive to the lens and are projected on the eye's retina as an image. That is, an eye simultaneously absorbs, refracts and displays light. Book [3] has studied the architectural shapes of the baroque era and compares the eye's structure with the structure of the dome in cathedrals of that period, where the crystalline lens perceiving and transmitting light into the temple interior, was placed at the dome's summit. The author John Hersey illustrates this comparison using a picture by Descartes, on which a huge human eye drawn to scale of an architectural structure, is oriented upwards together with the person looking through it [3, p. 57].

Thus the light lantern at the top of the dome is the divine all-seeing eye, which observes and sees everything which happens under the cathedral's roof. The supreme being blesses all the people who gather below. The congregation images, pictures on the retina of the divine eye. It sees them. The people observe light fluxes streaming through the lantern or crystalline lens of this eye. Ceiling paintings visible

through this light represent the sky and its inhabitants, thereby creating an illusion of the real world in the heavens. And light here is not only a virtual conductor between the earth world and the heavenly world, through which a parishioner finds himself able to communicate with God. Light is also a real instrument to create a mysterious, secret and at the same time, captivating world (Fig. 1).

The first example of this type of play with space was the picturesque method *trompe-l'oeil*, wherein a single wall plane becomes prominent, and further with the discovery of the linear perspective, illusory effects were strengthened with the emergence of the infinite depth of the represented. Finally, in the process of creating illusory space, technologies and engineering devices were developed which allow transmitting motion.

As has been noted above, an eye was the model on which the devices invented during the baroque era were based: the telescope, the microscope and the magic lantern. The all three devices use projective geometry to transmit images. J. Hersey wrote: "All three instruments were masterful manipulators of light. They collected, filtered, reflected, condensed and refracted it. More importantly, all three instruments projected images. In microscopes and telescopes, light acquired a new importance as a substance opening previously invisible worlds: with microscopes – the world of small subjects; with telescopes – the world of unprecedentedly huge sizes [3, p. 60]. J. Hersey wrote that knowledge in optics and in designing optical devices greatly influenced the structural architecture of cathedrals and churches. He compared the longitudinal sections of the churches of the time with an optical device, where lenses are

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[1] Galileo Galilei developed a microscope, which he named *occhiolino it.* – a little eye. The microscope and the telescope were understood as additions to the eye, opening unprecedented previously unseen worlds.
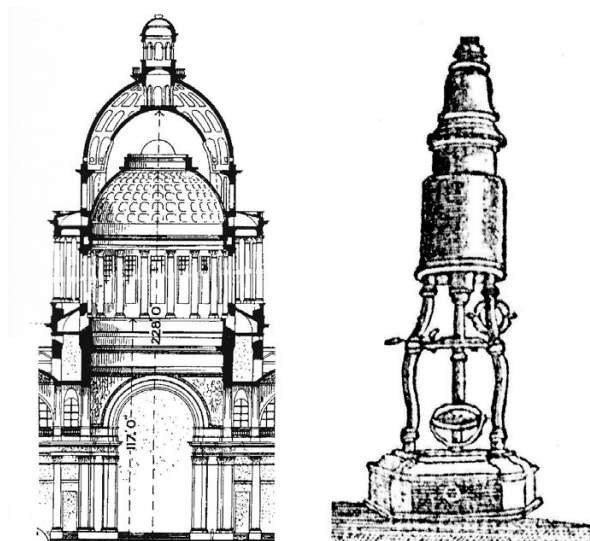
Fig. 2. Pantheon in Paris. A cross section fragment, 1758–89 (at the left) and an optical device image, 1750

built along one axis in a certain sequence, and in a cathedral the shells of the dome are built similarly [3, p. 63] (Fig. 2).

What technological solutions allowing for the simulation of the virtual, are currently available to architects? These are *3 D* video-mapping, media facades (media ceilings, media walls, media floors, etc.) and holography.

3 D **video-mapping** is a technology, which allows projecting static and dynamic video images onto different surfaces, including the facades

of buildings. Often the plasticity of the facade itself does not matter at all. The video-mapping effects are based on the laws of optics and on the physiology of our visual perception of space. We see not because we use our eyes but by the means of the brain. Eyes are the basic receivers which take in about 85 % of all information, and the brain simulates a complete image from the perceived fragments. Consequently, it can be deceived, for example when it represents 24 static pictures a second as a real moving image.

The technology of *3 D* video-mapping is not an invention of modern architects; it is an old method developed in a new fashion, using new technologies. A Renaissance or baroque ceiling paintings and wall frescoes are illusions of architectural elements, features and space itself which do not exist in reality. They are a distortion or a deformation of space by painting tools [4]. This is the method, which was possible and accessible in those days, and which helped to play with space and to move apart its boundaries. This realistic ceiling painting gives so much energy, dynamics and stage effects! (Fig. 3, at the left). The desire of an architect to amaze and surprise, to make an unforgettable impression on the observer is obvious [5]. Four centuries later, as can be seen in Fig. 3, a reinterpretation of this method is presented but with the application of modern technology. What has changed? Only the technology of representation.
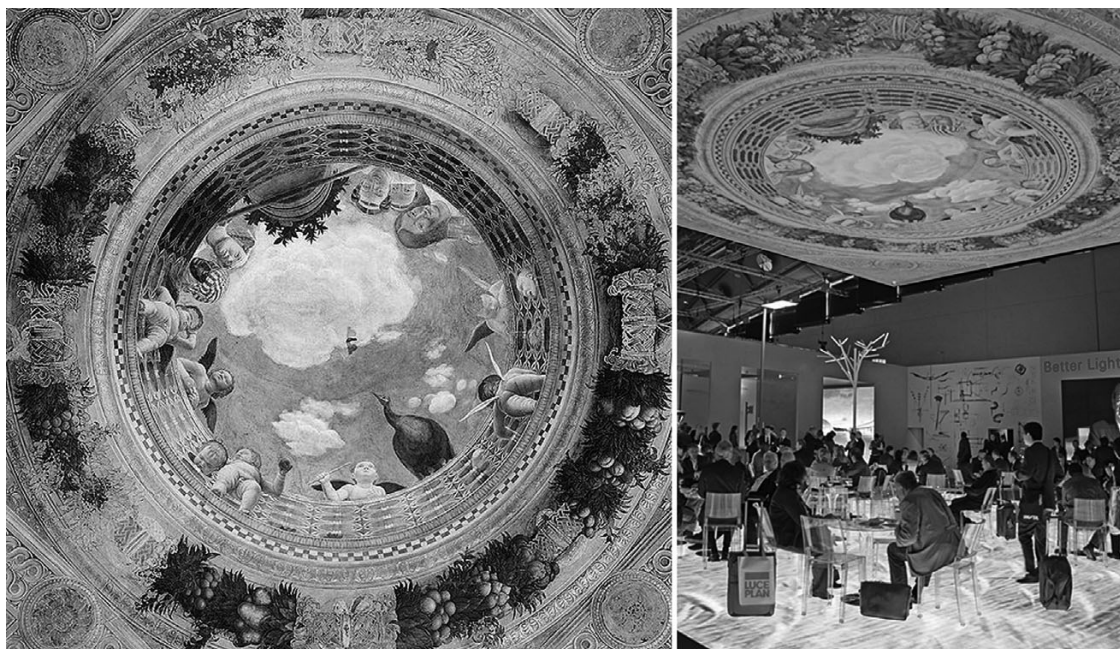

Fig. 3. A ceiling plafond of the Camera degli Sposi (art. Andrea Mantegna, 1474, Palazzo Ducale di Mantova, Italy) (at the left) and a video-mapping example at a light exhibition
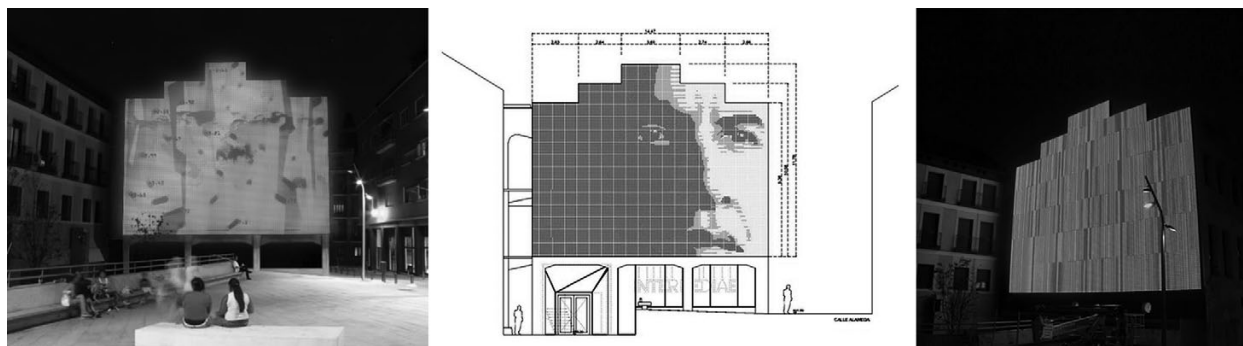
Fig. 4. A building media facade in the center of Madrid

There are some limitations to the video-mapping application. Using not just light and chromatic effects and projecting reasonable images, we still face the obstacle that volume and movement illusions can only be perceived from a certain point of view. The conditions for high-quality visibility of these effects are also limited to the dark times of the day and to spaces where there is no natural illumination.

Many major world cities spend a great amount of money to create a festive atmosphere attracting tourists with artificial illumination effects. A special genre of entertainment presentations appeared, in which important architectural objects and memorials are transformed. There is evidence from the leisure industry that the income from night tourism can exceed that of industrial production [6, p.3].

Using light projections, a building facade plasticity can be totally changed and really effective live scenarios created. Having such technologies at their disposal, modern architects can embody their most bold ideas.

Media facades with huge screens built within the architectural image of buildings, have found a broad field of application in modern construction. Here light as a cinematic art creates a unique memorable image in the architectural space of a city. The surface of the media screens together with the visual appeal, has information and communication components. Pulsing graphics and moving images create an illusion of a living organism which become reference points in the city space at any time. The most effective of these are displays with light-emitting diode light sources, which make media facades readable in sunlight. A building surface is used as an area of reflection and glow. The latter occurs from the outer side of a building surface or from the inner closed with transparent structures, which represent the screen.

What is interesting is that anyone who will take the trouble, can participate in the creation of a media facade image. There are websites, where dynamic images are programmed, or videoclips uploaded, which are censored, and transmitted to the media facade [7]. On specific days, the best works are shown, and such displays attract many locals and tourists (Fig. 4). Such technologies allow not only to influence the city medium, but also serve as a new form of communication between people and the space of the city [8].

An ancestor of these media technologies was the magic lantern invented by Dutch scientist Christian Huygens (1629–1695). First this device was no more than an optical toy that vagrant actors used to frighten audiences with phantoms suddenly appearing in clouds of smoke or on a transparent screen plane [9] (Fig. 5). Such games with light and engineering inventions led eventually to the invention of cinema. Cinema embodies the optical illusion philosophy of reality. "… the surface of a picturesque canvas or screen, which being in two-dimensional planes, can open an illusory depth. These are membranes hiding behind themselves nonexistent volumes" [10, p. 118 and 124].

Shows with display of static, and later animated slides accompanied by text, made the strongest impression upon spectators. Demonstration of light projections to a big crowd of people became art and bewitched audiences with light and motion illusions. Using only the simplest equipment, people learned to simulate virtual worlds, where magic lanterns allowed emmersion in illusions, penetrating deeply into a virtual world. Mikhail Yampolsky, a theorist of art and culture, wrote about the spectators' ability to immerse themselves into a virtual cinematic world: "To use the linguistic term, the **signifiers of** the cinema space are "transparent", they let spectators pass instantly to
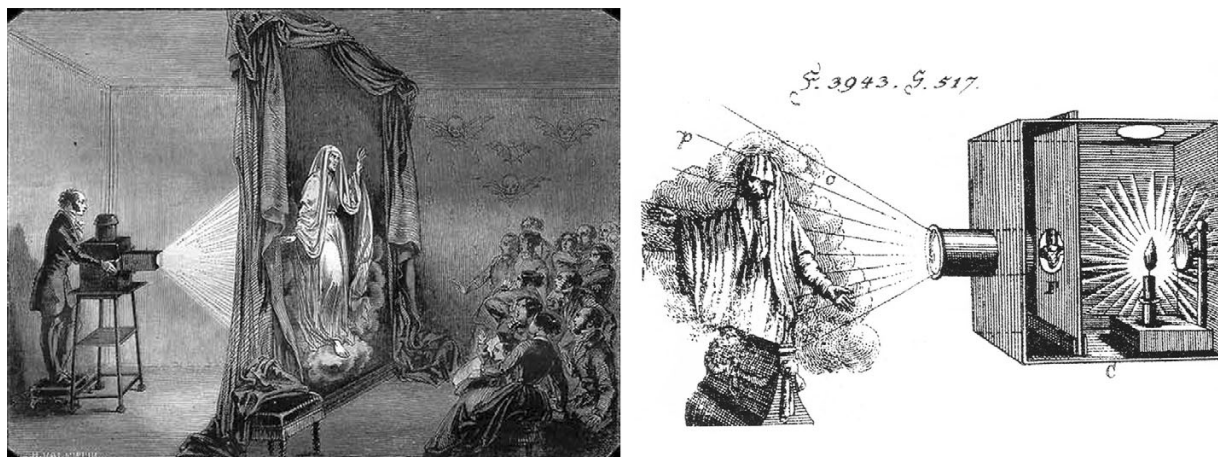
Fig. 5. Examples of magic lantern operation. Projections of light to smoke and onto a transparent screen

the subjects and bodies located in this space" [10, p.126].

Holography allows obtaining the stereoscopic images of objects. One of its advantages is an illusion of three dimensionality allowing object to be observed from different sides. The emergence of true stereoscopic holographic images came about with the appearance of lasers. "When we look at an illuminated plain holographic image containing information on shades, differences in element angles position for the right and left eye, we feel its depth. That is information on an object is turned for the brain as though into the object itself" [11].

Holography in architecture is a technology of the future. Developments in this field and the identification of potential ways of introducing it are ongoing. Only finishing materials with holographic effects are applied extensively. The correspondent plates will be used when finishing a multipurpose ensemble in France, for example (Fig. 6). Incident light will be reflected from a processed metal surface, and therefore the metal will obtain dynamic properties. This effect will be manifested when people move through it, changing illumination intensity or light source location.

As to the introduction of holography into architectural objects in forms other than finishing materials but as a technology, there are no implemented projects yet. Design solutions and ideas exist, but their implementation is impossible for now due to imperfect technologies, high costs and because the economic crisis.

The Asadov's Architectural Workshop has proposed the creation of a virtual architecture museum in Zaryadye, Moscow, where masterpieces of the Russian advant-guard could be exhibited as laser holographic projections. Andrey Asadov estimates that "it would be possible to make a schedule and to show every evening one of the masterpieces of the gold collection of the Russian architecture replacing them once a week. So directly at the Kremlin walls, an incredible futuristic show will grow attracting tourists and in the same time popularizing the heritage of Russian culture" [12]. Another potential application field for holography can be the presentation of design proposals and full-scale models of architectural constructions in conditions of the real medium.

Use of digital and light-dynamics technologies as expressive means in architecture becomes an integral part of buildings in a large megapolis. Consequently, there are fears over super-saturation and the aggressive influence of colour- and video-dynamic architecture on the people, who are already surrounded with noise, chaos and an abundance of audio and video information.

Modern technologies allow for the formation of illusory static and dynamic images in architecture, the key characteristics of which are its temporality, multi-variance and visual appeal. If historic buildings were constructed to exist for centuries, today building images are designed to exist for minutes. Thoughtless and universal integration of computer light- and video technologies into architectural space can transform a city into a huge entertainment park, but not into a comfortable medium for human life.

Despite all the fears, it is impossible to deny the influence of digital technologies on architecture and the architectural medium as a whole, and to make reference to the economic turndown and lack of money for such expensive projects. Architecture

Fig. 6. An ensemble in Saint-Roch district, Montpellier, France (a draft)). Architect Manuelle Gautrand

as an art is not a simple decoration and entertainment, which it becomes today, but also a responsibility to the people living within it for most part of the life. Therefore, studies should consider not just the instruments and their possibilities, but also the phenomenon of virtual reality itself in the architectural medium, as well as its influence on humans. This cannot be done by architects alone; collaboration in this field is necessary between architects, light engineers, psychologists, physiologists, sociologists, physicists, information technology specialists, etc..

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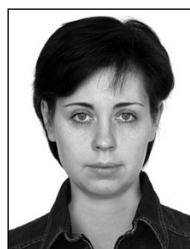
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[2]   Chapter 5 "Optics" of Euclid.

MODERNISATION OF LIGHTING DEVICES FOR UNDERGROUND ROLLING STOCK

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ABSTRACT

The necessity to modernise traditional headlights used on operating underground rolling stock, and the technical feasibility of this task implementation are described. Specific technological solutions developed by FAROS-ALEPH Joint-Stock Company and introduced to various series cars of the Moscow underground are presented.

Keywords: underground, underground car, headlight, light emitting diode, light distribution, luminous intensity, adjustment, optical camera, modernisation

Since 2010 a range of lighting devices with light-emitting diode light sources for application in underground cars have been designed and ready for implementation, which meet all the somewhat inconsistent requirements of underground operation. In work [1], the technological solutions of these devices were described in detail, a new approach to their standardisation was proposed, and values for the main lighting parameters were recommended.

However, by the time of the testing period of the 81–760 model car, its design and consequently the structure of most of its light devices (LD) were already confirmed. Headlights with light emitting diodes (LED) were the only objects of the operational tests as parts of the products, because the headlights would replace the traditional headlight units (Fig. 1).

The tests were performed in accordance with the standard technique; installation of the headlights on a car, adjustment of the light beam position with measurement of illuminance in a check point, and running in a real operating conditions for up to 30000 km.

As a result of the tests it was found that:

• The headlight's lighting characteristics completely meet the standards for comfortable working conditions of an engineer in tunnels;

• When coming to a station, the headlight illuminance level causes blinding of the passengers on the platform.

A conclusion arises: when the train is coming into a station, the driver should darken (dim) the LEDs in order to decrease the illuminance from the head-

a)   b)

Fig. 1. Headlamp units of the 81–760 model underground train: a) – traditional version; b) – pre-production model of the light-emitting diode headlight unit

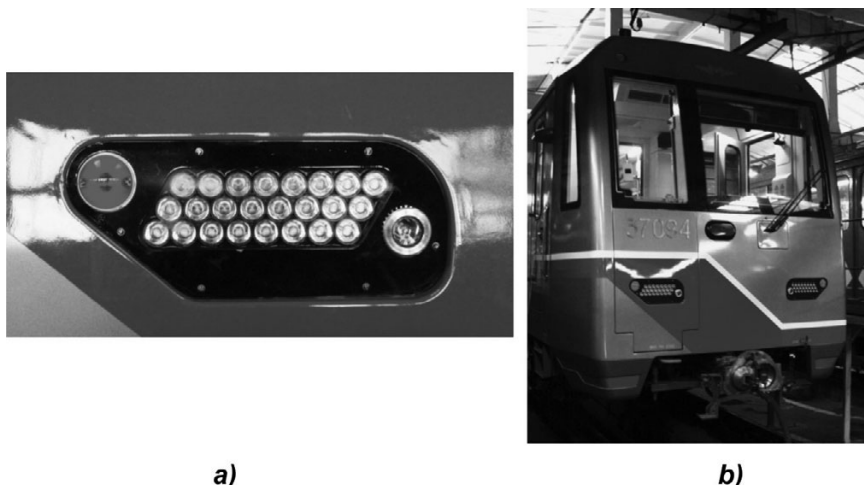*a)*   *b)*

Fig. 2. Appearance of the light-emitting diode headlamp unit

lights on the platform. Obviously, for this purpose the engineer needs to get a signal about the imminent station approach. However, for various reasons, obtaining such a signal is impossible, and the only possible solution is the formation of this signal by autonomous sensors installed inside the headlights.

Obviously to develop such a sensor or to use sensors of a known structure, their functions and operating criteria should be determined. In this case the most simple solution is a solution based on measurement of illuminance change in a tunnel or at a station, i.e. use of an illuminance sensor working out when a preset threshold value is reached. Unfortunately, to use sensors of known structures was found to be impossible because of a limited size of the niche in which the headlight is installed. Therefore, it was necessary to develop an original sensor easily integrated into a headlight of a "traditional" structure, which passed the test. In doing so, an elementary determination of the operation threshold value became a problem.

The reason this problem arose is that instead of standard illuminance for station platforms, which is set at 200 lx [5], the real illuminance at 30% of stations reaches only 35 lx. Besides this, illuminance from separate LDs located in tunnels for various purposes, is 30–40 lx. Therefore, headlights are either not dimmed at 30% stations, or falsely dimmed in tunnels.

This situation can be corrected in two ways:

• The underground system meets the standard requirements [5] at all stations, which is hardly possible, because in some cases this demands a radical revision of the illumination system (transition to other light sources, ballasts etc.), and all of this should be done within a limited time period. The underground system is not ready for this, but sooner or later this should happen all the same;

• Another criterion is used to determine the point at which headlights should be dimmed: for example, an image of boundaries of a station tunnel opening. Development, manufacturing and tests for such a sensor are certainly easier and cheaper, and crucially faster than expectations of the changing illuminance at platforms.

Therefore a compromise decision was accepted: before a new sensor can be installed, to use a sensor, which is already developed and built into headlights, with manual switching on at stations with low (less than 40 lx) illuminance values (Fig. 2).

Thus since January 2013, trains with LED headlights, which have a maximum luminous intensity of 384000 cd, have been deployed to the Moscow underground. This is more than 2.5 times more than the total luminous intensity of all headlights installed on the cars of other models operated in Moscow. The

Fig. 3. A retrotrain of A series

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Table 1

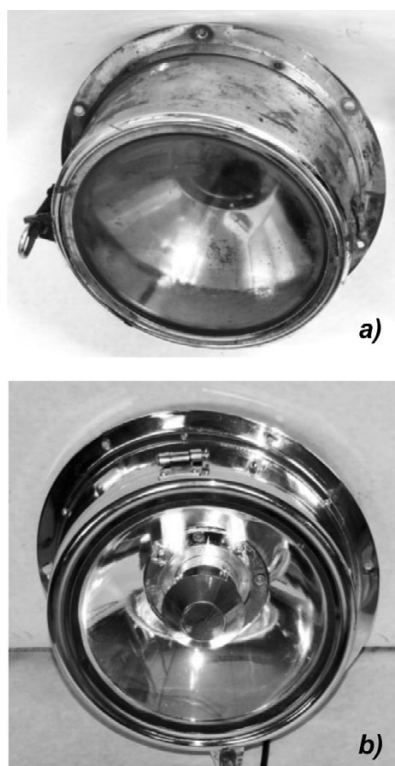| №	Underground cars	Number
1	E series and their modifications	611
2	81–717 models and their modifications	3176
3	81–720 models and their modifications	81
4	81–740 models and their modifications	700
5	81–760 models and their modifications	272

Fig. 4. Headlights of A series underground car: a) – before modernisation; b) – after modernisation

Fig. 5. Light distribution of a «retroheadlight» with car xenon MHL

Serpuhovsko-Timiryazevskaya line is almost completely equipped with them already.

It follows from this that to reach better level of working conditions for the drivers of different underground car models, modernisation of the installed headlights is required.

At present, many cars of different models are operated on the Moscow underground, the operation of which will last ten or fifteen years, and this makes the modernisation problem rather topical (Table 1).

Another reason for the inevitable modernisation of the operated underground car lighting system is the increase of platform standard illuminance up to 200 lx, which sooner or later leads to the operating engineer's discomfort due to the adaptation of the visual apparatus when entering a station.
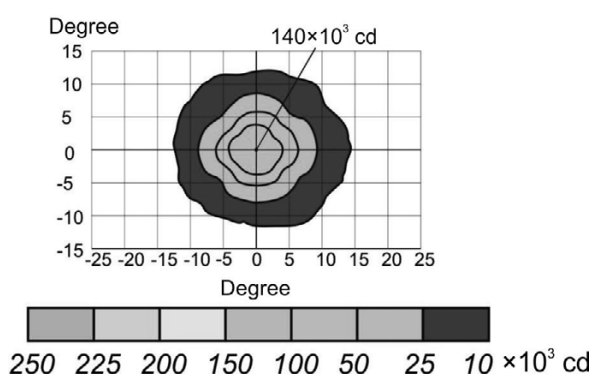
Naturally, with such a stated problem, the quality of its solution will be determined by two things: preservation of the car design and the price of modernisation.

And finally, there is one more archaic requirement to the head lighting system: the requirement, which is rather redundant in the current operating practice, of designing a system as two separately switched on LD groups. This was quite appropriate for «short-lived» ILs.

However, with growth in lamp service life, the operational services began to ignore this requirement, all the more so, one cannot see better in tunnels. Therefore, when using LEDs as light sources, the service life of which is ten times more than for ILs, and taking into account their group redundancy in the light-optical system, retention of this requirement seems to be inapproporiate.

MODERNISATION OF CAR HEADLIGHTS FROM THE 1930ˢ-1960ˢ

A special case among the light devices in modernisation is the headlights of the first underground cars of А, Б, Г and Д series. These are already out of service in Moscow, except for a unique retro train

Fig. 6. Location of the traditional and modernised headlights on the cars of models 81–717, 81–717.5, 81–717.5 M:
a) – on the 81–717 car; b) – on the 81–717.5 car; c) – on the 81–717.5 M car; a', b'and c' – the correspondent modernised versions
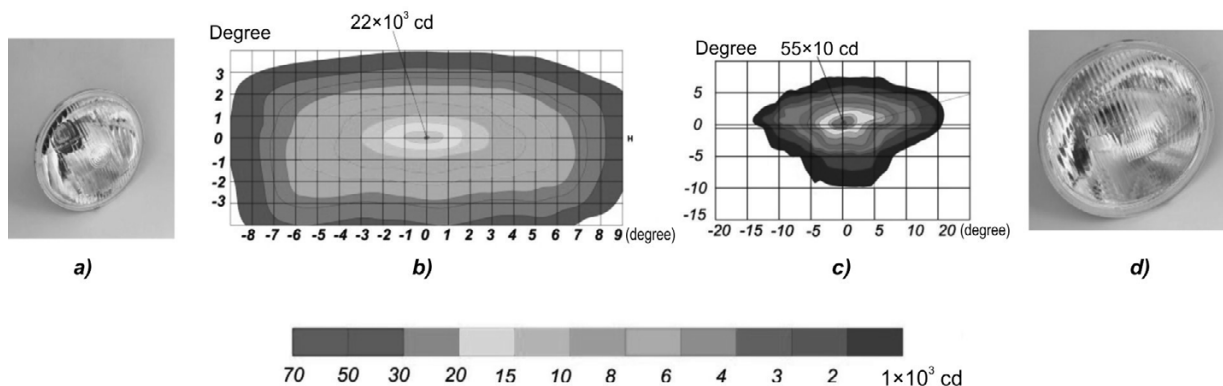

Fig. 7. Headlights of cars 81–717.5 and 81–717.5 M: a) – appearance of headlight ФГ145 (0145 mm); b) – light distribution of headlight ФГ145, c) – light distribution of headlight ФГ122; d) – appearance of headlight ФГ122 (0170 mm)

(Fig. 3), which is an operating historical piece recreated for the 75th anniversary of the Moscow underground. So, the primary goal of the project in this case was the retention of the original appearance of the headlights of the first car, whilst providing modern operational characteristics.

Naturally, the structure of such headlights should contain the same elements used in the original version: case, reflector, protection glass in handling fixture, lock (Fig. 4, a, b). It was necessary to restore them and fill with a new content, i.e. to use a modern light source with a greater luminous flux.

The calculations showed that car xenon MHLs of D series (Osram) with correspondent standard ballasts is the best solution for this purpose.

The modernised headlights with such light sources have provided a sufficient total rail head illuminance from two headlights (Fig. 5), with a reflector of a small coverage angle, ($\varphi = 80$ º). The illuminance value is equal to 3.0 lx at a standard distance of 305 m, convenient adjustment in front and practically excluded blinding the engineer and platform passengers. This was achieved by installing a screen from direct rays in the headlights.

The reached level of luminous intensity allows recommending this system for introduction to the E-series cars, which still operate on the system in a significant numbers.
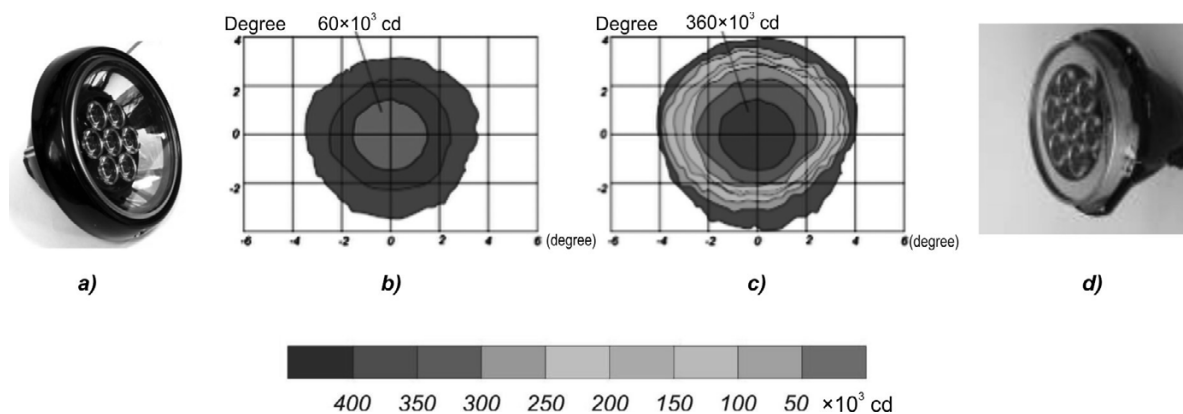
Fig. 8. Modernised headlight of cars of models 81–717, 81–717.5 and Ми 81–718:
a) – appearance of headlight of cars 81–717 and 81–717.5 M; b) – light distribution of one headlight; c) – total light distribution from six headlights; d) – appearance of headlight of cars 81–717.5

Fig. 9. A head car of model 81–720 (Yauza)

MODERNISATION OF THE 81–717, 81–717.5, 81–717.5 M, AND 81–718 MODEL CARS

As distinct from the E-series cars and their modification versions, an attempt was made to significantly improve illumination in tunnels due to doing away with the lamps of «distributed» luminous body in favour of using standard automobile light devices, the maximum luminous intensity which does not exceed 40000 cd. This was carried out on cars of the 81–717, 81–717.5 81–717.5 M, and 81–718 models.

In the beginning with cars 81 717.5 (Fig. 6) manufactured at the Leningrad car-building factory of I.E. Egorov, headlights ФГ-146 and ФГ-145 with the light opening diameter of 145 mm were used. The system contained six such headlights located in pairs on the boards of the car and in the centre of its top part forming three units (Fig. 6).

In the Moscow car version (model 81–717.5, Metrovagonmash factory, Mytishi), these headlights were replaced with headlights ФГ122 of a greater diameter: 170 mm, which gave a certain effect, as can be seen from their light distribution (Fig. 7). However even with the installation of six headlights in various configurations operating simultaneously in cars
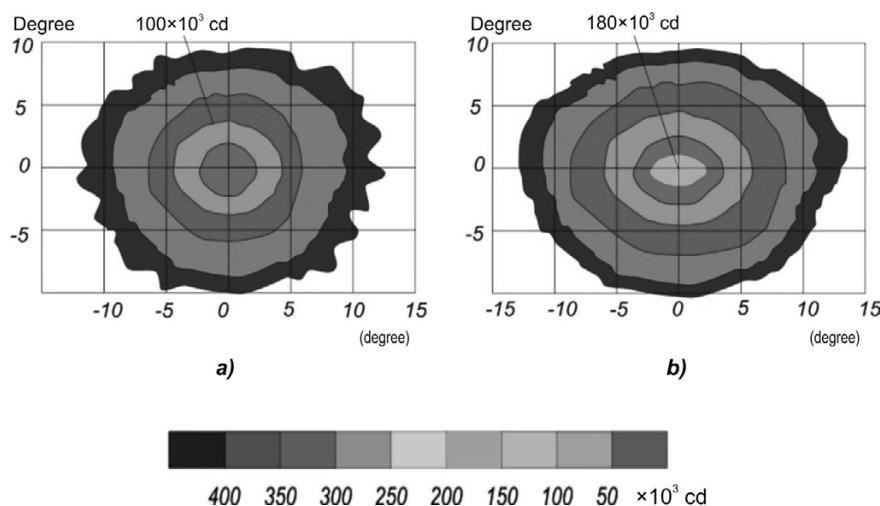

Fig. 10. Light distribution of lighting system of a car model 81–720 (Yauza) installed on the car 81–760: a) – of single headlight; b) – of the headlight system
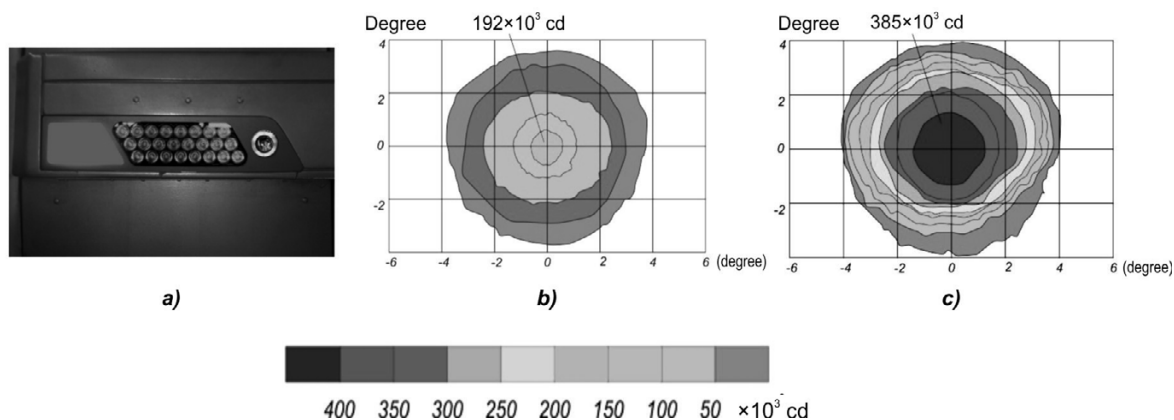
Fig. 11. Modernised headlight of cars of model 81–720 (Yauza):
a) – appearance of a headlamp unit; b) – light distribution of one headlight; c) – total light distribution of two headlights
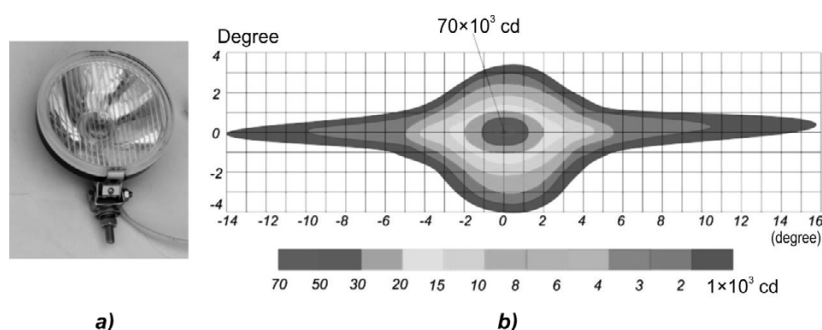

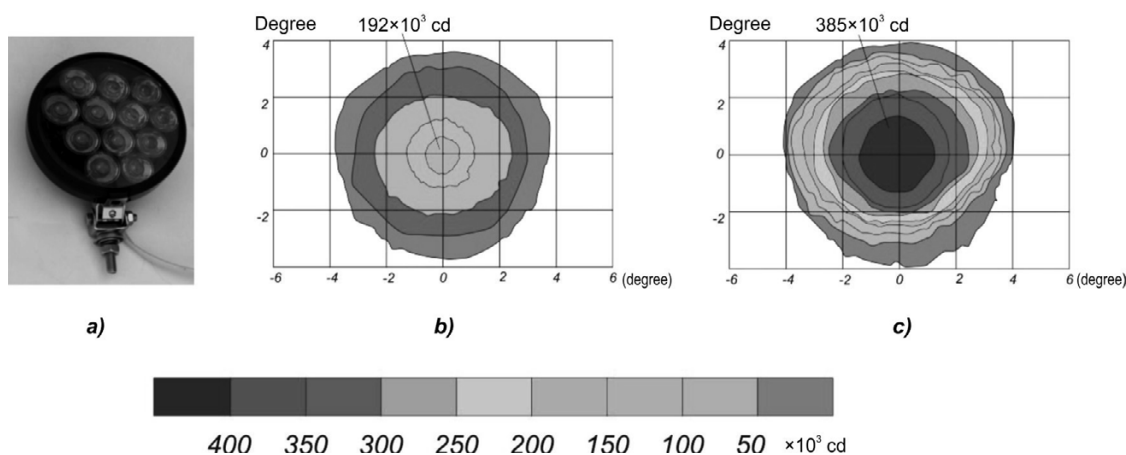Fig. 12. Headlamp unit of cars 81–716.6 and 81–740: a) – appearance; b) – light distribution

Fig. 13. Modernised headlamp unit of 81–717.6, 81–740 model cars:
a) – appearance; b) – light distribution of one headlight of four-headlamp illumination system; c) – total light distribution

81–717, one can obtain maximum luminous intensity of 180,000 cd, which is essentially less than what was reached with the above mentioned LED headlights on the 81 760 model car.

Therefore, to solve the problem of improving the drivers' working conditions in underground cars of different models, an attempt was made to raise the illuminance level in tunnels without significantly changing the design of trains, i.e. to develop a re-volutionary lighting system in the "old packing" for light opening of 145 and 170 mm diameters.

A satisfactory design solution (Fig. 8) for these car models was found when using elements of standard cases of traditional headlights and of the same modules with LEDs and secondary optics, as in the basic structure of the headlight for car 81 760. This solution provides maximum luminous intensity of 8000 cd. Also in this design version, heat remov-

Fig. 14. Location of traditional and modernised headlamp units on cars of models 81–717.6 and 81–740:
a) – traditional headlamp unit on car 81–717.6; b) – modernised headlamp unit on car 81–717.6; c) – traditional headlamp unit on car 81–740; d) – modernised headlamp unit on car 81–740

al conditions are improved (the headlight are installed on the external panel), and specific surface of the radiator is increased. As a result it was possible to increasing the maximum luminous intensity of one module up to 8600 cd due to the current increase. Then, depending on number the headlights installed on a car, the number of modules can be changed, which allows obtaining lighting systems similar in efficiency.

As the traditional lighting system of these trains includes six headlights containing seven modules each, their maximum luminous intensity will be no less than 360,000 cd, which is close to the total luminous intensity of the headlights.

MODERNISATION OF HEADLIGHTS OF CARS OF MODEL 81–720 (YAUZA)

Due to the unsatisfactory level of tunnel illumination, the developers of new cars gave up on the use of automobile headlights for head illumination replacing them with four light devices (Fig. 9). Obviously, the scattering angle of these LDs (± 10 °) is less than that of standard automobile headlights in the long-distance beam mode (±15 °), but in view

of the structure features of these elements (truncated paraboloid with a relatively small light opening), they are insufficient for the comfortable illumination of rail heads at the normalised distance of 305 m. The light distribution formed by such headlights is shown in Fig. 10.

The headlight installation point (opening size) allows using the light-emitting diode headlamp unit with LEDs developed for car 81 760, slightly changing its appearance (Fig. 11), fixing and adjustment elements. As a result, a correspondent light distribution was reached (Fig. 11).

MODERNISATION OF HEADLIGHTS OF 81–717.6 AND 81–740 MODEL CARS

Due to a maximum unification, the use of a unified module allowed reducing costs when constructing four-headlamp lighting system of cars 81–717.6 (Figs. 12 and 13).

And it is clear that to provide a basic luminous intensity level of 360,000 cd, it is necessary to have 12 modules in each headlight, but in this case the thermal loading of the LED increases significantly. Therefore, to provide a high reliability and effective
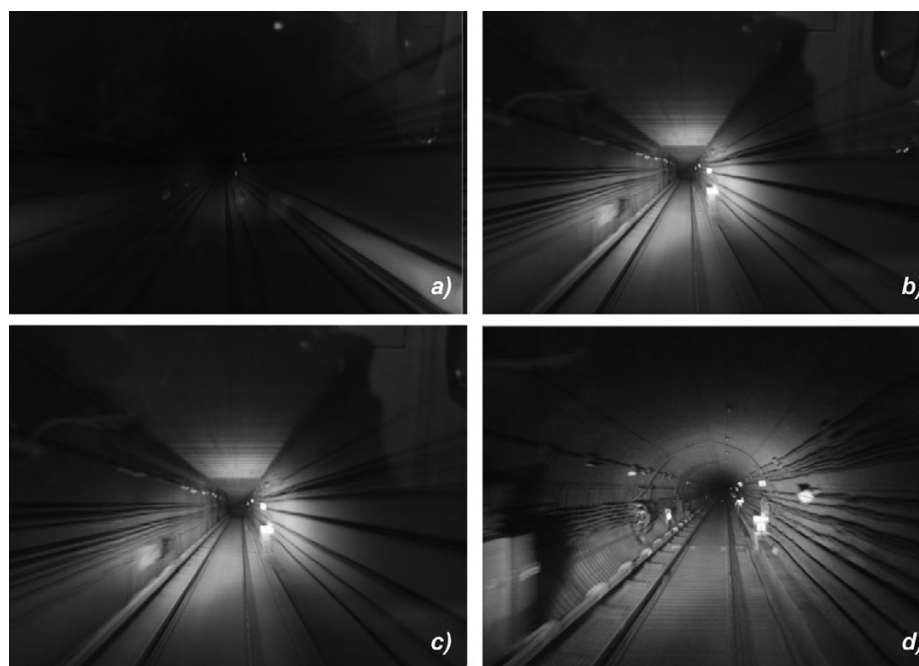
Fig. 15. Railway track illumination:

a) – with traditional headlights; b) – with a system of two headlights for model 81–760 cars; c) – with a system of four headlights of models 81–714.6 and 81–717.6 cars; d) – with a system of six headlights of models 81–714/717 and 81–718/719 cars

service life, a fan was added to the structure. Also, the installed headlights have a smaller diameter – 150 mm – and another structure of the adjusting unit (a spherical joint hinge). This predetermines a preliminary adjustment before the cover is installed. They have somewhat different style and look, so this also demanded a different approach to their modernisation. As the niche, in which the headlight is installed, is relatively small, a uniform (one for two headlights) ballast was developed to be mounted in each niche separately from the headlights.

A similar structure was used to modernise headlights for the Rusitch car 81–740. A feature of its illumination system is the use of four headlight searchlights separate from each other (Figs. 13 and 14).

The data provided above shows that the level of lighting reached by the headlights and the system as a whole (their axial luminous intensity is of 360,000 cd order), as well as their structure, full meets the initial conditions for modernisation. These conditions were the retention of the appearance of the cars, and the retention of service technology whilst providing the preset lighting characteristics.

One can easily estimate the results of this headlight modernisation by analysing photos of the road sites shown in Fig. 15, when illuminating them by different headlights with LED proposed to modernise cars of different models.

However, it should be noted that the high illuminance level reached in tunnels, in some cases causes negative consequences, for example, blinding of drivers of oncoming trains and, as has already been mentioned, blinding of passengers at stations.

Obviously a solution to the problem can be provided by darkening, i.e. switching to a lower level of the luminous flux securing in its turn an illumination level, comfortable for drivers of oncoming trains and for passengers on platforms.

As numerous experimental runs showed, this level should not exceed 0.8 lx at a distance of 305 m.

The proposed way of modernising headlights of the rolling stock allowed not only improving and unifying operating conditions for drivers of different models of underground cars, but also obtaining a number of advantages (Table 2). These advantages further improve the underground light medium, as well as its technological and economic parameters, which influence the operational efficiency of underground cars.

Besides the listed advantages of LED headlights, the test results showed that increasing the number of optical elements a lighting system promotes formation (when adjusting) of a more complex structure

Table 2 . Technical data of the headlights installed on an underground car

№	Parameters	Type of the headlight structure			
1	2	3	4	5	6
		Headlight FG-122 (with a HIL (car 81–717	Headlight with 24 LEDs (cars 81–720 and 81–760)	Headlight with 12 LEDs (car 81–740)	Headlight with 7 LEDs (car 81–717)
1	Lighting system type	Six-headlight	Two-headlight	Four-headlight	Six-headlight
2	Number of light-emitting diode modules	-	48	48	42
3	Greatest possible illuminance at a distance of 305 m, from one headlight, from system of headlights, lx	0.3 1.8	2.04 4.08	2.04 4.08	0.64 3.84
4	Power consumption, W, by one headlight, by system of headlights, W	70 420	65 130	32 128	16 96
5	Dimming	no	yes		
6	Light beam scattering angles, degree In horizontal plane, in vertical plane	±18/3 ±10/3	±3 ±3	±3 +3 + –5	±3 +3 + –5
7	Blinding by reflected own radiation	yes	no		
8	Working capacity retention with failure of one headlight	no	yes		
9	Area of the light opening, cm^2	226	193	100	80
10	Light beam adjustment	With partial dismantling	Without dismantling	With partial dismantling	
11	Power supply voltage, V	24	80		
12	Light source service life, h	1000	40000		
13	Optical element service life, h	25000	75000		
14	Power supply features	Onboard electrical system	Built-in ballast		
15	Shell protection level	IP54	IP65		
16	Repairability	partial	full		
17	Dimensions of the light module: depth, mm width, mm height, mm	84 0170	30–40 300–360 30–35	84 0170	84 0170
18	Mass, kg	2.0	3.9	2.9	2.7

of the light beam due to a greater variability securing better visibility conditions.

Unfortunately, along with the obvious advantages of light-emitting diode structures of the 81–760 car headlights, during their operation a basic disadvantage is revealed: a decrease in the headlight reliability (ballast failure mainly) after washing the cars. As to other series cars with LED headlights, such failures were not observed. An analysis of these failures showed that several of them take place due to:

• A discrepancy between the requirements placed by the developer of the car (IP64) and the real service conditions (IP68);

• An imperfection of the car structure predetermining a forced cooling of headlights by counter air flow;

• An imperfection of this structure of the headlights in the arrangement of active cooling and adjustment of light beam.

A subsequent modernisation of the headlight structure allowed preventing the failures and formulating requirements to their installation and design.

CONCLUSION

As a the result of the tests, the headlight with LEDs developed for 81–760 model underground cars, has been accepted by Metrovagonmash Open Society to be installed on serial cars.

Installation of modern headlights with LEDs on serial cars 81–760 requires a correspondent modernisation of headlights of different model underground cars, which are in operation.

The level of illumination reached in tunnels creates the preconditions for an increase of illuminance on platforms, at least according to the СП 32–105–2004 document.

The proposed principle of headlight modernisation allows replacing incandescent lamps with unified light-emitting diode modules without disturbing the design of different models of underground cars, and reaching almost equal visibility conditions for drivers of underground cars of old and new models.

Use of the LDs developed in the process of this illumination upgrade, allows to significantly raise their efficiency due to fully abandoning ILs.

When developing the structures of cars and LDs, it is necessary to provide a special cooling mechanism for headlights: for example, to take away air flow from the driver's cabin side through special air ducts or to design the headlights as autonomous units, preferably with a passive cooling system and with an adjustment of the light beam inside the headlight case.

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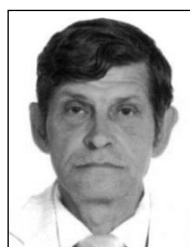
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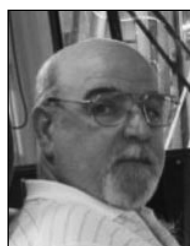
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INFLUENCE OF SINUSOIDAL AND RECTANGULAR CURRENT SHAPES OF AN INCREASED FREQUENCY ON RESONANT RADIATION OF LP MERCURY DISCHARGE

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ABSTRACT

The article presents experimentally derived results, which show that the efficiency of the radiation generation of arc LP mercury discharge in resonant mercury lines of 185 and 254 nm slightly depends on the shape of HF discharge current, as judged by the two shapes investigated at a specific power of about 2 W/s discharge.

Keywords: UV radiation, mercury discharge, LP, 254 nm, 185 nm, amalgam lamp, electron ballast, current shape, voltage shape

LP arc discharge in mercury vapour with inert gas as a source of resonant UV radiation at wave lengths of 254 and 185 nm is widely used in industrial settings for disinfection and cleaning of harmful substances in water and air. In this case, to generate UV radiation of a high power, amalgam lamps (AL) of 200–800 W power with 2–5 A current are used [1]. The industrial UV irradiating systems for water and air preparation contain tens, hundreds and even thousands ALs of general power consumption from tens of kW up to several MW [1]. Such systems usually work continuously and are often located in a limited area. Therefore, the efficiency of UV radiation generation becomes a key factor. This leads to continuous research into AL optimisation, namely by the increase of energy efficiency (further η_e)

of mercury LP discharge in resonant mercury lines and by the increase of AL's service life. For this purpose, studies are carried out to select an AL's optimum structure (geometry, composition and dosages of inert gas and of amalgam), as well as of the discharge current size and shape, etc.

One of the possible methods for optimisation is the selection of frequency and current shape of the lamps. For bactericidal LP ALs of more than 100 W power, special electron ballasts were developed. The study of current frequency influence on the generation of mercury resonant UV radiation efficiency [1–7] has shown that the optimum frequency lies in the interval between 10 and 100 kHz.

When changing frequency of the discharge current, the influence of different physical processes in the LP mercury discharge [2, 3, 5] also changes:

• The low frequency interval, in which the current is circular frequency $\omega \ll 1/t_D$, where t_D is a typical time of ambipolar diffusion ($t_D \approx 5$ ms). In this frequency interval, discharge is completely equivalent to the direct current discharge with a constant electron temperature (except for a short time interval, when the current is close to zero), and does not have an increased η_e in comparison with direct current discharge.

• In the high frequency interval: 1) at $\omega \gg 1/t_e$, where t_e is the relaxation time of the electron energy ($t_e \approx 2$ μs), the electron temperature, as well as
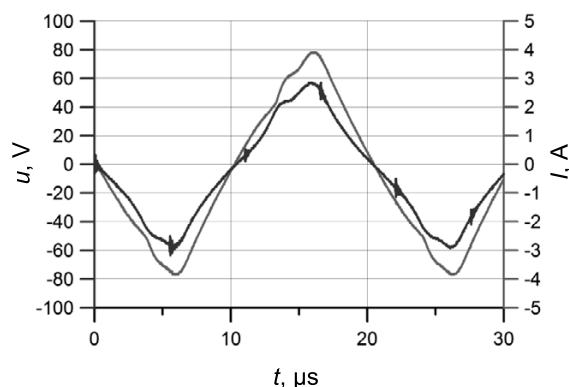
Fig. 1. The shape of the discharge current and voltage (current source of signal shape close to sinusoidal)

Fig. 2. The shape of the discharge current and voltage (rectangular pulse source)

the excited atom concentration do not change with time, and the generation of UV radiation is similar to that observed in a direct current mode; 2) at $1/t_e >> \omega >> 1/t_D$, electron concentration during the current period changes slightly, and the electron temperature fluctuates with a doubled frequency. If in this case $\omega << 1/t_a$, where t_a is a typical lifetime of excited metastable atoms ($t_a \approx 25$ µs), then concentration of the excited atoms also fluctuates during the current period; because of this, the excitation of mercury atoms decreases causing reduction in η_e. Minimum η_e in contrast with a direct current mode happens at a frequency of about 500 Hz.

• In the intermediate frequencies interval, $1/t_e >> \omega >> 1/t_a$, the concentration of mercury excited atoms does not change in time and (due to the fact that their excitation speed has a nonlinear dependency on the electron temperature) appears to correspond to the maximum electron temperature for the current period. Besides, because of the retention of an average electron temperature lower than the level expected at direct current, energy losses for elastic collision reduce. The combined influence of these factors leads to an η_e increase in comparison with direct current discharge. According to calculations [2, 5], maximum η_e is reached at a discharge current frequency of about 60 kHz, and this frequency depends on the discharge tube diameter, current value, and on gas pressure and type.

At present, some powerful ALs use a sine-shaped current of a frequency of about 50 kHz. In practice the frequency should be selected for each lamp type separately.

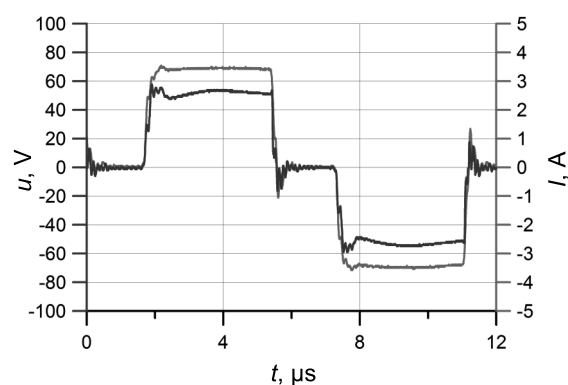Modern electronics allows creating compact and economic power supplies for discharge lamps not only of different frequencies, but also of different current shapes. However influence of the latter on η_e is poorly studied.

In the monograph [5], the correspondent data on the use of voltage rectangular pulses of different filling factors for power supply of LP mercury discharge are collected and analysed. Similar experimental data on the use of rectangular current pulses with steep edges of different filling factors at a frequency of 10 kHz are also established for an average specific discharge power of about 0.2 W/cm [6]. It was shown that the filling factor influence on η_e takes place only for VUV radiation (at a wavelength of 185 nm): when the filling factor increases from 1 to 4, the gain reaches 30 %.

Despite the positive results obtained, this method of discharge power supply is not widely developed yet. First, there is no regular experimental research on the currents used and the dosages of lamp filling, which does not allow making proper demands on the electron ballasts. Secondly, the source of UV radiation in large-scale industrial plants is usually located at a distance of several tens of meters from the power supply. And in this case the capacitance and inductance of the connecting cables, as well as the active resistance suppress HF components of rectangular pulses, transforming them to sine-similar. Consequently, the transmitting system should have a correspondent compensation. To decrease the resistive losses, which grow with frequency increase, it is necessary to apply a special expensive cable. A radio-frequency emission from the rectangular pulse high-frequency components is also possible. To suppress this, special cables and filters are also needed.

There are no publications of experimental data of η_e dependence on the discharge current shape at above a specific power, of about 2 W/cm. This

Table

Current shape	Filling factor	Frequency, KHz	I, A	U, V	P, W	η_e, rel. units	
						UV-C, 254 nm	VUV, 185 nm
Sine-similar	–	50	2.5	37	92.5	1.02	1.53
Rectangular	1.5	90		41	102.5	1.04	1.60

was the reason of carrying out this experimental research. A current source with an HF (50 kHz) signal of a shape close to sinusoidal (Fig. 1), and a source of different polarity rectangular HF pulses (90 kHz) with a front edge duration of about 300 ns and a filling factor of 1.5 (Fig. 2) were used. In both cases, current effective value I was equal to (2.5 ± 0.1) A, which provided an approximately equal energy contribution to mercury discharge with approximately equal voltage effective values U on the discharge gap. The discharge occurred at an optimum pressure of mercury vapour in a quartz tube with an inner diameter of 16.6 mm, an external diameter of 19 mm, and an inter-electrode distance of 410 mm. These parameters are most typical for widespread AL in industrial UV installations.

Relative measurements of η_e were performed, taking into account the experience of leading manufacturers of bactericidal UV lamps (see e.g., [8, 9]). As a radiation receiver in the UV-C interval, radiometer *RM 22* of *Dr. Gröbel GmbH* Company was used, and in the VUV interval the special detector of *Hamamatsu* company was investigated. In order to prevent absorption of UV radiation by the generated ozone, the receivers were placed in immediate proximity from the quartz glass. The receiver window was in physical contact with the discharge tube wall. These measurements allow comparing η_e obtained when using different types of power supplies.

The measurement results of effective electric parameters and of the correspondent η_e values are given in the Table. The Table shows that at a specific power of about 2 W/cm, a somewhat substantial increase of LP mercury discharge η_e in UV-C (254 nm) and in VUV (185 nm) intervals is absent, if the sine-shaped discharge current is replaced with rectangular.

Retaining the current effective value of 2.5 A, the current pulse shape does not significantly influence the specified $\eta_e$ values. The transition to rectangular current pulses increases the high frequency resistive losses in transmitting wires, which leads to a reduction of general energy efficiency of the correspondent UV irradiating installations.

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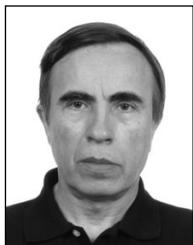
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EXPERIMENTAL RESEARCH INTO THE ELECTRICAL AND OPTICAL CHARACTERISTICS OF ELECTRODELESS UV LAMPS OF THE TRANSFORMER TYPE

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ABSTRACT

The article presents the results of experimental research into the electric and optical characteristics of a discharge electrodeless UV LP lamp. Induction discharge of the transformer type was excited in the lamp using a mixture of mercury vapour (10^{-2} mm Hg) with inert gases *Ne* (60%) + *Ar* (40%) (1 mm Hg) at a frequency of 225 kHz in a closed tubular envelope of quartz glass of 53 mm diameter and 760 mm length. With increase of the lamp power from 80 to 170 W, power losses in its inductor decreased from 45 to 24 W, and energy efficiency of the lamp discharge part in the mercury line of 253.7 nm increased from 17 to 29%.

Keywords: induction discharge, LP discharge, inductor, UV radiation

INTRODUCTION

One of the main disadvantages of modern powerful amalgam LP lamps, which are the most widespread artificial source of hard UV radiation, is a comparatively low service life (about 12000 h), which is caused by their electrode wear. In therefore seems appropriate to use induction excitation of the discharge, which allows abandoning the use of electrodes and therefore obtaining a lamp service life more than 30000 h [1]. Also, the induction lamps can work with an significantly lower pressure of the inert gas, which gives additional potential to increase the energy efficiency of the radiation sources [1, 2].

The studied object of the research was an induction lamp of the transformer type with a discharge closed envelope (tube) of quartz glass (Fig. 1). Overall dimensions of the lamp are 340×135 mm, the diameter of the wide envelope part is 53 mm, the diameter of the envelope in the inductor location area is 38 mm. The lamp's geometrical dimensions were selected to be close to the *Endura 150 W* (*Osram*) lamp size. The lamp was filled with a mixture of *Ne* (60%) + *Ar* (40%) at a pressure of 1 mm Hg. The source of mercury vapour was an indium amalgam. For the discharge excitation, an inductor of the *Endura 150 W* lamp was used, which represented two split-type ferrite rings of 2.5 cm^2 cross section of 43 mm inner and 65 mm external diameters. A 16-winding inductive coil of a multicore wire with teflon insulation was reeled on each ring. The coils were connected in parallel.
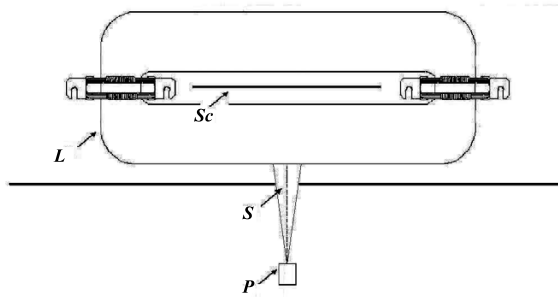

Fig. 1. Appearance of the lamp and a diagram explaining the principle of measuring UV radiation flux in a mercury line of 253.7 nm: *L* – lamp, *S* – slit, *P* – photodetector, *Sc* – screen
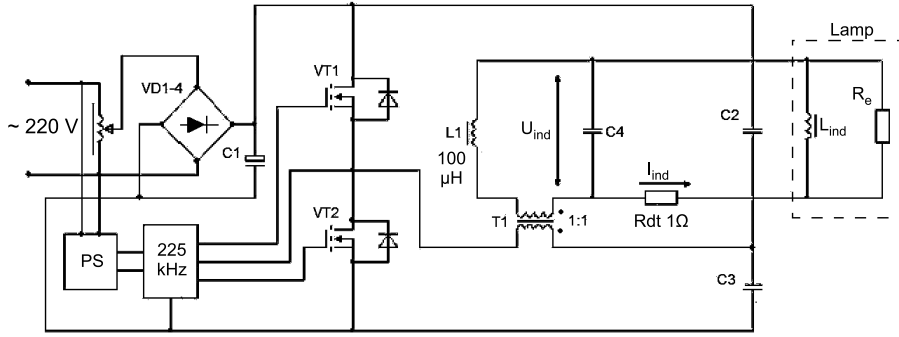
Fig. 2. Simplified principle diagram of electron ballast for a transformer type lamp

EXPERIMENTAL INSTALLATION AND THE RESULTS OF THE MEASUREMENTS

The electron ballast was operated at a frequency of 225 kHz and allowed changing the lamp operating mode. For this purpose, the voltage applied to the electron ballast input rectifier, was controlled using a laboratory transformer, and hence the inductor winding voltage (IWV) was adjusted accordingly.

In order to measure the inductor current and its winding voltage, the broadband oscillograph *Tektronics TDS640 A* was used. The power P_l consumed by the lamp, was determined as

$$P_l = T^{-1} \int_0^T u(t) i(t) dt.$$

The results of the lamp's electric characteristics measurement are given in Figs. 3–6 and in the Table.

It can be seen from Fig. 3 that as well as in the event with the two-electrode discharge, the current-voltage characteristic of the lamp (IWV dependence on the inductor current) has a falling trend, which leads to P_l decrease with IWV increase (Fig. 4). It should be noted that the inductor current hereinafter means the sum of the currents flowing along the inductor windings connected in parallel.

It can be seen from Fig. 5 that the inductor losses grow with IWV increase with a dependence close to the quadratic. The basic contribution to the inductor power losses P_{ind} is made by the ferrite rings losses [3]. When measuring P_{ind}, the inductor was connected to the electron ballast without a discharge envelope.

Decrease of P_{ind} with increase of P_l (Fig. 6) can be explained by IWV reduction (Fig. 4).

The experimental research results allow plotting a current-voltage characteristic of an induction dis-
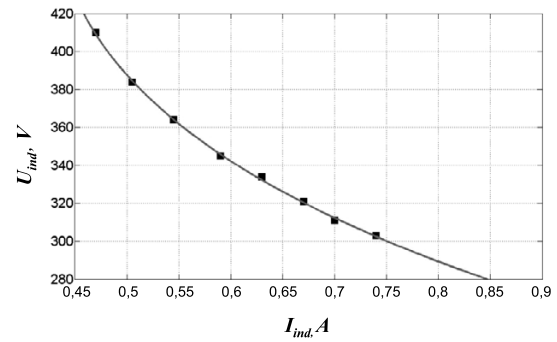

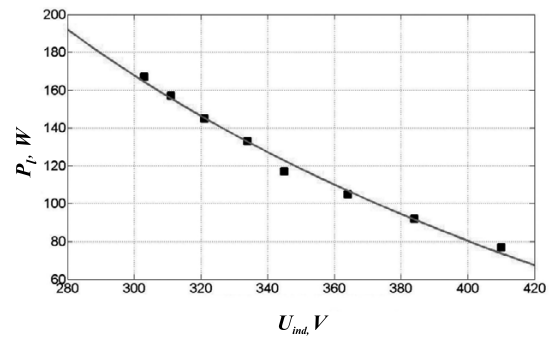Fig. 3. Experimental current-voltage characteristic of the lamp

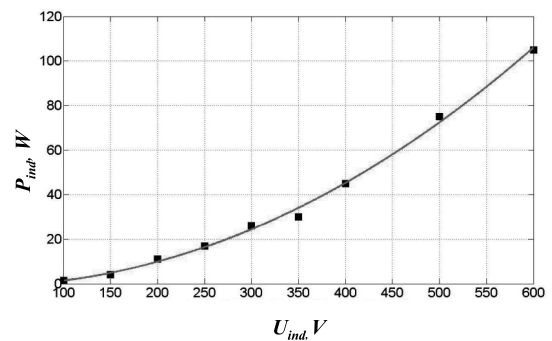Fig. 4. Power dependence of the lamp P_l on the inductor winding voltage U_{ind}

Fig. 5. Power loss dependence in the inductor P_{ind} on the inductor winding voltage U_{ind}
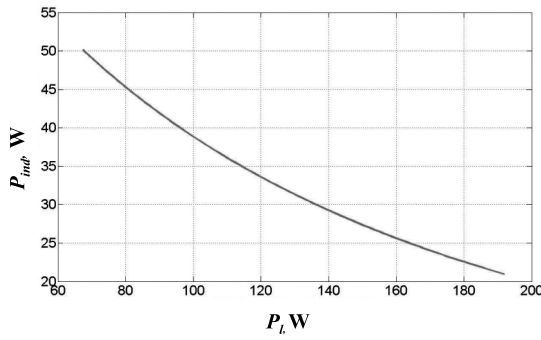
Fig. 6. Power loss dependence in the inductor P_{ind} on the lamp power P_l
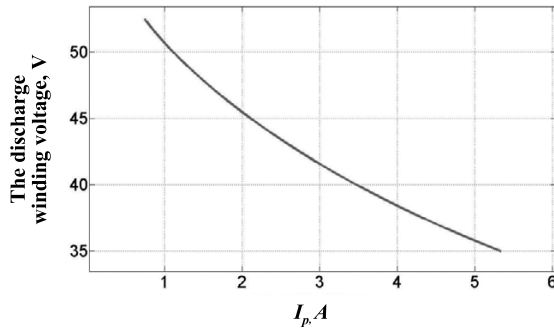

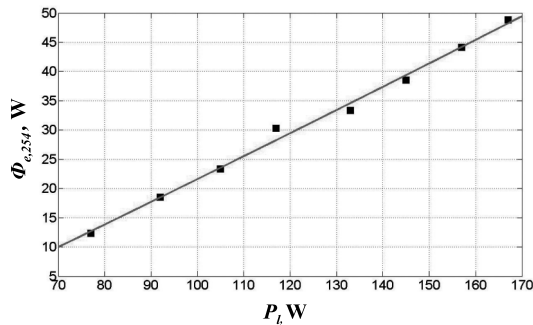Fig. 7. Calculated current-voltage characteristic of the induction discharge

Fig. 8. Dependence of the lamp discharge part radiation flux in the mercury line of 253.7 nm $\Phi_{253.7}$ on the lamp power P_l

charge, which can be useful when simulating work of the lamp-ballast combination (in particular, to determine the discharge operation point). To find out this current-voltage characteristic, first phase difference between the inductor current and IWV was determined:

$$\varphi = \arccos(P_l \cdot (U_{ind} \cdot I_{ind})^{-1}), \qquad (1)$$

Where U_{ind} and I_{ind} are effective IWV and inductor current accordingly. It is considered hereinafter that the inductor current and IWV are sinusoidal, which allows operating with complex-valued ex-

pressions of these values: $\widehat{U}_{ind}$ and $\widehat{I}_{ind}$ accordingly. This assumption is quite reasonable, since the electron ballast operates at a frequency close to the L_1C_4 circuit resonant frequency (Fig. 2).

Using a direct check by means of the multipurpose oscillograph *Tektronics TDS640 A*, it was found that the IWV harmonic factor was not more than 15%.

Assuming that equivalent resistance of the "inductor-discharge" circuit has an active-inductive nature, we have the following:

$$\widehat{I}_{ind} = I_{ind}\exp(-j\varphi), j^2 = -1, \qquad (2)$$

and the discharge current can be calculated using the formula

$$\widehat{I}_p = 0.5 \cdot n \cdot \left[\widehat{I}_{ind} - \widehat{U}_{ind} \left((j\omega L_{ind})^{-1} + R_{nom}^{-1} \right) \right], \qquad (3)$$

where n is number of windings in each coil, L_{ind} is equivalent inductance of the "inductor-discharge" circuit, $R_{nom} = U_{ind}^2 P_{ind}^{-1}$ is an equivalent resistance characterizing the inductor losses, which are calculated using P_{ind} dependence on U_{ind} given in Fig. 5. The 0.5 factor in formula (3) is caused by the two coils connected in parallel. The discharge winding voltage U_d was calculated as $U_d = 2 \cdot U_{ind}/n$.

In Fig. 7, a current-voltage characteristic of the induction discharge is presented. It was calculated in accordance with the experimental data using formulae (1)–(3). It exhibits a falling trend, which is typical for discharge of an LP lamp of the transformer type.

The values of intensity of a high-frequency electric field calculated in the discharge process as $E = U_d/L_d$ (see the Table), are well consistent with the measured values of electric field intensity in the discharge process of the transformer type lamp with similar structural characteristics [4]. Here $L_d = 760$ mm, is the discharge winding length.

Precise measurements of radiation flux in resonant mercury lines of 253.7 and 184.9 nm is not a simple problem, because integrating spheres for measurements in UV intervals are used extremely rarely due to the fast photo-degradation of their inner coating [2]. Besides, the line of 184.9 nm lies in the vacuum UF spectrum interval, and this significantly complicates experiments.

The authors used the following method of radiation flux $\Phi_{e,254}$ measurement in the 253.7 nm

Table

Inductor winding voltage U_{ind}, V	Inductor current I_{ind}, A	Lamp power P_l, W	Specific radiation flux of the lamp discharge part in a line of 253.7 nm, W/cm	Discharge current I_d, A	HF electric field intensity in the discharge, V/cm
410	0.47	77	0.16	0.92	0.67
384	0.51	92	0.24	1.47	0.63
364	0.55	105	0.31	2.00	0.60
345	0.59	117	0.40	2.58	0.57
334	0.63	133	0.44	2.96	0.55
321	0.67	145	0.51	3.43	0.53
311	0.70	157	0.58	3.85	0.51
303	0.74	167	0.64	4.19	0.50

mercury line of the lamp discharge part (LDP)[1]. The lamp was installed into a grounded blackened metal box of 2.0×0.7×0.7 m size. Opposite to the lamp, a screen with a slit of 3 cm width was located. It served as "a cutting out" part of the LDP. An additional screen was also applied to prevent a flare of the photodetector by the back half of the lamp. The photodetector (a calibrated photometric head) of the radiometer[2] was placed at a distance of 150 cm from the slit. With its help, the part of $\Phi_{e,254}$ cut out by the slit was determined using the inverse square law. Then $\Phi_{e,254}$ was calculated in the assumption that the lamp was a Lambert radiator.

A diagram, explaining the principle of $\Phi_{e,254}$ measurement is shown in Fig. 1. In accordance with it [2],

$$\Phi_{e,254} = \frac{\pi^2 i_p L_{sp}(L_{sp} + L_{sd})h}{S_p \Delta_s},$$

where L_{sd} =10 cm L_{sd} is distance from the slit to LDP, L_{sp} is distance from the slit to the photodetector, Δ_s is width of the slit, h is LDP length (with due regard for overlapping of a part of LDP radiation with inductors), i_p is photodetector current, S_p is photodetector sensitivity.

$\Phi_{e,254}$ dependence on the lamp electric parameters was measured with an optimum mercury pressure. In doing so, the amalgam placed in a special

appendix, was either warmed up, or cooled by a powerful fan. The optimum mode was determined by the registered $\Phi_{e,254}$ maximum.

As it can be seen from Fig. 8, a P_l increase causes $\Phi_{e,254}$ growth, which is close to linear. In order to evaluate the efficiency of UV radiation generated by the IWV, the P_{ind} dependence on LDP (Fig. 5) was taken into consideration. LDP energy efficiency $\eta_{e,\,254}$ in the mercury line of 253.7 nm, can be calculated as

$$\eta_{e,254} = \Phi_{e,254} \cdot (P_l - P_{ind})^{-1}.$$

The $P - P_{ind}$ difference determines the lamp discharge power P_d.

For the curve $\eta_{e,254}(P_d)$ Fig. 9, a slow decrease at $P_d > 80$ W is typical. At the same time, as it was shown above, with P_l increase, P_{ind} decreases. Therefore, creating highly effecient lamps of a raised power is essentially possible. This is confirmed by the graph given in Fig. 9. And increasing P_l to a limit is not practical, as the $\eta_{e,\,254}$ dependence on P_d should probably have a maximum in the P_d interval, which is not investigated in this work. Other methods of $\eta_{e,254}$ increase for lamps of similar structure, consist in the inert gas pressure decrease and in optimisation of the amalgam composition, as well as in selection of the quartz envelopes (tubes) with a maximum high transmission at a wave length of 253.7 nm. At present, the authors continue to carry out experimental and theoretical studies in this direction.

CONCLUSION

The experiments have shown the prospect for LP electrodeless UV mercury lamps of the transformer type of a raised power (> 200 W).

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[1] Radiation flux in the mercury line of 184.9 nm was not measured due to the absence of appropriate measuring equipment.

[2] Radiometer *IL1700* of *International light technologies company* with photometric head *SED240/W* with cosinusoidal angular characteristic, which sensitivity on 253.7 nm wave length was equal to 3.04 µA·m²/W.
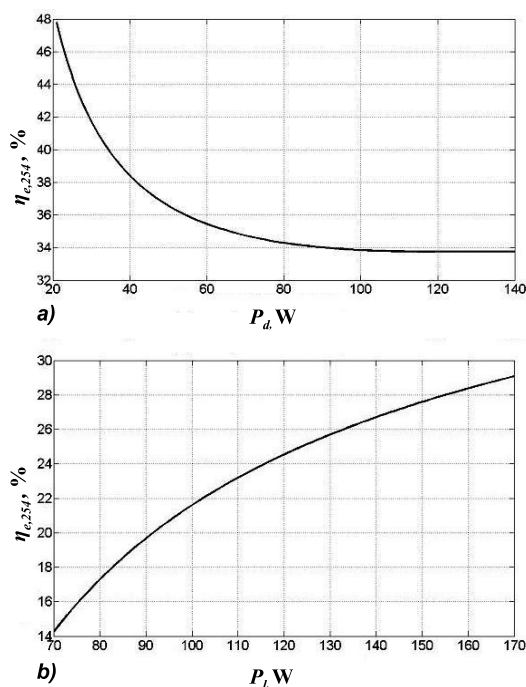
Fig. 9. Dependences of energy efficiency of the lamp discharge part in the mercury line of 253.7 nm $\eta_{e, 254}$ on the discharge power P_d (a) and lamp power P_l (b)

However, to select their most effective versions the optimum gas mixture composition and pressure has to be identified, as well as the optimum discharge envelope (tube) length and diameter, and amalgam composition and its location in the envelope.

Another possible applications of this UV type is worth mentioning: as electrodeless lamps can operate at a rather low (< 01 mm hg) pressure of inert gas, it is possible to expect obtaining a comparatively high (> 20 %) LDP energy efficiency in the mercury resonant line of 184.9 nm [5]. The application field of such lamps optimised for effective radiation in this line, can be rather wide: from ozonation to photolithography in micro- and nanoelectronics.

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RESEARCH INTO THERMAL OPERATING MODES OF A STREET LUMINAIRE WITH LIGHT EMITTING DIODES USING THE IR THERMOGRAPHY METHOD

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ABSTRACT

The article is dedicated to experimental research of the thermal mode of a street luminaire with light emitting diodes (LED). The IR thermography method was used to obtain data on temperature time dependence on the light-emitting diode matrix (LEDM) surface. Based on the thermogram analysis, the warming-up speed and maximum temperatures of the LEDM surface were determined. The data collected on the thermal operating mode study of a street luminaire with LEDs using contact measurements of temperature and density of the thermal flow are also presented.

Keywords: LEDM, IR thermography, surface temperature, thermal flow density, thermal mode

It is well known that one of basic causes of premature LED failure and decreasing service life is overheating as a result of not observing the proper thermal mode. Therefore, the issue of the LED thermal mode determination in lighting devices during the operation process is important.

At present, indirect methods of determining LED thermal parameters using their electric characteristics [1] are widely applied, however, they only allow obtaining averaged values. In order to reveal local places of the LEDM overheating, we need to know the temperature distribution across their surface. A spatial analysis of LED temperature fields is possible when processing their spectral characteristics obtained by scanning by the area [2], but this method is complex due to the required hardware and demands a long measurement period. The IR thermography method opens up a wide range of opportunities for experimental research of temperature fields across the LEDM surface [3, 4]. Its advantage is an immediate temperature distribution recording across the surface and a dynamic understanding of the correspondent thermal process.

Some results of experimental research of the thermal mode of a street luminaire with LEDs (and more specifically – with LEDMs) and some results of temperature measurement across LEDM surface are presented in this paper.

A SHORT DESCRIPTION OF THE STUDIED SUBJECTS

The experimental research was carried out using a street luminaire of ЖКУ 51–250–002-У1 type, in which a standard lamp (HPSL of 250 W power) was replaced with two LEDMs *3 F50* of white glow and 50 W power. These were produced according to the COB technology. The LEDMs were fixed on a duralumin mounting plate of 5 mm thickness and closed with optical lenses (Fig. 1). A good thermal contact between the LEDMs and the plate, the plate and the case was provided using organic silicon heat-conducting paste КПТ-8.

The *3 F50* LEDM of white glow represented a group of 50 light-emitting 1-W crystals of *Epistar* production with light efficacy of about 90–100 lm/W. They were placed in five rows by ten crystals
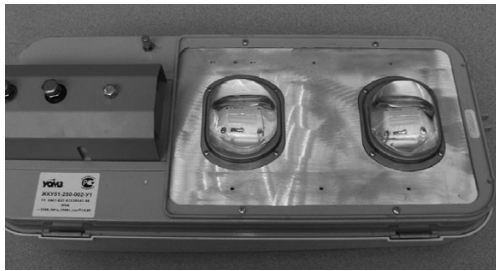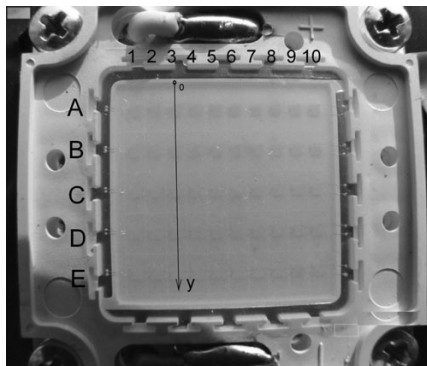
Fig. 1. A luminaire with two LEDM 3 F50

Fig. 2. Appearance of the LEDM 3 F50

each. The crystals were connected in series-parallel, placed upon a massive metal substrate and were covered with a phosphor layer from top. The size of the LEDM surface part covered with a phosphor was equal to 22×22 mm. In the picture (Fig. 2), LEDM crystals rows along horizontal are designated as A, B, C, D, E, and crystals columns along vertical are: 1, 2… 10.

STUDY OF THE LUMINAIRE THERMAL MODE

The luminaire thermal mode was studied with almost constant environmental temperature of 23.7⁰ C,

and relative humidity of 30%. A measuring instrument of thermal flow density ИТП-МГ4 "Поток" (Flow) was used with a set of sensors, which allowed measuring thermal flow temperature and density on the mounting plate surface and ambient temperature at certain time intervals. The locations of the sensors are shown in Fig. 3.

The luminaire was placed horizontally at a distance of 0.8 m from the floor, the light flux was directed downwards. After switching on the voltage supply to the luminaire and illumination, the sensors of the measuring instrument ИТП-МГ4 recorded time change of the thermal flow temperature and density. The obtained information was accumulated in the instrument memory, and afterwards it was processed by a PC.

As can be seen from Fig. 4 a, the mounting plate surface temperature after the luminaire switching on, quickly increased at the beginning. Then the increased speed gradually fell and in two hours the temperature had a value close to equilibrium of 7.9 °C, and the luminaire was switched off. The same Fig. shows the temperature value of the surrounding (air) medium. It can be seen that during the experiment, the temperature practically did not change. As a result, 120 minutes after the luminaire was switched on, the temperature difference between the surface plate and environment was equal to 50.2 °C.

As it can be seen from Fig. 4, the density of the thermal flow from the plate to the environment changed in time with the plate temperature, and in 120 minutes it stabilized at 470 W/m².

The reason of the substantial increase in temperatures and thermal flow density is the LEDM's thermal emission. It is possible to reduce the LEDM
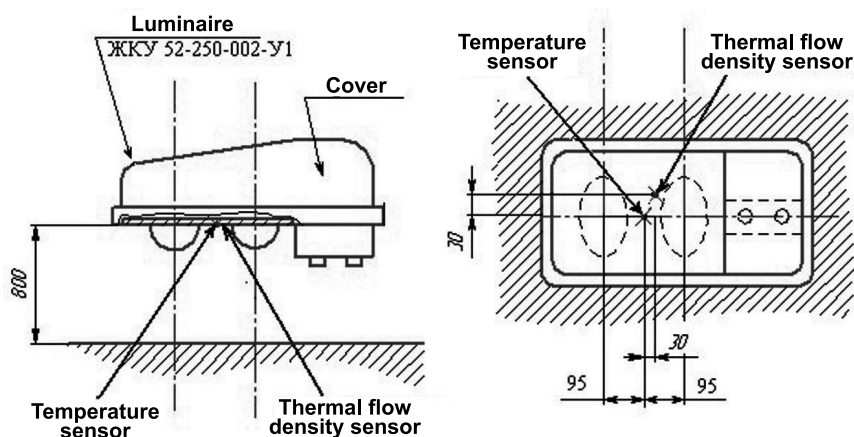

Fig. 3. A layout of the experiment

heating up by intensifying the mounting plate cooling process. The experiment results with versions of additional cooling of the mounting plate are given in the Table:

• Version 1, without any additional plate cooling (the plate area was equal to 0.047 m²), was taken as baseline case to be compared with other versions by the efficiency;

• In version 2, to increase the heat dissipation surface, two additional duralalumin angles were installed on the mounting plate (the area of each angle was 0.012 m²). In this case, the plate temperature t_p rose in comparison with air temperature t_{air} by 48 °C within two hours (two hours was the set time for all versions). In comparison with the baseline, the increase of the cooling efficiency Δt_{ef} was equal to 2.2 °C, where $\Delta t_{ef} = \Delta t_b - \Delta t$, and Δt_b is Δt for the baseline version, and growth of the cooling relative efficiency θ was equal to 4 %, where $\theta = (\Delta t_b - \Delta t) \cdot 100 / \Delta t_b$;

• In version 3, a film was glued to the mounting plate from its outer side to increase thermal emissivity of the surface and to strengthen the radiant heat exchange. Δt_{ef} and θ increases amounted to 5 °C and 10 % respectively;

• In version 4, the angles and the mounting plate were glued over with a film to increase thermal emissivity of the surface. In this case, Δt_{ef} and θ were equal to 7.5 °C and 15 %;

• In version 5, an additional duralumin plate of 3 mm thickness and of an area of 0.028 m² was added, on which LEDMs with optical lenses were installed. The additional plate was fixed to the basic plate using two radiators of 0.092 m² area. Δt value for the additional plate amounted to 42.7 °C, and Δt_{ef} and θ values were equal to 9 °C and 18 % respectively;

• Version 6 was similar to version 4 differing from it in that the luminaire cover was removed. In this case, Δt_{ef} and θ amounted to 14.7 °C and 29 %;

• Version 7 was similar to version 3, differing from it by the addition of two lateral duralumin plates of 2 mm thickness and of 0.1 m² area. In this case, Δt_{ef} and θ were equal to 15 °C and 30 %.

These experiments allowed determining the influence of some additional engineering solutions on cooling the mounting plate, which facilitated the LEDM's cooling. The growth in temperature and thermal flow on the surface of the LED luminaire mounting plate indicated the LEDM temperature rise nothing but indirectly.
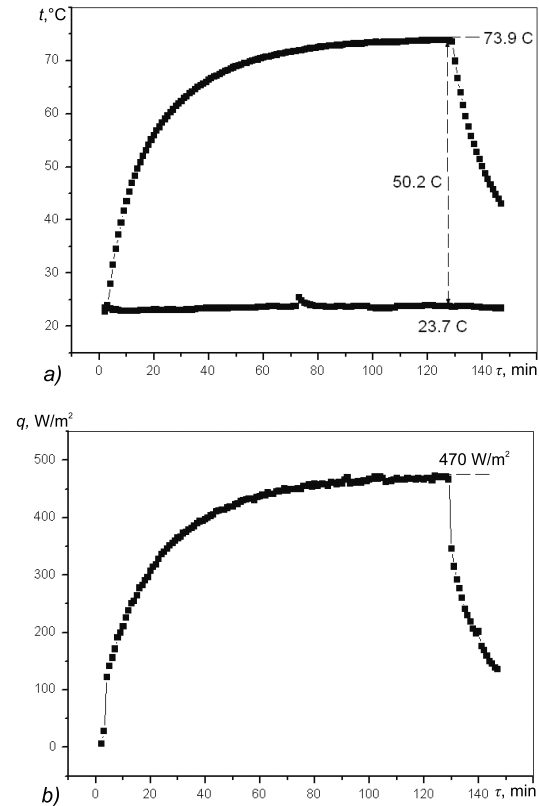

Fig. 4. Time changes of temperature t (a) and of thermal flow density q (b) on the luminaire mounting plate surface

To determine the LEDM surface temperature, it was necessary to measure it directly, and to determine the areas with local overheating; it made sense to record temperature time changes across the entire LEDM surface.

MEASUREMENT OF THE TEMPERATURE FIELD ON THE LEDM SURFACE

The experiments measuring surface LEDM temperature were performed using the IR thermography method. An infrared imager *Termo Tracer TH 7102 WX* of *NEC* Company production was used. It was equipped with a non-cooled microbolometer matrix (*uFPA microbolometer*) of 320×240 mm size operating in the 8–14 μm spectral interval. The measurements were carried out using a macroscopic lens *TH71–377*, which allowed registering objects of 100 μm spatial resolution. The infra-red imager field of vision was 32×24 mm, and consequently the entire light-emitting surface of the LEDM was displayed on the thermogram.

The measurement was started at the moment voltage was supplied to the LEDM. The infra-red imager
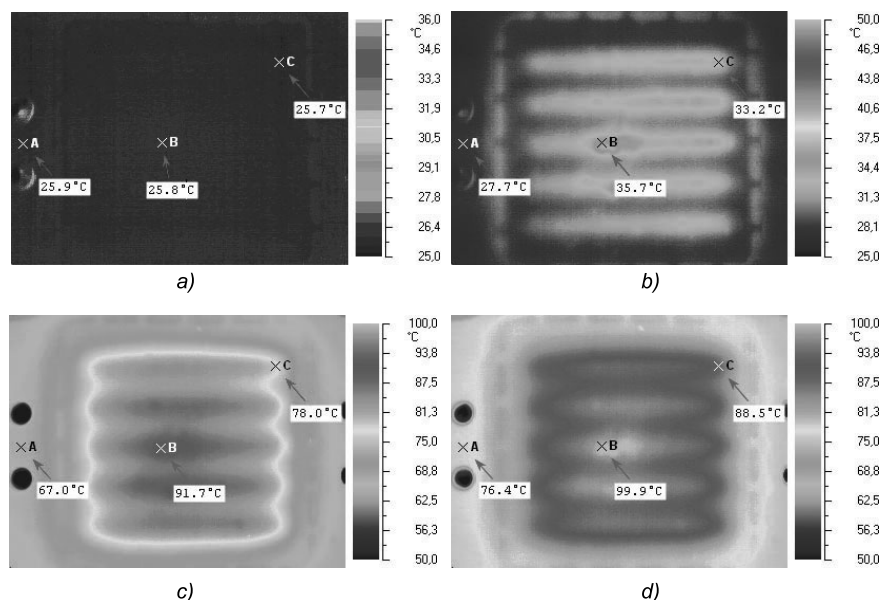
Fig. 5. Thermograms of the LEDM light-emitting diode surface at different moments in time moments after switching on:
a) –at switching on; b) – in 10 s; c) – in 10 min; d) – in one hour

recorded temperature distribution across the surface with several seconds interval in the form of a thermogram. To calibrate the thermogram more precisely, LEDM surface temperature at some points was measured directly by a contact method by means of thermocouples. By comparing the contact and contactless temperature measurements, the LEDM surface thermal emissivity was determined. This was equal to 0.96. The experiments were carried out at $t_6 = 25.8$ °C. Typical thermograms of the LEDM surface for different moments after the switching on, are presented in Fig. 5. The thermograms are marked as follows: the case temperature is point A; the surface temperature over the central crystal C4 (according to Fig. 2) is point B; the surface temperature over the last crystal A10 is point C.

At an initial moment after the luminaire was switched on (Fig. 5), the LEDM surface temperature distribution was uniform and corresponded to the air temperature, and the temperature gradient across the surface did not exceed 0.1 °C. In ten seconds (Fig. 5), maximum the surface temperature was over the crystals at the LEDM centre (for example, over crystal C4 the temperature was 35.7 °C), and the surface temperature over the last crystals by the perimeter was slightly lower (over crystal A10 the temperature was 33.3 °C); the LEDM case temperature amounted to 27.7 °C. After ten minutes from switching on (Fig. 5), the surface temperature over the crystal at the LEDM centre was 91.7 °C, and over the end crystal it was 78.0 °C. The LEDM case

temperature reached 67.0 °C. Following on from this, the LEDM surface temperature gradually increased, and in one hour after switching on (Fig. 5) it reached a maximum value, after which it practically did not change any further. This state can be named the LEDM starting operation thermal mode. In this case, the surface temperature over crystal C4 at the LEDM center was 99.9 °C, over the end crystal A10 it was 88.5 °C, and the LEDM case temperature was 76.4 °C. These measurement results show that the LEDM started the operation thermal mode before the luminaire case elements. And a maximum LEDM temperature (99.9 °C) even without the optical lens, was essentially higher than the temperature maximum of the luminaire mounting plate (73.9⁰ C).

Based on the thermograms obtained as a result of the experiment, diagrams of the LEDM surface temperature changes at typical points were plotted depending on time change (on the case it was point A; at the center over crystal C4 it was point B; over crystal A10 it was point C, Fig. 6).

It can be seen from the presented data that basic heating occurred during the first ten minutes after switching on, and then within an hour, a gradual temperature increase on the LEDM surface took place. During the entire heating process, the surface temperature over the crystals at the LEDM centre was 5 °C higher than over the end crystals, and 20 °C higher than on the LEDM case.

After the luminaire was switched off, the LEDM surface temperature decreased sharply, and in one

Table. Efficiency of different versions of the luminaire mounting plate cooling methods

№	Version	t_n, °C	$t_в$, °C	$\Delta t = t_n - t_в$, °C	Δt_{ef}, °C	θ, %
1	Mounting plate with two LEDMs – the basic version (Fig. 1).	73.9	23.7	50.2 ($=\Delta t_b$)	0	0
2	The basic version + two angles	72.1	24.1	48.0	2.2	4
3	The basic version + a film	69.2	24.0	45.2	5.0	10
4	The basic version + a film + two angles	67.0	24.3	42.7	7.5	15
5	The basic version + an add. plate on two radiators and a film	67.1	25.9	41.2	9.0	18
6	The basic version + a film + two angles + removed cover of the luminaire	59.1	23.6	35.5	14.7	29
7	The basic version + a film + two add. lateral surfaces	59.9	24.7	35.2	15.0	30

minute the temperature across the all LEDM was already less than 60 °C, after which it continued to decrease gradually.

Using the thermograms for practical reasons, the temperature distribution on the LEDM surface along axis *y* was also determined (see Fig. 2) at different moments in time (Fig. 7): where positions of the crystal rows corresponded to each maximum, and a midway between these rows corresponded to each minimum. And a gradual rise of the LEDM surface temperature was observed. It is follows from Fig. 7 that at a maximum luminaire warming-up, separate local heating areas took place on the LEDM surface up to temperature about 100 °C.

LEDM SURFACE TEMPERATURE MEASUREMENT OVER SEPARATE CRYSTALS

When measuring the light-emitting diode LEDM surface temperature over separate crystals, the Tirm-02 C IR thermal imaging microscope was used with a cooled *InAs* matrix of 128×128 size operating in 2.65–3.05 μm spectral interval. The measurements were performed using TM 8 lens with spatial resolution of 8 μm. The field of vision of the infra-red imager was 1×1 mm, which corresponded to the size of separate light-emitting crystals of the LEDM. The experiments were carried out at ambient temperature of 27.0 °C. During the first hour after switching on the luminaire the temperature change on the LEDM surface over crystal C4 (Fig. 2) was recorded by means of the IR microscope. Based on the obtained thermograms, a temperature change diagram over this crystal surface (Fig. 8) was plotted, which matches the similar data of the temperature dyna-
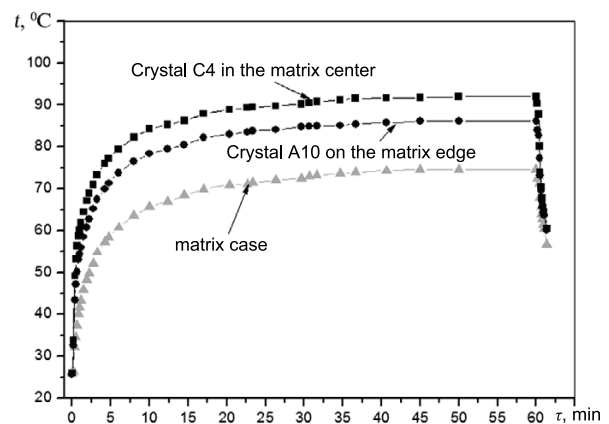

Fig. 6. Temperature time change at different points on the LEDM surface
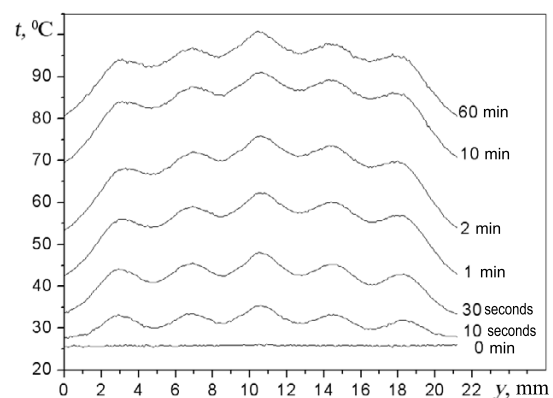

Fig. 7. Temperature profiles on the LEDM surface at different time moments

mics obtained using infra-red imager *Termo Tracer TH 7102 WX* (Fig. 6).

The temperature measurements accomplished with an IR microscope, confirmed that the temperature on the LEDM surface over separate crystals when working LEDM *3 F50* at the room environment temperature, was about 100^0 C.
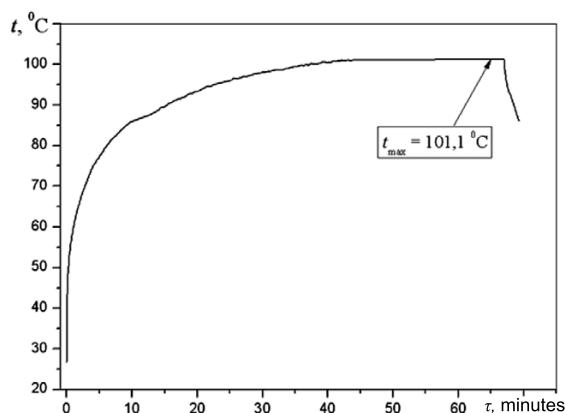
Fig. 8. LEDM temperature time change over surface
of crystal C4

CONCLUSION

The performed experiment on a street luminaire thermal mode with LEDMs produced data on thermal flow temperature and density values on the luminaire mounting plate surface, as well as determining the period which is needed in order for the luminaire surface temperature to reach the operation thermal mode (about two hours). The influence of different engineering solutions on the mounting plate cooling efficiency was experimentally determined. The best results were obtained when using additional lateral plates because of a significant increase of the heat-dissipating surface area.

Using the IR thermography method, thermograms of the street luminaire LEDM surface were obtained at different moments in time after it was switched on. Analysing the obtained results shows that a basic LEDM surface heating occurred within the first ten minutes after switching on, and then within an hour the temperature increased with a gradual deceleration. Besides, in the process of the experiment, the temperature distribution across the LEDM surface was revealed to be non-uniform.

The performed experiments show that on the LEDM street luminaire surface, sections with increased temperatures were observed, where temperatures were significantly higher than the temperature on the mounting plate surface.

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ENERGY-EFFECTIVE TECHNOLOGIES FOR HOUSING AND UTILITIES USING A CASE STUDY OF ENERGY SAVING ILLUMINATION IN ENTRANCE HALLS OF APARTMENT BUILDINGS

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ABSTRACT

A real life case study of energy saving in housing and utilities is presented.

The potential of using auto controlled illumination systems for entrance halls of multistory apartment buildings is analysed. This system identified movement in an entrance hall and depends on external illumination.

Energy efficiency of this system, its financial benefits and payback period are estimated.

An economic evaluation of an autonomous system for entrance hall illumination using photo-electric batteries is given.

Keywords: illumination, energy saving, housing and communal services, entrance halls of houses, automatic adjustment of illumination, illumination sensors, movement sensors, autonomous illumination system

The environment provides inexhaustible sources of natural energy. Increasing energy efficiency in buildings depends on a transition to renewable energy sources as a part of the system. In particular, this concerns the illumination of housing and utilities, including entrance halls of multistory apartment buildings of mass fabrication. In this case, sunlight, as a renewable energy source, is transformed into electricity by photo-electric batteries. This approach can make the system of electric illumination of entrance halls and staircases in apartment buildings completely autonomous.

The work presented in this article is a calculation simulation of annual consumption of the energy necessary to illuminate entrance halls and staircases of apartment buildings comparing different illumination systems.

As a case study for this research, a real nine-floor five-entrance brick apartment building of the series II-29, is examined. It is located in the Ivanovoskoye area of Moscow, 22–2 Stalevarov street. As part of the research, an evaluation of efficiency of existing illumination systems was performed and a technical solution to modernise and increase energy efficiency was proposed[2].

The calculation of the effectiveness of the entrance hall illumination system was made based on average seasonal observations concerning light switching on and off. It is the most widespread method of illumination control in building entrance halls in the Russian Federation.

The observations performed allowed establishing the baseline picture of switching off and switching on light in the entrance hall of the case study building (Table 1)[3].

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[2] The work was performed within MGSU National research university master dissertation preparation

[3] As a result of the observations, it was possible to register days when illumination worked round-the-clock system (probably, the reason was human factor)

Table 1. Baseline switching on and off cycles in the entrance hall

Month	Switching off time	Switching on time
January	9–00	17–00
February	9–00	17–00
March	7–20	20–00
April	6–40	20–00
May	6–00	21–00
June	5–30	22–00
July	5–30	22–00
August	5–30	22–00
September	6–40	20–00
October	7–20	20–00
November	9–00	17–00
December	9–00	17–00
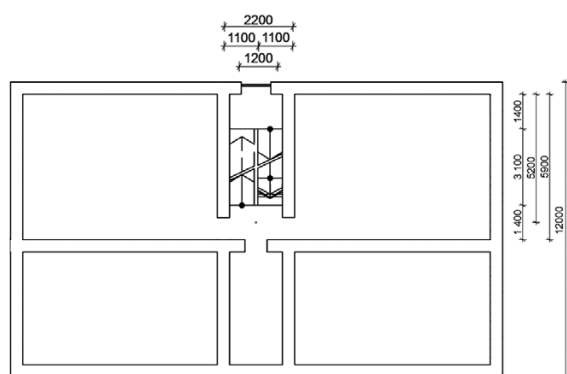
Fig. 1. Layout of a fragment of the staircase of a nine story brick house of П-29 series

Fig. 2. A section drawing of the fragment given in Fig 1

According to the observed values, the annual operating time of the artificial illumination $T_{year \cdot art}$ would equal 4,466.28 h, and the annual usage time of natural light $T_{year. \, nat}$ would equal 4,293.72 h.

The energy efficiency of this approach, resulting in mixed illumination in the entrance hall, is impressive, but its health impacts are a disadvantage. To confirm this, some illuminance measurements on the landings of the three bottom floors were made shortly before and after switching on and switching off of the artificial illumination. The measurements were performed using pulsmeter luxmeters TKO-PKM (08).

As the research finished in April, 2013, the results of the measurements were compared with the calculated values for the same month.
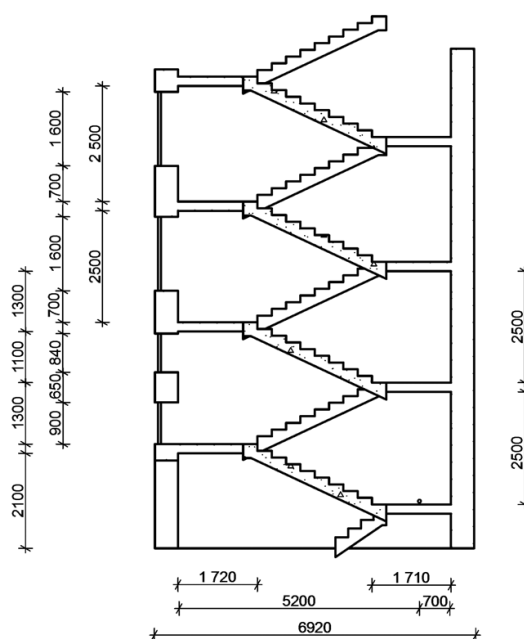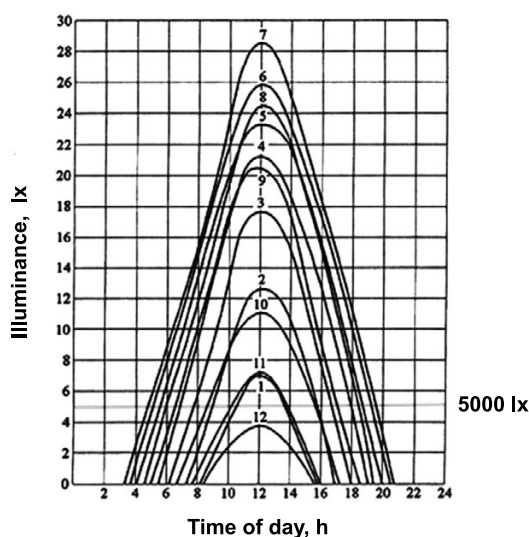
Calculation of daylight factor and critical illuminance for natural illumination of the entrance hall is based on the СП 23–102–2003 standard (Natural illumination of inhabited and public buildings)

To fulfil this stage of the research, in accordance with the real time, a layout of a fragment of the staircase and a cross section of the staircase of the house (Figs. 1 and 2) were made. According to Building

Fig. 3. Ecr = 5000 lx

Fig. 4. Ecr = 2886, 3037 and 10869 lx

regulations 23–05–95*, the normalised value of daylight factor on the staircase with a combined illumination is equal to 0.1 % at the floor. A normalised illuminance value amounts to 20 lx. Accordingly, critical illuminance E_{cr} = 20 lx/0.1 % = 20000 lx. With this external illuminance, the artificial light should be switched on and off.

The performed calculations of the daylight factor allow dividing the entrance conditionally into three areas by natural illuminance level.
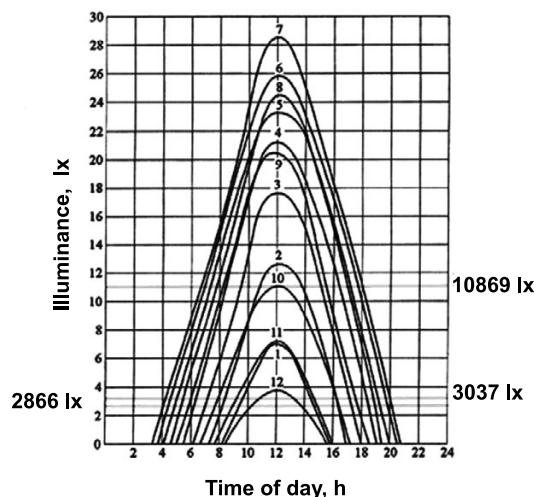
The landing on the ground floor relates to the first area. This is the darkest place in the entrance hall. The daylight factor here is 0.18 %, and E_{cr} in a reference point is 10869.6 lx. The daylight factor and E_{cr} data in practice should meet the standard requirements for illumination of entrance staircases. In this case $T_{year.art}$ = 7064.4 h and $T_{year.nat}$ = 1696.6 h.

The highest readings all relate to the third area (of the second – eighth floors). The daylight factor in reference points is equal to 0.70 %. E_{cr} = 2866 lx. It is much better than on the landing of the ground floor. $T_{year.art}$ = 4760.06 h and $T_{year.nat}$ = 3999.94 h.

It is known from papers on illumination design that for light-climatic zoning, a value of E_{cr} = 5000 lx has been accepted. It is considered that the artificial illumination is usually switched off and on at such external illuminance level [1].

In this research, the calculation was made with E_{cr} = 5000 lx. This leads to a $T_{year.art}$ = 5537.33 h and $T_{year.nat}$ = 3222.67 h.

In accordance with the diagram of the natural diffuse illuminance changing for Moscow (Fig. 3), the landing of the ground floor is illuminated insuf-ficiently (the illuminance standard levels are not met), and the landings of the first and upper floors (2–8) are excessively illuminated in the morning and evening (excessive electricity consumption).

An analysis of the results shows that detailed calculations of the daylight factor and E_{cr} are necessary, making reference to real technical data of specific buildings and their location in-situ, and it is necessary to design a modern energy-efficient illumination system. So that this system would correspond to standard requirements, calculation values of the daylight factor should be used.

It should be noted that the calculation of the daylight factor should be made whilst accounting for the effect of buildings opposite. It would be best verify the results of the calculations using observed measurements of daylight factor at reference points, which would increase the accuracy of the calculations of the energy efficiency system.

An illumination system for an entrance hall adjusted by natural illuminance sensors, which automatically limit operation of the movement sensors

The system of automatic control of artificial illumination in a building staircases should be double-step. The sensors for artificial illumination adjustment switch on and off the sensors detecting movement in the evening, depending on external natural illuminance levels. And the latter sensors in their turn, switch on and off the system of artificial illumination of the staircase during movement of the inhabitants in the entrance hall and on the landings. The operating time for the first step adjustment sen-

Table 2. Pedestrian activities time

№	Action	Time, s (h)
1	Opening of the entrance hall door → time to go to the lift (or apartment door) accounting for time to check the mail box	60 (0.016)
2	Opening of the entrance hall door → time to go to the lift (baby buggy)	
3	Entering the lift/moving a baby buggy from the lift	30 (0.008)
4	Opening of an apartment door	50 (0.013)
5	Opening of the entrance hall door → coming upstairs/downstairs to the site between the ground and the first floor, accounting for time to check the mail box	60 (0.016)
6	Coming upstairs/downstairs from the site between the ground and the first floor to the pace of the first floor (for the residents walking from the first floor)/ from the site between the first and the second floors to the pace of the second floor (for the residents walking from the second floor)	40 (0.011)
7	Coming upstairs/downstairs from the site between the ground and the first floor to the landing of the first floor accounting for time to check the mail box (for the residents walking from the second floor)	90 (0.025)
8	Opening of the entrance hall door → coming upstairs/downstairs to the second floor accounting for time to check the mail box	
9	Lift waiting time (a standard time interval – the waiting period)	
10	Lift waiting time (most possibly, a long time interval – the waiting period)	180 (0.05)

sors was calculated based on E_{cr} values (Fig. 4). E_{cr} of the ground floor landing is equal to 10869 lx. E_{cr} of the first floor landing = 3037 lx, E_{cr} of the 2–8 th floors is equal to 2866 lx.

Photo-electric sensors measuing E_{cr} are installed on the window ledges of the staircase.

They should have shading screens protecting them from exposure of direct sunlight, except for entrances on the northern side of the building.

Actual values of vertical illuminance E_{vert} on the sensors should be reduced to E_{cr} values using illuminance coefficients (E_{vert}/E_{gor}) using observed measurement.

The second step is the switching on and switching off of the artificial illumination system by the movement sensors, when external natural illuminance is lower than E_{cr} [2]. In this case the work of the system depends on such parameters as the activity of the residents (movement of people and their entrance) determined by number of the people entering the entrance hall and leaving it, and by the lift

waiting period. To do these calculations, real measurements of these factors were made.

The results of monitoring residents' activity over a period of seven days (week days + weekends) allowed obtaining and using for further calculations some numerical data (Fig. 5). Periods of opening of the entrance hall door, walking to the lift, coming upstairs/downstairs to the first and second floors, as well as lift waiting period (Table 2) were measured[4]. Accounting for residents' activities, the duration time of these actions, illumination and movement sensor operation, $T_{year.nat}$ and $T_{year.art}$, were computed (Table 3).

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[4]   These time measurements are not arbitrary. They are based on the proposed calculation procedure, which in essence consists of separating of human actions by the illuminance areas with due regard for time characteristics of walking from the entrance hall to the apartment. This method allows bringing the calculation simulated conditions as close as possible to the real operational conditions.

Table 3. T$_{year.nat}$ and T$_{year. art}$ of the proposed system (floor-by-floor area-based illuminance)

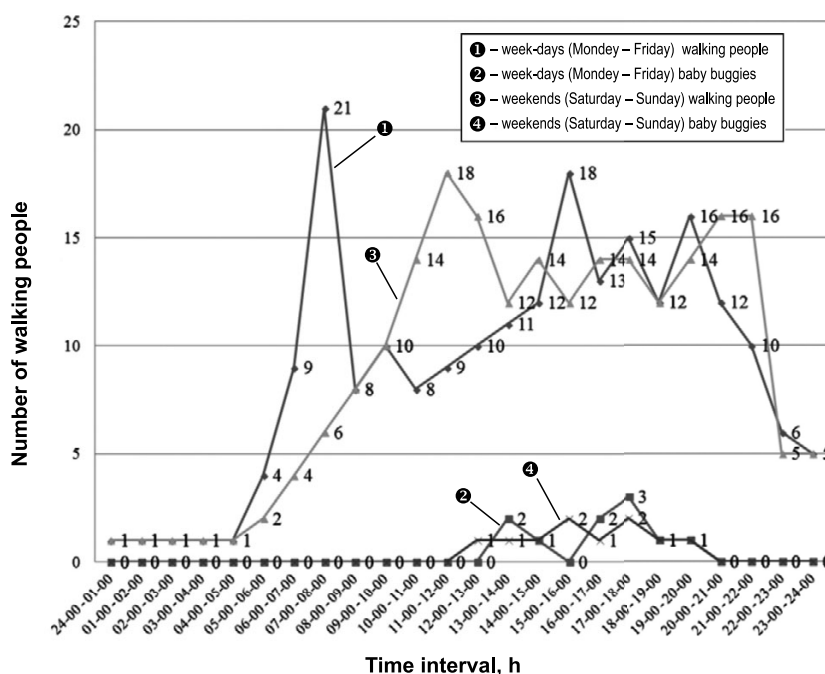| Area	Floor pace	E$_{cr}$, lx	T$_{year.nat}$, h	T$_{year art}$, h
1	ground	10869	5993.3	2 766.7
2	first	3037	8605.0	155.0
3	second	2876	7378.2	164.4
	third			
	forth			202.9
	fifth			
	sixth			
	seventh			
	eighth			

Fig 5. Activity of walking people

In Fig. 6, a diagram of monthly power consumption using the proposed illumination system is given. The diagram is plotted based on the mentioned measurements and observations of the basic factors with due regard for energy losses in the ballasts and power supply circuits[5].

The following four types of artificial illumination systems were researched:

1. System I, which is currently use on staircases (switching on and switching off system at a certain time);

2. System II, which is computed using E$_{cr}$ = 5000 lx;

3. System III, which is computed using area-based E$_{cr}$ values calculated within the research process with illumination and movement sensors and with energy saving lamps;

4. System, which is computed using area-based E$_{cr}$ values with illumination and movement sensors and with light-emitting diode lamps.

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[5] Taking into account a provision of the Federal law of November, 23 rd, 2009 № 261-ФЗ "On energy saving and increasing power efficiency…" prescribing the use of energy saving lamps for illumination of apartment building entrance halls.
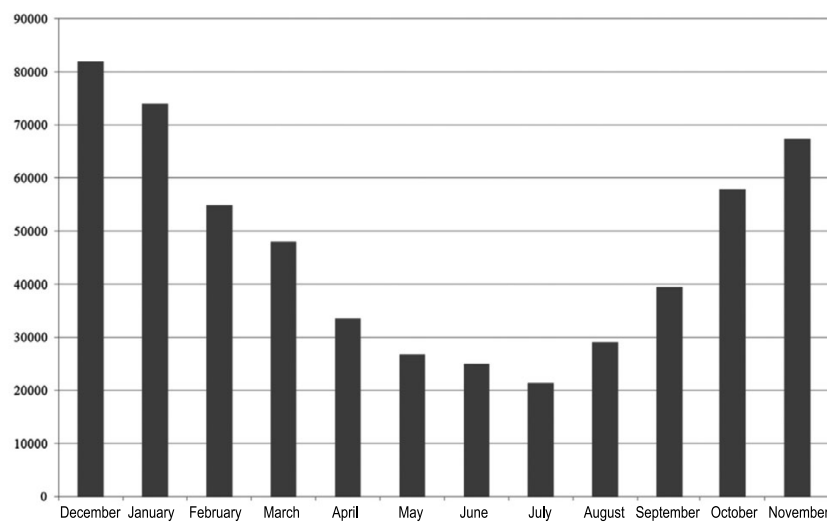
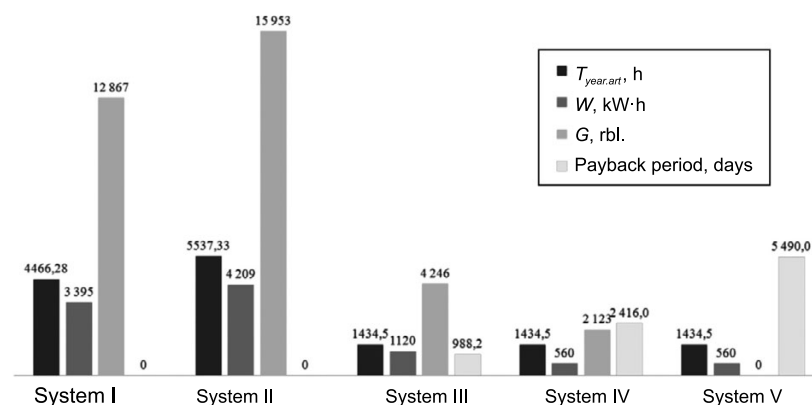Fig. 6. Power consumption by months, W·h

Fig. 7. A diagram of comparison of the considered illumination systems

For this research 19 energy saving lamps of 40 W power and of 1700 lm luminous flux of each were used; the calculation of power consumption and of economic component for illumination systems was made using the characteristics of these lighting devices.

In system III considered for a comparison, and in system IV, which we propose, light-emitting diode lamps (LED lamps) of 20 W power, will be used (light flux of each one is up to 1900 lm).

System I: $T_{year.\ art}$ = 4466.28 h; annual power consumption W = 3395 kWh; annual cost of electric power G = 3395 kWh; 3.79 rbl. X kWh = 12867 rbl.

System II: $T_{year.\ art}$ = 5537.33 h; W = 4209 kWh; G = 15953 rbl.

As one can see, G in systems I and II is almost identical, and illuminance at the staircase and in the entrance hall on morning and evening in both cases is insufficient.

System III: $T_{year.\ art}$ = 2766.7 h (the first area), 155.0 h (the second area) and 1381.8 h (the third area); W = 1120 kWh; G = 4246 rbl.; payback period = 2.7 (988 days).

Automatic light adjusting reduces G in systems I and II practically three and four times accordingly.

In this case on the staircase and in the entrance hall, the standard illuminance is provided.

System IV: $T_{year.\ art}$ = 2766.7 h (the first area), 155.0 h (the second area) and 1381.8 h (the third area); W = 560 kWh; G = 2123 rbl.; payback period = 6.6 years (2416 days).

Cost of the photoautomatic devices in systems III and IV are taken into consideration in the calculations. System III is capable of saving annual-
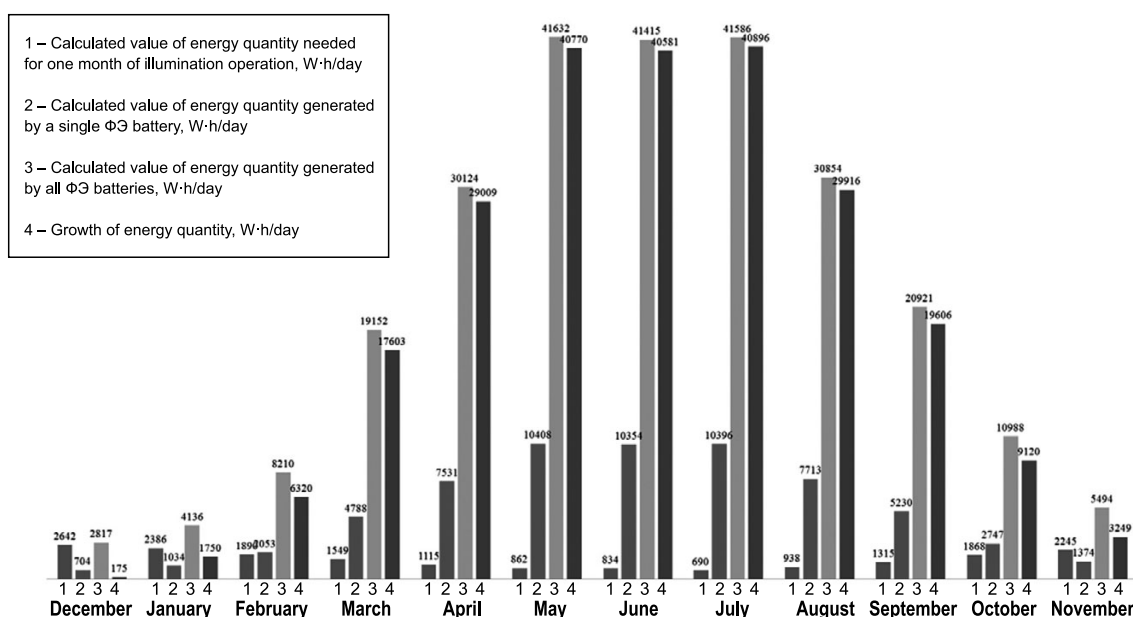
Fig. 8. Monthly consumption and energy enlargement during a day, W-h

ly up to 8634 rbl. (67%). In comparison with illumination system I, which now operates in the entrance hall, system III can save up to 8634 rbl. a year (67%).

System IV proposed by the authors is most energy-effective. It can annually save up to 10744 rbl. (83.5%) in comparison with system I, 13830 rbl. (86.7%) in comparison with system II and 2123 rbl. (50%) in comparison with system III. However, the cost of illumination using light emitting diodes is still too high.

Concerning energy efficiency and energy saving, we have considered in addition one more autonomous system using photo-electric transformation of solar energy (system IV + photo-electric batteries[6]). The results of our calculations and comparisons (Fig. 7) allow suggesting that this system in principle can be implemented and can facilitate energy saving. An advantage of this system (system V) is its autonomy, and a disadvantage is its high cost (about 200,000 rbl. [3]) and accordingly a low (15-year) recoupment period.

And one should note the fact that the latter system with photo-electric (solar) batteries, in December being the most "dark" month of year, is capable of generating energy normal for this period, and in other months it generates some energy excesses (Fig. 8).

Ideally, these surpluses should be added to the power supply circuit of the energy generating company. At present, this principle is already implemented in EU, the USA, Canada, Japan and in some other countries, and action of the stimulating programs increases sales volume of "green" energy year by year [4, 5].

A well-adjusted system of such sales will essentially reduce payback periods of illumination systems with photo-electric batteries for entrance halls. In our case the illumination system is capable of providing an energy surplus of up to 7000 kW·h a year and accordingly, to "earn" up to 26000 rbl. accelerating the payback to five years.

So, when the longevity of the investment is considered, autonomous systems of illumination of entrance halls with a photo-electric power supply, are most effective.

CONCLUSION

Based on the document developed by the Min-region of the Russian Federation[7], which provides a full structuration of power consumption by introducing standard and above permitted standard modes of power consumption, with corresponding limit and

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6 The productivity data of these batteries depending on external illuminance were taken from work [3].

7 This came into effect on the 1st July, 2013 and determines a social standard of power consumption in 16 pilot regions of the Russian Federations, and since the 1st July, 2014 over the whole territory of the RF.

super-limit tariffs, including communal areas (staircase sites), the authors consider illumination system IV as the most acceptable in the present economic conditions for communal areas.

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ANALYSIS OF PROPERTIES OF LIGHTNING-OPTICAL EQUIVALENTS OF TRADITIONAL BULBS FOR DIMMING

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ABSTRACT

A wide range of equivalents hit the market prior to the introduction of laws prohibiting the sale of energy intensive prime set bulbs. Year after year the offered range becomes more and more opulent. The major disadvantage of compact fluorescents and LED light sources installed in households was their deployment in combination with light intensity regulators – so called dimmers. The response to this problem was the introduction of traditional bulbs equivalents. The paper presents the results of laboratory measurements of the change in photometric and colorimetric parameters as a function of dimming levels of light sources suitable for dimming. A conventional bulb was examined as well to investigate the question: how far are the changes coherent with photometric and colorimetric parameters of a classic bulb.

Keywords: light source, dimmer, spectral distribution, correlated colour temperature, colour rendering index, luminous flux

1. INTRODUCTION

Due to the gradual withdrawal of traditional light bulbs from the market, once traditional bulbs burnt out the user had no choice but to replace them with their energy saving equivalents. The range offered by producers of electrical light sources is very wide. LED lights, halogen bulbs and compact fluorescent lights are all on offer. Unfortunately, only a few of these (apart from halogen bulbs with a voltage capsule) render themselves to dimming. While there

are numerous publications describing the features of the equivalents of traditional light bulbs [1, 2, 3, 4, 8, 9, 10, 11, 12, 13, 14, 15], when it comes to light sources designed to work with a regulator of luminous intensity the available literature is rather limited. This may arise from the fact that firstly they are not commonly used in households and secondly that their prices are three or even four times higher than those of typical energy saving equivalents.

2. SUBJECT AND RANGE OF RESEARCH

Measurements were made of a traditional 60 W light bulb and its three equivalents: a halogen bulb, a compact fluorescent lamp and an LED source. General information about the sources tested can be found in Table 1. A schematic model of the lamps tested is presented in Fig. 1.

According to the producers, light sources such as a halogen bulb and a LED source can be regarded as close equivalents of a traditional 60 W light

Fig. 1. The models of the light sources tested, 1-traditional light bulb, 2-halogen bulb, 3 – compact fluorescent lamp, 4 – LED source

Table 1. General information about the sources tested

L #	U, V	P, W	Φ, lm	Durability life span, h	class	Dimming range
1	230	60	_ 710	1 000	E	x
2	230	42	_ 630	2 000	C	x
3	220–240	20	1 300	16 000	A	2–100 %
4	220–240	12	_ 810	25 000	A	100 %

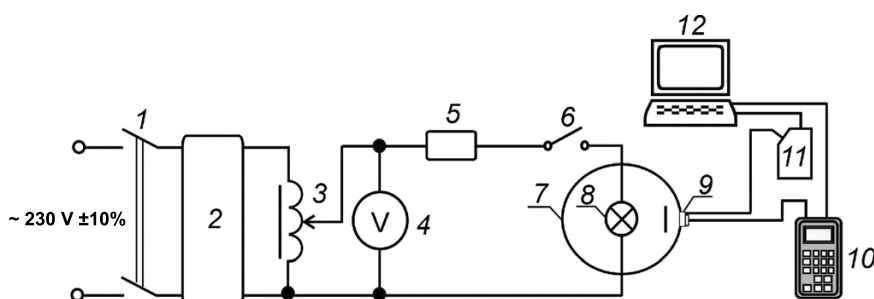1 – traditional light bulb, 2 – halogen light bulb, 3 – compact fluorescent light source, 4 – LED source
x – no information

Fig. 2. Schematic diagram of the measuring system

1, *6* – mains switches, *2* – voltage stabilizer *3* – autotransformer, *4* – digital voltmeter, *5* –light intensity regulator, *7* – integrating sphere, *8* – tested light source, *9* – port, *10* – steering unit of a luxmeter, *11* – spectrometer, *12* – PC computer

bulb as far as the luminous flux is considered. At the same time, an integrated compact fluorescent light is an equivalent of a traditional 100 W light bulb. Even though the range of equivalents of traditional light bulbs on offer is very wide, only a few producers offer dimmable light sources. It is worth stressing that while in the case of non dimmable compact fluorescent light and LED sources the market offers light sources, which are equivalents for basically the whole range of normalized power, in the case of dimmable sources the equivalents of traditional bulbs of only specific powers e.g. 60 W or 100 W are available. It might be expected that when regulating the light stream of classical light bulbs their other parameters will be affected. This article concentrates on the photometric and colorimetric features of the tested light sources. To assess how much those changes are convergent with changes in the selected parameters of the traditional light bulb the appropriate measurements were made.

The curves of spectral distribution in a range between 380–780 nm (with a 1 nm interval) were measured in five settings of the thyristor light intensity regulator (the dimmer), on the basis of these measurements the chromatic coordinates, correlated co-

lour temperature and colour rendering index were calculated. Luminous intensity values were added.

As producers of compact fluorescent lights and LED sources state in their specifications that their products are able to work with any type of dimmer when testing the relative values of the light stream, two methods of dimming applied in households were used. The first was through regulation of the flow angle, which means cutting each alternating current half-cycle. Such a solution is used in thyristor dimmers. The second involved altering the voltage amplitude, which can be achieved by using the autotransformer.

3. RESEARCH MEASURING SYSTEM AND MEASUREMENT METHOD

Before carrying out the measurements in accordance with the standard method [5] the sources to be tested were burnt for 100 hours at a nominal voltage.

A mains electric current of 230 V ±10 % (1) is passed via a switch on to the voltage stabiliser (2), which ensures its constant efficiency (Fig. 2). It is further regulated by an autotransformer (3), while its voltage is checked by a voltmeter. Then,
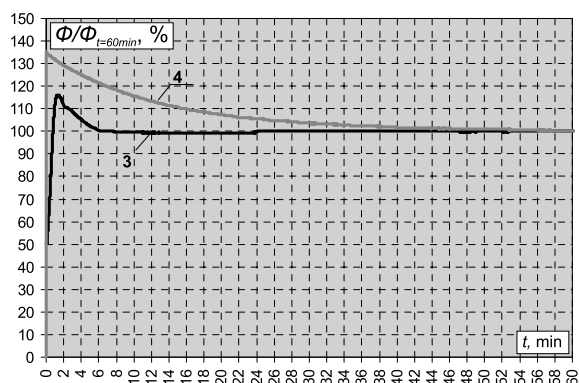
Fig. 3. Relative changes of the luminous flux of the equivalents of traditional bulbs, after connecting a nominal voltage with an RMS value 230 V: 3 – fluorescent light, 4 – LED source
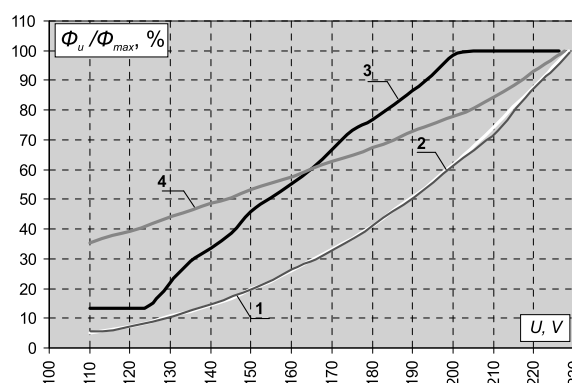

Fig. 4. Relative changes of the luminous flux of tested light sources with the voltage regulated by a thyristor dimmer, 1 – traditional light bulb, 2 – halogen bulb, 3 – compact fluorescent light, 4 – LED source
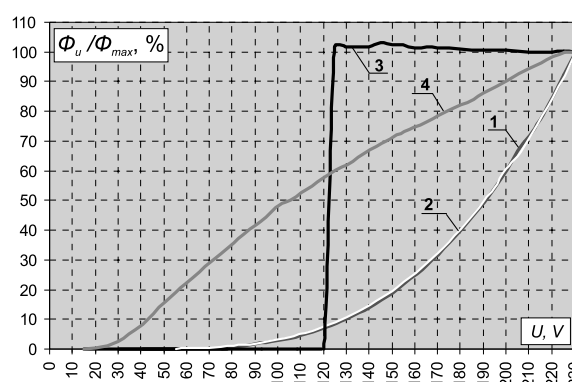

Fig. 5. Relative changes of the luminous flux of the tested light sources with the voltage regulated by autotransformer, curve markings identical to Fig. 4

via a light intensity regulator (5) and a switch (6), the current is transferred to the tested light source (8) which is located in an integrating sphere. In the port of the sphere (9) a photoelectric cell of a lux-meter (10) and an optical fibre working with a spec-trometer (11) are placed. All the measurements are transferred to a computer, and saved on a hard disc as a file, which can be opened by any spreadsheet application.

The spatial scattering of luminous flux emitted by particular light sources was established using the well-known goniophotometric method.

4. RELATIVE CHANGES OF THE EMITTED LUMINOUS FLUX

Measurements were taken for the conventional bulb and its three replacements, working with light intensity regulators, in order to establish the influ-ence of the knob setting of the dimmer on the value of the emitted luminous flux. As the values of the luminous flux emitted by particular light sources differ, changes in the lamp brightness are present-ed as relative values (non-dimensional) normal-ised by the values obtained at the maximum setting of the dimmer knob. By using an autotransformer as a regulator of the light intensity, the maximum level entails setting the knob to a position in which the effective level of the voltage on the secondary side is 230 V. A visualisation of the results (using two ways of regulating the light intensity) is pre-sented in Figs. 3–4.

In the case of a compact fluorescent light (source 3) and an LED (source 4) changes in the luminous flux were observed just after connecting to the pow-er source, even before any regulation of the lumi-nous flux was attempted. This made it possible to determine the time needed to stabilise the luminous flux. The relative changes in the value of the lumi-nous flux of sources 3 and, 4 starting from the mo-ment of connecting the power source, are shown in Fig. 5.

5. SPATIAL SCATTERING OF THE LUMINOUS FLUX CURVES

It is commonly known that the spatial scatter-ing of the luminous flux depends on how the sur-face of the light emitting solid of the light source is shaped. In the case of incandescent bulbs this can be a tungsten filament and in the case of fluorescent lights – discharge tubes. When we take into con-sideration electro-luminous light sources, the fac-tor influencing the shape of the photometric solid is their construction and the kind of optical system
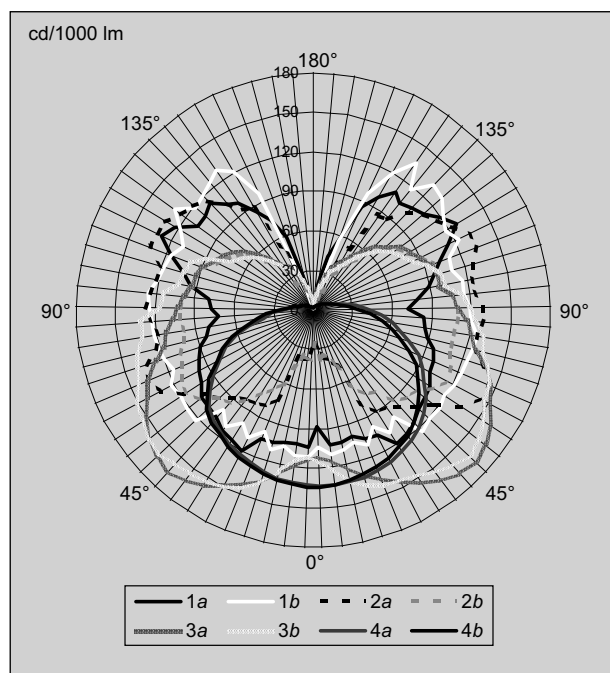
Fig. 6. Luminous intensity curves of the tested sources: 1-incandescent light bulb, 2 – halogen light bulb, 3 – compact fluorescent light, 4 – LED source, in two planes perpendicular to each other a) C0-C180, b) C90-C270
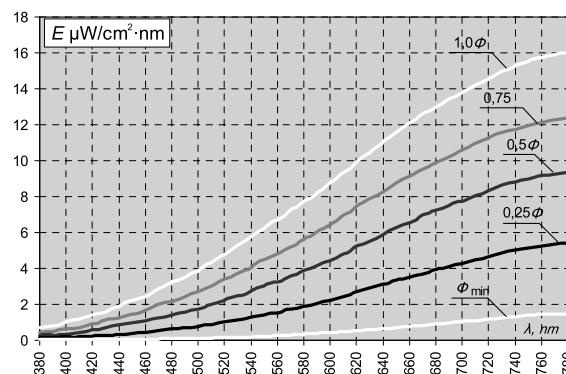

Fig. 7. Spectral distribution curves of the incandescent light bulb (source 1) working with a thyristor light intensity regulator

the voltage on the lamp was 143 V (which equals 0.5 F). Considering the fact that the luminous intensity curves remained practically the same (except for capacity), further measurements of the remaining light sources were abandoned.

6. CHANGES OF THE SPECTRAL DISTRIBUTION CURVES

For specific settings of the knob of the thyristor light intensity regulator corresponding to the following values of the luminous flux: 100% (the maximum value), 75%, 50%, 25% and the minimal value (which is different for particular light sources), the following spectral distributions were observed (Figs. 7–10).

The registered spectral distributions emitted by the tested light sources in particular settings of the thyristor light intensity regulator knob were the basis for calculating the following: the values of the chromatic coordinates x, y (CIE 1931), the correlated colour temperature T_{cc} and the colour rendering index R_a. The results are presented in Table 2.

In order to establish how much the obtained values differ from the values obtained for the incandescent light bulb, the appropriate information was added to Table 2 as well. Namely, data on the difference values for: chromatic points Δx, Δy, correlated colour temperature ΔT_{cc} and colour rendering index ΔR_a were added.

As incandescent light bulbs and their energy saving equivalents (fluorescent light, LED sources) produce light in different ways, their parameters, such as the correlated colour temperature and the colour rendering index, have to differ. However, to understand to what degree those changes (while

applied. As current technology is based on single diode low stream light sources, the number of LEDs is multiplied for practical reasons. These are usually placed on one surface. This strengthens the luminous flux. Such a solution was employed in the tested LED lamp, which is the number 4 tested light source. Additionally, the producer equipped this light source with a milky semi-spherical shade. This plays the role of a secondary (exterior to the LED matrix) optical system. Details about the possibilities of shaping the spatial scattering of the luminous flux when using LED sources can be found in the references [5].

Different shapes of the surface from which luminous flux is emitted for the tested lamps thus result in different spatial scattering of luminous flux.

Curves of luminous intensity are shown in Fig. 6. Particular polar curves (established on the basis of measurements with 5° angular steps) were converted into an omni-spatial light source of 1000 lm.

The luminous intensity curves shown in Fig. 6 were determined while the tested light sources were stabilised by a mains voltage of RMS 230 V. When it comes to the compact fluorescent light source, the measurements were taken one more time after connecting a thyristor light intensity regulator. The knob of the dimmer was set in such a position that

Table 2. Comparison of chromatic coordinates *x, y* (CIE 1931), the correlated colour temperature T_{cc} and the colour rendering index R_a while regulating the light intensity of the tested light sources with a thyristor dimmer

L,#	x	y	Δx	Δy	$T_{cc},$ K	$\Delta T_{cc},$ %	R_a	$\Delta R_{a,}$ %
The maximum value of the luminous flux (1,0 Φ)								
1	0.4533	0.4076	-	-	2770	-	99.9	-
2	0.4442	0.4044	0.0091	0.0032	2918	5.3	99.3	-0.6
3	0.4423	0.3948	0.0110	0.0128	2836	2.4	84.0	-15.5
4	0.4359	0.4625	0.0174	-0.0549	3437	24.1	74.9	-24.6
75% of the maximum value of the luminous flux (0,75 Φ)								
1	0.4592	0.4088	-	-	2696	-	99.3	-
2	0.4521	0.4069	0.0071	0.0019	2783	3.2	98.8	-0.5
3	0.4471	0.4001	0.0121	0.0087	2803	4.0	83.7	-15.7
4	0.4409	0.4596	0.0183	-0.0508	3338	23.8	73.1	-26.4
50% of the maximum value of the luminous flux (0.5 Φ)								
1	0.4698	0.4105	-	-	2565	-	98.9	-
2	0.4618	0.4084	0.0080	0.0021	2656	3.5	98.2	-0.7
3	0.4542	0.4049	0.0156	0.0056	2736	6.7	82.0	-17.1
4	0.4453	0.5936	0.0245	-0.1831	3268	27.4	72.0	-27.2
25% of the maximum value of the luminous flux (0.25 Φ)								
1	0.4843	0.4105	-	-	2396	-	98.1	-
2	0.4712	0.4099	0.0131	0.0006	2544	6.2	97.9	-0.9
3	0.4562	0.3948	0.0281	0.0157	2711	13.1	81.5	-20.3
4	0.4516	0.4564	0.0324	-0.0459	3153	31.6	71.0	-28.1
The minimal value of the luminous flux (Φ_{min})								
1	0.5053	0.4060	-	-	2142	-	94.1	-
2	0.4834	0.4101	0.0219	0.0499	2398	10.7	93.8	-1.0
3	0.4381	0.3711	0.0672	0.0349	2695	20.5	79.1	-19.0
4	0.4612	0.4489	0.0441	-0.0429	2964	38.4	70.0	-34.0
Numbers correspond to symbols of the tested light sources as in Table1.								

regulating the luminous flux) are in phase with the changes observed in a traditional light bulb it seems reasonable to present colorimetric parameters in relative non-dimensional values (Figs. 11 and 12). Values obtained without dimming of the light sources (dimmer knob set to maximum) were chosen as reference values.

Relative changes of photometric parameters obtained after changing the position of the dimmer from maximum to minimum are shown in Table 3.

7. CHANGES IN LUMINOUS EFFICACY

As far as light source are concerned, the requirements of modern light technology are not limited to the ability of obtaining a large enough light flux. The economic factor, which is dependent on the efficacy of the light source used, has played an important role for a long time. The luminous efficacy is a parameter which informs the efficiency with which the light source provides visible light from the mains
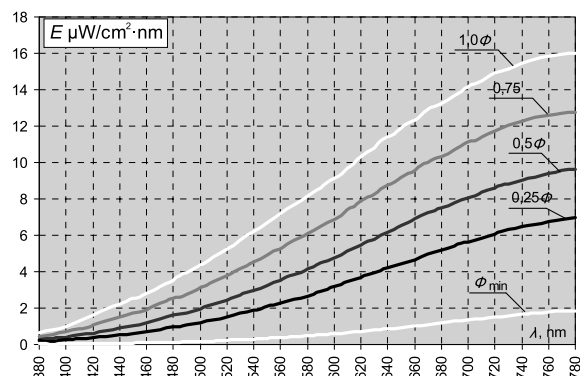
Fig. 8. Spectral distribution curves of the halogen bulb (source 2) working with a thyristor light intensity regulator
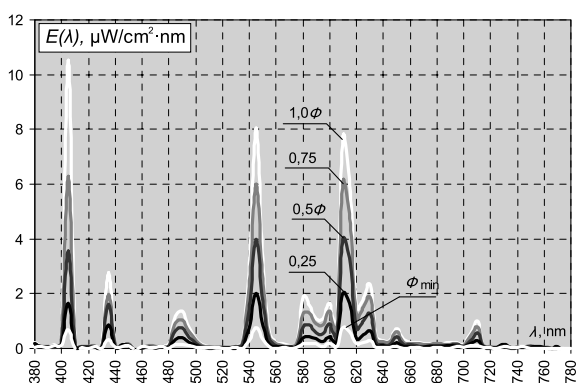
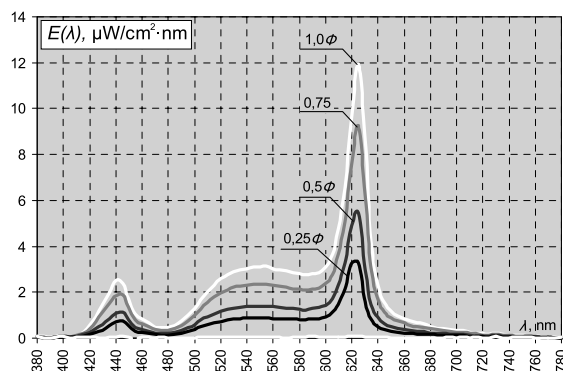| Source	1	2	3	4
ΔT_{cc}	22.7%	17.8%	4.9%	13.8%
ΔR_a	5.8%	5.5%	5.8%	6.5%

Fig. 10. Spectral distribution curves of the LED source (source 4) working with thyristor light intensity regulator.

Fig. 9. Spectral distribution curves of the integrated compact fluorescent light (source 3) working with a thyristor light intensity regulator

electric power. It is self evident that the luminous efficacy of the tested light sources when connected to the mains power is different. However, in the author's opinion, it is informative to analyse the changes in this parameter during dimming. To investigate whether dimmer light is more economical, a power analyzer was connected into the measuring system shown in Fig. 2. This was to measure the active power used by the light source installed in an integrating sphere. The results of the measurements are presented in Fig. 13. The measurements were taken when the lamps tested worked with a thyristor light intensity regulator and with an autotransformer. Taking into account the results presented in Fig. 5., in the case of a compact fluorescent light the measurements were taken only while working only with a thyristor light intensity regulator.

8. SUMMARY

The following conclusions can be drawn on the basis of the measurements obtained. Incandescent light bulbs have the biggest range of light intensity regulation regardless of the type of dimmer. When it comes to the compact fluorescent bulb and the LED source, the degree to which they can be dimmed significantly depends on the type of light intensity regulator used. When applying a thyristor light intensity regulator, the luminous flux emitted by the compacted fluorescent light can be reduced by approximately 87%, and in case of the LED source by approximately 64%. When the thyristor dimmer was replaced with an autotransformer with a voltage range between 125 and 230 V a fractional increase (about 2–3%) in the luminous flux was observed in the compact fluorescent light bulb. Lowering the mains voltage to below 125 V resulted in no luminous flux emission. Therefore, it can be assumed that the autotransformer is not suitable for use as a dimmer with a compact fluorescent light source. As far as the LED source is concerned, applying the autotransformer as a dimmer made a full range of luminous flux regulation possible (from 0% to 100%).

In the cases of the tested lamps, the registered luminous intensity curves differ significantly. The halogen bulb emits the smallest amount of the luminous flux to the lower half-space. Whereas, the LED source basically emits half-spatial light. In analysing

the spatial scattering curve of the LED source, one may ask if this light source can be regarded as a type of directional lamp. To answer that question in accordance with the EU Commission Regulation [7], the percentage of the luminous flux within a solid angle of π sr, corresponding to a cone with angle of 120^0, has to be determined.

In order to do this, simple measurements were made, based on which it was established that the luminous flux falling into the solid angle is at 62 % of the total luminous flux emitted by that source. Therefore, taking into account the fact that the percentage of the total luminous flux falling inside the solid angle is lower than 80 %, then in accordance with the definition given in the EU regulation [7] this light source is a non-directional lamp. In spite of categorising the LED source, together with incandescent light bulbs, as a non-directional lamp the lighting effect of both sources is different.

Another parameter characterising the quality of the emitted light is the colour rendering index. As light intensity of the tested sources was lowered, a fractional decrease in the colour rendering index was observed. With certain approximation, it can be stated that it was at the same level for all sources tested.

As the light intensity decreases, the ordinate values of the spectral distribution curves also decrease. As the degree of these changes is not the same for the whole range of visible optical radiation, there are also changes in the colour temperature. For the incandescent bulbs the maximum drop in colour temperature was 20 %. In the case of the energy saving equivalents (i.e. the highest energy class sources) it is lower.

Summing up the above it can be concluded that a halogen bulb can be treated as an immediate equivalent of an incandescent bulb. That is due to the fact that it has an identical range of luminous flux regulation and similar colorimetric parameters whose changes when dimmed were at a similar level. Unfortunately, taking into account its spatial light scattering, the results obtained for the compact fluorescent lamp were more optimistic.

Whilst talking about spatial light scattering – typical of the given light source – it must be considered that the luminous curves presented will only matter when those lamps are installed in a lamp holder without any shades. In reality such situations are very rare. Light sources in households are usually placed lamp holders equipped with diffusing shades. In such cases the light-emitting solid without
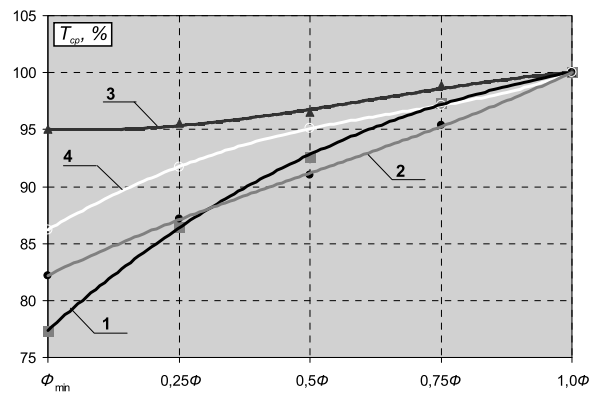

Fig. 11. Relative changes of the correlated colour temperature T_{cc} in the luminous flux function, 1 – traditional light bulb, 2 – halogen bulb, 3 – integrated compact fluorescent lamp, 4 – LED source
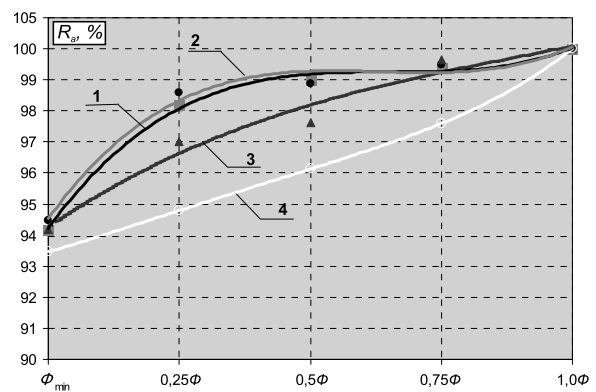

Fig. 12. Relative changes of the colour rendering index R_a in the luminous flux function. Curves markings as in Fig. 11
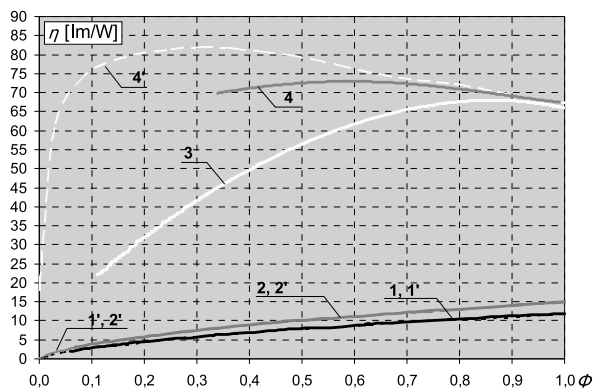

Fig. 13. Changes in the luminous efficacy when testing the light intensity of the four sources. Curves markings as in Fig. 11. Curves 1', 2' and 4' refer to lamps working with an autotransformer

any shade will be transformed causing a light effect which is not necessarily negative.

From a user's point of view, the most important element seems to be the luminous flux regulation range offered. When producers state that their product is 100 % dimmable they imply that the light intensity of a lamp can be reduced to zero, no matter what type of dimmer is used. However, the results of the tests, even though they were carried out for only one light source, contradict this claim. According to the results, the information regarding the dimming range provided by producers should come with the following caveat: "depending on the type of dimmer used".

The economic aspect seems to play an important role as well. Decreasing the light intensity in both incandescent bulbs and compact fluorescent lights results in lowering the light efficacy. The results are quite different with regard to a LED source. When dimming this light an increase in the light efficacy can be observed. It is worth noticing that when dimming the LED source the light efficacy is significantly influenced by the method of regulating the light intensity used.

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CONTENTS

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