ISSN 0236-2945

LIGHT & ENGINEERING

Volume 27, Number 4, 2019

Editorial of Journal
"Light & Engineering" (Svetotekhnika), Moscow

The purpose and content of «Light & Engineering» is to develop the science of light within the framework of ray, photometric concepts and the application of results for a comfortable light environment, as well as for visual and non-visual light technologies, including medicine. The light engineering science is a field of science and technology and its subject is the development of methods for generation and spatial redistribution of optical radiation, as well as its conversion to other forms of energy and use for various purposes.

The scope of journal includes articles in the following areas:

- Sources of light;
- Light field theory;
- Photometry, colorimetry and radiometry of optical radiation;
- Visual and non-visual effects of radiation on humans;
- Control and regulation devices for light sources;
- Light devices, their design and production technology;
- Light devices for the efficient distribution and transportation of the light energy: hollow light guides, optical fibers;
- Lighting and irradiation installations;
- Light signaling and light communication;
- Light remote sensing;
- Mathematical modelling of light devices and installations;
- Energy savings in light installation;
- Innovative light design solutions;
- Photobiology, including problems of using light in medicine;
- Disinfection of premises, drinking water and smell elimination by UV radiation technology;
- Light transfer in the ocean, space and other mediums;
- Light and engineering marketing;
- Legal providing and regulation of energy effective lighting;
- Light conversion to other forms of energy;
- Standardization in field of lighting;
- Light in art and architecture design;
- Education in field of light and engineering.

Journal "Light & Engineering" had been founded by Prof. Julian B. Aizenberg in 1993

LIGHT & ENGINEERING

СВЕТОТЕХНИКА

Editorial of Journal "Light & Engineering/Svetotekhnika"

Moscow, 2019

Editorial Office:

Russia, VNISI, Rooms 327 and 334
106 Prospekt Mira, Moscow 129626

Tel: +7.495.682.26.54
Tel./Fax: +7.495.682.58.46
E-mail: lights-nr@inbox.ru
http://www.l-e-journal.com

Scientific Editors:

Light & Engineering" is an international scientific Journal subscribed to by readers in many different countries. It is the English edition of the journal "Svetotekhnika" the oldest scientific publication in Russia, established in 1932.

Establishing the English edition "Light and Engineering" in 1993 allowed Russian illumination science to be presented the colleagues abroad. It attracted the attention of experts and a new generation of scientists from different countries to Russian domestic achievements in light and engineering science. It also introduced the results of international research and their industrial application on the Russian lighting market.

The scope of our publication is to present the most current results of fundamental research in the field of illumination science. This includes theoretical bases of light source development, physiological optics, lighting technology, photometry, colorimetry, radiometry and metrology, visual perception, health and hazard, energy efficiency, semiconductor sources of light and many others related directions. The journal also aims to cover the application illumination science in technology of light sources, lighting devices, lighting installations, control systems, standards, lighting art and design, and so on.

"Light & Engineering" is well known by its brand and design in the field of light and illumination. Each annual volume has six issues, with about 80–120 pages per issue. Each paper is reviewed by recognized world experts.

CONTENTS

VOLUME 27 NUMBER 4 2019

LIGHT & ENGINEERING

Dear Readers!

You are holding the first special issue of the Light & Engineering Journal, based on the original editions of the reports at the conference "Light in the Museum", which was held from April 18 to 20, 2018 in Sant Petersburg at the State Hermitage Museum.

The editors of the journal believe that this form of publication will occupy an important place in the work of our editorial board. To create a special issue, two conditions are necessary: firstly, the presence of an important and relevant scientific and technical problem, and secondly, the presence of an organization capable of uniting the efforts of specialists to solve this problem.

In this case, the State Hermitage Museum, VNISI named after S.I. Vavilov and the Scientific and Technical Council of the lighting industry "Svetotekhnika", which, with the support of the Russian Committee of the International Council of Museums (IKOM of Russia), provided the possibility of holding the conference "Light in the Museum".

Lighting of museum objects should provide the possibility of their adequate visual perception, but at the same time have a minimal negative impact on the safety of these objects. The lighting designer always seeks to resolve the dilemma: it's good to see the collection today or "good" to see it in the future. The inconsistency of these requirements, designed to meet the needs of contemporaries and protect the interests of future generations, leads to the fact that in contrast to the usual practice of standardizing lighting, which stipulates the minimum acceptable level of illumination, in the case of museum lighting, the maximum permissible value of illumination is usually normalized.

At the same time, the use of LEDs opens up completely new perspectives in museum lighting, in the spectrum of which there is no UV radiation that is most destructive for works of art.

At the conference, almost 30 reports were made in all areas of museum lighting and two round tables were organized: "Principles of exposure lighting in modern museums" and "Lighting equipment for lighting museums."

This issue contains articles written on the basis of reports from both museum staff who formulated lighting requirements and identified the problems they face when organizing museum objects lighting, as well as lighting technicians and lighting designers who analyze the possibilities of modern lighting equipment and describe approaches to solving problems exposure lighting.

On behalf of the Editorial Board
V.P. Budak Editor-in-chief of the Light & Engineering / Svetotekhnika Journal, Prof., Doctor of Technical Sciences, Full Member of RAEN

Light & Engineering
Vol. 27, No. 4, pp. 5–10, 2019
https://doi.org/10.33383/2018-145

WHY IT IS NECESSARY TO REVISE THE STANDARDS OF EXHIBITION LIGHTING

Alexei V. Bogdanov and Vladimir A. Smirnov

The State Hermitage Museum, St. Petersburg
E-mail: bogdanov@hermitage.ru

ABSTRACT

In the modern world, one of the main functions of museums is to organize the preservation of pieces of art and arrange their presentation to museum visitors. Since the modern exhibition is based on the artificial lighting, it is necessary to properly arrange this lighting; otherwise, it can negatively affect the safety of museum pieces. The article sets out the views on the criteria of professional lighting of works of art, as it is always a compromise between the custodians and the lighting engineers. The authors also attempt to disclose the processes of organizing museum lighting and give a generalized description of the standards and rules, which serve as a basis to realize this lighting. The main reasons for the need to rethink these standards and rules (and even to revise them), in connection with the emergence of new LED sources, have been outlined.

Keywords: museum, lighting engineering, classification of museum pieces, preservation of museum pieces, lighting standards, museum exhibition lighting, daylighting, artificial lighting, LED sources, exposure to light on exhibits, optimal conditions for the perception of fine art

1. INTRODUCTION

The cultural development of people involves visiting various events, museums, which are open all year round. The museum is the most interesting place in terms of lighting, because here you need to create the correct composition and its lighting so that the visitors would come again and again [1].

The museum lighting involves many details necessary to achieve high-quality lighting of various exhibitions and works of art. However, it should be kept in mind that, one way or another, the modern exhibition is based on artificial lighting.

The museums, regardless of their focus area and specificity, almost always have one single goal: the education. They hold a variety of exhibitions aimed at introducing people to cultural values, as well as demonstrating the achievements in various areas of human activity: from art to archaeology. Therefore, the lighting system is the most important for museums, as it is the means to achieve the desired result: to focus visitors' attention on the elements of the exhibition. Museum lighting is considered to be the most complex of all other types of lighting.

In museums, the light should perform the following functions:

– Fully illuminate the exhibited items;
– Create accent lighting depending on the purpose of the exhibition;
– Provide full lighting of the rooms so that people can freely move through;
– Advantageously emphasize the works of art or other exhibited items against the background of the museum premises.

It is difficult to create high-quality lighting of exhibited items in museums for the following reasons:

– Exhibition rooms in museums should be spacious;
– In one room, the exhibition can be arranged in various ways: along the walls, in the centre, on special showcases and pedestals, or in both versions;

– The lighting installation in each room should be based on certain standards and requirements, which are given in the regulatory documentation;

– It is not always possible to properly arrange daylighting in museum premises due to the specifics of the structural arrangement and in addition, the daylighting changes throughout the year depending on the season and weather conditions;

– For the exhibition lighting to be of high quality, the lighting system in the museum premises should be universal to provide high-quality lighting regardless of the exhibition arrangement;

– In the case of poor-quality engineering and selection of lighting equipment for the installation of lighting systems, the standards of lighting and requirements for the lighting of art pieces may be infringed. When installing the lighting system, it is necessary to comply not only with the requirements and standards, which we will further discuss, but also with the purpose of the exhibitions.

The vast majority of museums around the world, as well as exhibitions and galleries, organize exhibitions of fine arts. For them, the most important is the installation of artistic lighting. In addition, the main goal here is to organize the correct light image of the exhibited items to provide a powerful emotional and psychological impact on visitors. In such a situation, museum lighting is to seek a compromise between the poles apart: ensuring the preservation of exhibition items (for example, paintings with certain dose limits[1], which, as a result of prolonged light exposure, can be discoloured and destroyed), on the one hand, and the need to adequately demonstrate masterpieces, on the other hand [1].

Improper lighting (strong, bright, containing infrared and ultraviolet radiation) has a devastating effect on exhibited items with low light resistance. In order to avoid such negative developments, there are certain requirements for the organization of proper artistic lighting. Such requirements include the correct selection of lighting according to the following parameters:

– Colour rendering: the right colour rendering of the light source can best convey the colour solution of the displayed paintings or other works of art;

– Illuminance: this indicator at high values can lead to a rapid discolouration of the exhibited items;

– The distance from the exhibition to the light source. Coming from a short distance, a constant and directional luminous flux is able to heat the illuminated surface, which, again, can lead to damaging the paints and canvas.

Considering the fact that the works of art acquire the value over time, which also destroys them, the installation of museum lighting of this kind requires the highest professionalism, as well as extensive expertise in the art and lighting engineering. Only in such a situation not only the requirements and standards would be complied with, but also the peculiarities of each piece of art presented at the exhibition would be taken into account. **In this situation, the skills of a lighting engineer and the modern equipment, after the exhibited items themselves, are the key to the success of art museums and exhibitions** [1].

2. MUSEUM EXHIBITION LIGHTING

In addition to artistic lighting, the museums often use exhibition lighting to highlight the certain areas of the premises.

Such lighting of museum exhibition halls shall comply with the following requirements:

– High-quality presentation of an item, so that visitors can fully view all its elements and details: colour, material, and texture;

– Taking into account the physiological features of the human visual analyser;

– The safety of exhibited items. Under light exposure, the paper becomes yellow, the organic elements disintegrate, and the chemical composition of the paints is subject to irreversible changes.

At the same time, in order not to overstrain human vision, the exhibition lighting should protect visitors from the blinding effects of luminaries for paintings, all kinds of glare. Besides, the design of lighting installations should be taken into account: skilfully conceal them, if it is a palace interior, and make them most lightweight and imperceptible in the exhibition space.

When selecting the light sources to illuminate paintings in a gallery or museum, it is necessary first of all to be guided by specific tasks. Incandescent, traditional, and halogen lamps have the advantage of a constant spectrum that provides a perfect colour rendering with the colour rendering index equal to 100. However, the legislation explicitly prohibits their purchase for cultural institutions fi-

[1] In respect to museum lighting, it is an integral of the illuminance over the time for a certain period of time

nanced from the state budget. It is worth noting that due to such requirements for museum lighting, the standard methods in this situation will not ensure the desired result, but rather accelerate the damage of exhibited items. Here, not only the standards of lighting level, as well as the state standards for lighting equipment, should be taken into account, but also many additional factors. For example, in the exhibition of paintings, when installing optimal lighting, it is important to consider the texture and colour of the walls, as well as the architectural aspects of the exhibition room and the arrangement of window openings. The ideal conditions for exhibiting a variety of works of art are the premises completely closed from the natural light [1].

3. THE STANDARDS SET FOR MUSEUM LIGHTING

All lighting systems installed in museums are aimed at the most effective presentation of the exhibited items, as well as at their preservation. All this is ensured by the lighting standards, prescribed in the special documentation, but they are set for incandescent lamps and cannot serve as a guide when using LEDs.

In this situation, unlike industrial, public, and residential premises, where the standards have minimum values, they are given to the maximum for museums. This means that these standards shall not be exceeded.

Moreover, each type of exhibited item has its lighting limits [1, 2]:

- Newsprint paper, fabrics, and watercolours have a maximum lighting level of 50 lx;
- Oil paintings have a level of 150 lx;
- Precious stones and metals have a level of 500 lx.

In addition, the requirements prescribe the minimization of infrared and ultraviolet radiation in the radiative flux. Ultraviolet radiation can have a direct negative impact through the destruction of molecular bonds, and infrared radiation can have the indirect one, provoking ageing of materials due to increased speed of chemical reactions at high temperature. In addition, the greatest danger is ultraviolet radiation.

National standards, recommendations, and requirements, as well as the state standards, were developed when the harmful impact of light on some works of art was not yet fully studied. Therefore, today in the world there is a clear tendency to revise the standards for museum lighting.

According to one of the recommendations, the museum pieces should be given a “rest” after 2–3 years of continuous exhibiting. This allows to extend their storage life, and also to some extent mitigates the harmful impact of permanent lighting for several years.

Obviously, the greatest impact on the works of art is not so much by the lighting as by the amount of energy they absorb. Therefore, today it is proposed to set the exposure rate for each item.

For this reason, daylighting and artificial lighting systems of exhibition halls and museum depositories should be considered as the factors that, to one extent or another, standardize the exhibition cycle. As can be seen, in terms of organizing the museum lighting, there are quite a lot of nuances, standards, and requirements, which are obligatory to comply with if you want to preserve the exhibited works.

Today, it is recognized that the best conditions for showcasing the works of fine art are the rooms without daylighting. This is not only due to the fact that sunlight carries a certain proportion of ultraviolet radiation, which adversely affects the art paintings. The following things ensure the high-quality and full-fledged lighting of exhibited items: the absence of glare from windows on the works of art and the absence of additional outdoor lighting [1].

However, at the same time, historical buildings very often play the role of museums:

- Mansions;
- Palace buildings;
- Railway stations.

In a situation where there are still windows in the rooms, it is preferable to close them tightly or to curtain them off. In this case, the windows should be covered with special films capable of absorbing ultraviolet radiation. However, it is impossible and often not necessary to completely obscure the daylight. Its absence changes the architecture of buildings, prevents the perception of buildings as works of art. Therefore, a compromise between daylighting and artificial lighting should be found. The search for the compromise is the skill of a museum lighting engineer. Therefore, the following requirements are currently necessary for museum premises and depositories:

- Strict compliance with regulations, which are mostly based on previous research;

Table 1. Classification of Museum Exhibited Items by Light Resistance [2]

Name of exhibited item and materials	Light resistance group	Colour group	Shape
Painting:			
Oil, tempera	II	3, 4	Flat
Watercolour, pastel	III	3, 4	Flat
Graphics:			
Black and white	III	1	Flat
Colour	III	3, 4	Flat
Iconography	III	3, 4	Flat
Manuscripts, books, newspapers	III	1	Flat
Photos	III	1, 3	Flat
Stamps	III	4	Flat
Jewels	I	3	Volume
Coins, medals, orders	I	2	Relief
Badges	I	4	Relief
Weapons	I	2	Volume
Clothing, fabrics, tapestry, lace, carpets, fur, leather	III	2, 4	Flat
Bone	II	2	Volume
Porcelain, ceramics, glass, enamel	I	2, 3	Volume
Utensils:			
Glass, metal	I	4	Volume
Wooden	II	4	Volume
Sculpture:			
Marble, gypsum, cast iron,	I	1	Volume
Bronze	I	2	Volume
Furniture:			
Wooden	II	3	Volume
With bronze parts	I	2	Volume
Minerals, rocks	I	1, 2, 3	Volume
Stuffed animal or bird	III	4	Volume
Technical Equipment	I	1	Volume

– Setting the luminous flux with quality colour rendering;

– High adaptability of the premises to different levels of daylighting;

– Elimination of harmful effects from lighting devices;

– Convenience and appropriate arrangement of exhibitions.

Only guided by these requirements, it is possible to create optimal and high-quality museum lighting according to its technical characteristics.

The museum premises, as well as the exhibited items, shall be subject to strict requirements. These requirements should be developed. Guided by them, it will be possible to achieve optimal lighting for any item: artistic, biological, etc. These rules and

Table 2. Proposed Illuminance Levels for the Main Museum Premises and Exhibited Items [2]

Lighted Item	Proposed average illuminance, lx	
	Horizontally at 0.8 m from the floor	At exhibition or working surfaces
A. Premises		
General lighting of the exhibition rooms, in which all the main exhibited items are specially illuminated	50	
General lighting of rooms with large volume exhibition, as well as rooms where the central exhibition is furniture, finish, or decoration	50–100	
General lighting of historical and natural-historical museums	50	
General lighting of technical museums	200	
Lobbies, walkways, and stairs for visitors	50	
Reserve stocks (in aisles)	50	
B. Exhibited items standing separately, as well as arranged on walls, stands, tables, shelves, showcases		
Exhibited items of Group I of light resistance, with very small details (for example, jewellery, coins, etc.)		300–500
Exhibited items of Group I of light resistance (e.g. marble sculpture, porcelain, weapon samples, etc.)		200–500
Exhibited items of Group II of light resistance (e.g. oil painting, wood, ivory, etc.)		75–150
Exhibited items of Group III of light resistance (e.g. watercolour, tempera, pastel, fabrics, manuscripts, etc.)		30–50
C. Museum staff workplaces		
Work tables in reserve stocks		200
Stands with exhibited items in reserve stocks		30

requirements shall be strictly complied with by all museums.

Since the presentation of a painting or sculpture requires a sufficiently high illuminance, while the preservation of the exhibited items is ensured at low levels, the museum lighting is always a compromise: the right solution here should be sought between the poles. Standard lighting techniques and the regulations in force specify only the right focus but do not provide ready-made answers. The situation is complicated by the fact that, in each case, many other factors have to be taken into account alongside the rules, for example, the colour and the texture of the walls, the architectural characteristics of the room, the arrangement of windows, and daily and meteorological changes in the lighting of the exhibition space. Moreover, the size of a work of art and its arrangement relative to the windows and other exhibited items should be always kept in mind, not to mention that it is impossible to adequately represent any work of art without deep insight into the author's conception. The ideal environment for each exhibited item inside the exhibition is always created by the efforts of a group of professionals, which includes lighting engineers, installation specialists, and art critics [3].

Today, due to the rapid progress in the production and introduction of light sources such as LEDs, the standards specified by the legislative and permissive documents developed for old light sources are outdated and cannot be the base for lighting project developers.

The current regulations in the Russian Federation have been developed for a long time and are mostly experimental because, at the time they were established, the impact of lighting on materials was not properly studied.

Today, a determined line is being set around the world to revise the generally accepted standards of exhibition lighting. The research initiated in Germany does not allow to agree with the staff of museums and art galleries who state that after three years of the exhibition it is necessary to give "rest", as in this case they are preserved much better. The experts found out that not even the illuminance level, but the relevant irradiation, the value of which is measured in each case, has a great impact. However, there are many known examples when watercolour works are in standard conditions under open daylighting for more than a hundred years and do not lose their properties, disproving any rules. In fact, the optimal lighting for each exhibited item should include the setting of the optimal irradiation rate, which depends on the chemical composition of the exhibited item.

The museum pieces (paintings, graphics, sculptures, arts and crafts, works of ethnography, archaeology, etc.) are very diverse in size, texture, they may be flat or voluminous, colour or black and white, light-resistant or not, located on the floor, walls, in special stands, showcases, cabinets, vertically, horizontally or inclined.

The classification of exhibited items depending on their light resistance, colour characteristics, and shape is given in Table 1. According to light resistance, all exhibited items are divided into 3 groups: high (I), medium (II), and low light resistance (III). According to colour characteristics there are 4 groups: achromatic or grey (1), that is, having no apparent colour characteristics; monochrome (2), having more or less identical colour on the whole surface; multicolour tonal (3), in which the colour tone of the surface changes, but it is possible to distinguish the predominant one; multi-coloured mottled (4), for which all colour tones can be considered identical [2].

It should be borne in mind that among the types of minerals classified in a particular group of light resistance, there may be types with different light resistance. For example, precious gems are mostly of high light resistance, but some of them (aquamarine, amethyst, alexandrite, turquoise) are less resistant to light. Some types of paints, glasses, ceramics, etc. may also have lower light resistance.

Optimization of lighting systems for museum premises subject to the requirements of storage and exhibiting should be decided on the basis of the lighting standards given in Table 2 [2].

REFERENCES

1. Osobennosti osveshcheniya v muzeyah: tipy podsvetki i normy [Features of lighting in museums: types of lighting and standards], 2016. URL: https://1posvetu.ru/svetodizajn/osveshhenie-muzeev.html
2. Devina R.A., Brednyakov A.V., Dushkina L.I., Rebrikova N.L., Zayceva G.A. Muzei'noe khranenie hudozhestvenny'kh cennostei': prakticheskoe posobie [Museum storage of art treasures: practical guidelines] // Tipografiya Ministerstva kul'tury RF, Moscow, 1995, 204 p.
3. Spetcifika e'kspozitcionnogo osveshcheniia v muzee [Specificity of exhibition lighting in museums]. URL: https://svetpro.ru/htm/informations/osvechenie_v_musee_info1.html

Alexei V. Bogdanov,
Ph.D. in Engineering Science, Associate Professor. Graduated from the Leningrad Electrotechnical Institute of Communications named after Prof. M.A. Bonch Bruevich (1984). Deputy General Director of the State Hermitage Museum

Vladimir A. Smirnov,
Graduated from the Leningrad Electrotechnical Institute named after V.I. Ulyanov (Lenin) (1980). Leading Engineer of the Office of the Chief Power Engineer of the State Hermitage Museum

Light & Engineering
Vol. 27, No. 4, pp. 11–16, 2019 *https://doi.org/10.33383/2018-146*

ASPECTS OF EXHIBITION LIGHTING IN THE STATE HERMITAGE

Boris G. Kuzyakin

State Hermitage Museum, St. Petersburg
E-mail: kusyakin@hermitage.ru

ABSTRACT

The article provides a brief overview of the aspects of exhibition lighting in the State Hermitage. The purpose of this publication is to give guidance to potential participants in the lighting projects of the Hermitage exhibitions on the challenges or limitations they have to face and on the exhibition lighting requirements they will be imposed by the museum.

Keywords: State Hermitage Museum, exhibition lighting, lighting of expositions

The purpose of this publication is to emphasize those special conditions that may complicate or hinder the work of both the designer and the exhibition lighting engineers in the State Hermitage. The issue of exhibition lighting, which is essential for any museum, is particularly relevant for the Hermitage. Traditionally, the Hermitage is ahead of all in terms of being equipped with the modern systems, and is often lagging because of its vastness. In ongoing exhibition, we have both showcases with lighting systems of the early 60s of the last century and LED systems of recent generations. The same can be said about the concepts laid in the creation of all these systems: From the naive "you need to screw in a bigger bulb" to planning the controlled distribution of light in the exhibition space.

From the conference "Light in the Museum" held from 18 to 20 April 2018 on the territory of our museum, we expected not only the opportunity to discuss the current state of affairs related to the issues claimed but also the opportunity to benefit from its work in our practical activity. There are many exhibitions in the Hermitage with the lighting not to be considered satisfactory. However, in many cases, the situation can be improved by the use of modern lighting systems, as progress in this industry has been noticeably accelerated in recent decades, and the scientific developments moved from the stage of experiments to the stage of mass production and entering the market of lighting equipment including LED devices of various purposes and quality. Moreover, the evolution of light sources is moving in the favourable direction for museum practice: Lighting fixtures become smaller, more economical, more efficient and safer, less visible.

The conditions in question, with a few exceptions, are not unique. For the most part, these are the usual problems of lighting the exhibitions in old palace buildings. Their combination in one museum complex is unique, multiplied by the scale of one of the largest museums in the world, where the period between the reconstructions of several exhibition sections can be measured by decades.

The first and obvious aspect that should be kept in mind during all further discussions on the topic "What to do with lighting in the Hermitage?", is that the expositions of our museum are located in the complex of buildings differing in time and original purpose: from the palace of Prince Menshikov, the first palace in St. Petersburg under construction, to the restoration and storage centre, the multi-stage construction of which has not yet been completed. Historical buildings, which are now occupied by the museum, are protected as architectural monuments, and this dictates very strict terms of their use, limiting the possibility of their adaptation under the needs of the current exhibition, including the lighting. The word "adaptation" is a key one, because even the building, which was designed in the 19th century as a museum, does not correspond to modern concepts of the exhibition lighting, as well as to the modern ideas about the exhibition. The Hermitage branch at the Imperial Porcelain Factory is located on the top floor of a reinforced-concrete factory building, the eastern wing of the General Staff Building, where various ministries were located, was constructed as a building for government agencies.

We will not consider the technical limitations that complicate the creation of modern lighting systems in the interiors of historical buildings. We will touch upon another aspect of these limitations – to what extent it is permissible to introduce not just in historical interiors, but for the most part, in those created by outstanding architects, the elements of modern engineering equipment with a purely modern and sometimes quite aggressive design.

The criteria in this area have evolved over time. For example, at the turn of the 70s – 80s, the proposal to introduce a suspended bus bar in the interiors of the French art exhibition on the second floor of the Winter Palace was completely rejected by the exhibition owners – the department of Western European art, as well as the museum management and the department of the chief architect. Over the next decades, we used suspended bus bars in historic halls with preserved interior decoration only at temporary exhibitions. This restriction actually lost its force quite recently, when in the Romanov gallery after the exhibition of works by Jan Fabre the bus bar was not dismantled, but remained as if forever, and it no longer caused protests – both museum staff and visitors have long been accustomed to such a kind of lighting equipment like the busbar and the luminaries hanging on it. The eye of the modern museum visitor is already accustomed to "bracket out" of perceived architectural environment such items together with other modern technical stuff.

Due to the wide variety and complexity of such situations in the Hermitage, we do not have a single recipe for such a case. Each situation is discussed individually, and the decision is made as a result of a certain balance between the daily needs of the going museum and the desire to preserve everything and not to change anything. At the same time, there are no pre-defined restrictions of conceptual nature. Not only technical innovations can be discussed, but also those related to the aesthetics. The main thing is that they should not be self--sufficient, "an invention for the sake of invention", for the sake of demonstrating the technical capabilities of the manufacturing company, for example, or dramatic transformation of the architectural environment, or self-expression of the lighting designer. We need to understand why, for what purpose, this or that concept is proposed going beyond the limits, how it helps to solve the core task – to ensure adequate perception of outstanding works of art presented at the exhibition.

The experience has shown that the most productive working practice is the mandatory phase of field modelling of new lighting systems, in which a commission consisting of representatives of the scientific department, supervising the exhibition, the department of history and restoration of architectural monuments, the department of the chief power engineer and the exposition and design department considers the established in the current exhibition the lighting fixtures, as well as the structures necessary for their fastening, which in this case can be represented as fragments. The same procedure is mandatory for all new, i.e. unfamiliar, lighting fixtures. This is due to the fact that according to only technical data, drawings and pictures in the catalogue, the art historian can hardly imagine what the luminary will look like in the interior, especially to imagine based on graphs and diagrams, how it will illuminate the exhibited item. The technical specifications, even the most detailed ones, will not give the other specialists a complete picture of the real light spot from a particular device, its uniformity, the degree of contours delineation, the presence of light rings, extraneous light, the presence of glowing cracks or holes on the casing during operation, etc.

In addition to the special status of the protected architectural environment, the palace buildings have other peculiarities.

For example, the proportions of the halls are such that the lighting fixtures installed on the cornices are focused on the exhibited items at an angle not sharp enough for the glare to be reflected in the floor or at least below the visitor's eyes. Many rooms are decorated with artificial marble walls or other shiny materials, which reflect the light sources installed above the cornice (as well as the windows facing the sunny side of the building). It should also be mentioned that the cornice may not be in the room – depending on the architectural treatment, a flat horizontal mould can be used instead, for example, on which the bus bar cannot be installed. And there can be simply a complex arch covering without any horizontal wall articulation. In such a situation it is sometimes possible to use a suspension bus bar, which, in addition, would provide illumination of walls at the proper angle. But the ceiling without moulding or painting for palace premises is very rare and, in most cases, does not allow a suspension bus bar using.

The bus bar installed on walls or hanging is not the only method of arrangement of exhibition lighting systems. At temporary exhibitions we widely use lighting devices on separate brackets, which are installed on exhibition stands. As necessary, this method is also used at the permanent exhibition. An example of the exhibition illuminated in this way is the tent-roofed hall, where for the first time in the Hermitage second-generation LED luminaries were used to illuminate paintings.

There are usually two other light sources on the exhibition, which, in most cases, do not help the correct lighting installation. These are windows, most of which, in the case of the front living quarters, look to the south-east or south-west and at least part of the day are exposed to direct sunlight. At the same time, illuminance changes in the exhibition surfaces could have reached several hundred lx during the day. Now this difference is smaller, due to the use of light-protective films and curtains, but still exists. Daylight, of course, is the least controlled component of the overall light scene.

For the Hermitage, the issue of open windows, that is the windows not closed with light protection means, is rather sensitive and, from time to time, is tensely discussed. There are views of rare beauty on Palace Square, Neva, the Spit of Vasilievsky Island and Peter and Paul Fortress from the windows of the palace complex. In a sense, it is also a part of the historical palace space. At the same time, the open windows in some cases do not just interfere, but do not even give the opportunity to properly arrange the exhibition lighting. The palace was built as a palace, not as an art gallery. Sometimes it is necessary to set priorities: What is more important for the visitor to view – an outstanding work of painting or architectural beauty outside the window. The museum management determined the answer to this question once for all: “Everything is more important and at once.” In each case we look for a compromise (or palliative).

Another disturbing source of light in the exhibition is historical lighting fixtures (chandeliers and floor lamps). In some rooms of the grand enfilade they are the only light sources. Their specific feature is a lot of glare reflected in all the paintings in the hall. These lighting fixtures are often designed or purchased for specific interiors and are an integral part of the halls design. Chandeliers can also be used in the general light scene, especially if this source is controlled (switching in parts, lighting regulation). Floor lamps seem to be the most harmful form of historical lighting fixtures as regards the glare, because they have light sources below all others. They are sometimes quite monumental constructions made of bronze and coloured stone and can simply decorate the hall with their presence, but they can only be turned on if there are no items on the walls to be viewed (paintings, for example). The most “injured” from the attempt to use this form of lighting fixtures to illuminate the exhibition is the Van Dyck Hall.

In some cases, a number of lighting issues can be solved by installing additional lighting devices on the chandelier hooks under the ceiling, i.e. above the chandelier itself and so as not to interfere with its perception as works of applied art. Until recently, we also considered such a technique prohibited, but now it is already included in some projects. This was made possible, in particular, as a result of the “LED revolution” and the continued miniaturization of lighting devices, the reduction of their weight and energy consumption.

Among the possible technical solutions of the exhibition lighting, which are used in the museum, one can mention such a form as a suspended busbar with ceiling lighting. This combination of lighting fixtures is usually used to create a certain level of overall illumination or for architectural lighting purposes, while the luminaries installed on the same busbar from the bottom are responsible for the local illumination of the exhibited items. This is quite common at our new exhibitions.

The list of the basic light sources forming the museum illumination should be concluded by lighting in showcases. In some halls containing “showcase” displays, this source can be considered as the basic source. Illumination of showcases in the Hermitage is represented by all kinds and techniques. From lighting fixtures with fluorescent lamps of the late 50s to lighting systems of large showcases with organic materials in the Pazyryk Hall, where light sources are installed in the adjacent room, and the light is supplied in the showcases by fibre light conduits with a length of more than 11 m. This way eliminates the possibility of heating the exhibited items and increasing the temperature in the hall. In the Romanov gallery and in the Hall of Egypt, the ever-memorable Soviet lamps under the incandescent NBB-341 lamp produced in Tallinn live out their days. Once they, due to the porcelain cartridge, all-metal casing and swivel mounting, were practically the only Soviet lamp that did not cause complaints from the fire department and were installed throughout the museum in a large number, luckily were they inexpensive. Fibre-optic lighting dominates at the permanent exhibitions of the last two decades. The light sources in these showcases are halogen or LED ones. It should be noted that this scheme of the lighting installation makes it easy to reconstruct the light block to a modern light source. The entire setting of the light scene is maintained, only the light generator (containing a halogen lamp) is changed to LED one.

It is worth noting that the Winter Palace is a particularly problematic area in this text, which does not mean that everything is much easier in the rest of our museum complex.

The General Headquarters also suffers from lighting problems, although at least during the second stage of restoration works, it was possible to avoid significant mistakes. In this complex, for the first time in our museum we used LED luminaries to illuminate painting, although the bulk of lighting fixtures here are devices with halogen light sources. The LED luminaries of the first generation were used in some exhibitions (the department of the ancient world), where the accuracy of colour rendering was not essential.

The Menshikov Palace is still one of the most complex buildings in terms of exhibition lighting.

In the exposition of this section of the Hermitage there are small and relatively low rooms, where there is no space for installation of lighting fixtures, as the walls and ceiling are tightly covered with historical finishes, painting, etc., as well as (a local unique feature) Dutch tiling.

There are also complex places on our expositions where it is very difficult to find the right solution, at least within the traditional schemes. Here is an example of such a difficult situation: three large paintings were moved to the exhibition hall of the Department of the History of Russian Culture after restoration. The only lighting source in this hall is a chandelier, as the electrical equipment was designed for a showcase exhibition, a hall with preserved finishes, i.e. nothing can be hung from the ceiling, nothing can be attached to the walls, there is no power supply on the cornice, the hall width is comparable to the size of the paintings, the angles of reflection from the devices installed on the cornice would be such that all light sources would be reflected in the painting.

In this situation, it was decided to place the light sources at the bottom so that the glare would go to the ceiling. After the relevant experiments and the display of the full-scale layout, one of the Petersburg companies made for us floor devices with LED sources, which solved the problem. This experience is very useful in view of the future need to illuminate large paintings in the major hall of the museum in the Old Stock Exchange, where it is almost the only way to avoid reflections of light sources in huge pictures hanging, moreover, on a shiny wall.

Therefore, I want to draw attention to such a type of lighting device, which could be in demand in the museums, as a railing of exhibited items combined with the lighting fixture of the lower illumination. In the past, the attempts to use such a type faced the limitations related to the relatively large size of light sources. The LED revolution and the trend of size reduction of lighting devices seem to be already giving us the opportunity to overcome such limitations.

The next peculiarity of our exhibitions, which should be taken into account when designing illumination, is the exhibition composition mostly mixed. That is, the exhibition contains all types of works of art, both visual and applied. As regards lighting arrangement, those exhibition compositions have difficulties associated with the combination of materials of different light resistance groups. A marble sculpture, a painting and, for example, a piece of upholstered furniture covered with three hundred years old cloth, or an even older tapestry, may be located side by side. We try to group the exhibited items in such a way as to solve lighting problems conveniently. However, this is not always possible, and in some cases special solutions will be required.

By the way, we can say a few more words about such solutions. In most cases, even the most powerful manufacturers try to provide us with their standard products, for obvious reasons all of them try to avoid developing lighting systems "for a specific situation". We can bring to the attention of all those who wish to participate in the improvement of lighting in the Hermitage: someone has long filled the standard positions ("hang a bus bar, turn on lamps"), and non-standard ones are as much as you want. Be ready to think and offer competent lighting projects, not just sell equipment from the catalogue. Moreover, this wish should be followed by a warning that non-standard (that is, absent on the market, experimental, "homemade") equipment is extremely undesirable because it presents the problems to consumer with maintenance, spare parts and repairs, and in most cases is a one-time.

The exhibitions with uniform material in terms of light resistance, such as the exhibition of the Imperial Porcelain Factory, are also present in the Hermitage, but rather as an exception. Both in the complex of buildings and in the General Staff there are special exhibitions of painting. As far as I know, in the perspective plans of all scientific departments, the mixed nature of the exhibitions remains, which reflects the nature of our collection. The Hermitage positions itself as an encyclopaedia of historical and cultural character.

In general, the above is sufficient to imagine the situation.

A few more words about common and seemingly understandable subjects to indicate the criteria (I apologize if it looks corny).

So, museum light, museum lighting – what, in general, is it? Its main property is that it is the controlled light. In simple terms:

– It illuminates where it is necessary;

– It doesn't illuminate where it isn't necessary.

Both functions are equally important. Or the same, but more detailed:

– First, the lighting in the museum should ensure a comfortable perception of the exhibited items and information materials placed at the exhibition, as well as, for example, the architecture of historical interiors of the Winter Palace, etc.(here, as always, the devil is always in the details);

– Secondly, the lighting by its physical parameters should not cause damage to the items exhibited in any way (heating, destruction of sensitive pigments – fading, launching destructive photochemical reactions in oxidized metal products, destruction of organic matter by UV radiation, etc.);

– Lighting should not interfere with this perception, blind and highlight the things distracting from the perception of exhibited items, create areas with ambient light, glare and etc.

For such exhibited items, as painting, the illumination "correcting" the author's intention by means of accented illumination of individual parts of the painting or experiments with the contrasts of colour temperature, capable of causing in perception the "shift" of the illuminated item in warm or cold direction relative to the general environment are not allowed. This does not apply to recreation areas, lobbies, stairs, etc., where not only changes in colour temperature, but also other lighting schemes are possible. Only the actions, which cause the blinding of visitors with bright light or dynamic light effects after which, according to physiology, there is a need to adapt the eyes to normal lighting, are excluded.

As a result of properly installed exhibition lighting, a certain meaningful light scene should be constructed with the correct distribution of light.

The correct distribution of light is an essential indicator; it is the result of the work of the designer and the lighting engineer. It is possible to create a feeling of dull and insufficient lighting for perception of the exhibited items even with a large concentration of lighting devices and other light sources. Unfortunately, this is quite typical for many of our great halls where, for example, lighting was arranged by intensive lighting of the ceiling. The light is focused on the ceiling – it is the brightest object in the room – and on the floor. The area of exhibited items, and other visual information, i.e. walls, are in the least lighted area.

Since the peculiarity of the human perceptive organs is the ability to adapt from the strongest signal, the exhibition with this technique of illumination will seem dim and inadequately lighted, even if the absolute value of illumination on the surface of the exhibited items significantly exceeds the standard.

Finally, there is something else about the conference, post factum. With the overall positive assessment and unconditional recognition of the necessity of this event, it should be noted that the division into sections, however, did not work out optimal, depriving some participants of the opportunities to discuss issues related to different sites where the work took place at the same time.

The entry list turned out to be too multifarious – scientists, museum staff, businessmen, representatives of manufacturers or suppliers of equipment, designers of various profiles – this whole company could not found common ground: the humanitarians were tormented trying to figure out "how many lx" would be enough, someone plainly used the event for advertising purposes, etc., but it seems that the work in the general flow would be more productive, at least in this case, at a "wide reach" conference, on all issues at once.

If we say the same in a more positive way – as, however, many different people are "hungry" for the definition of criteria in the evaluation of the newest light sources in museum lighting! We hope that we will continue.

Boris G. Kuzyakin
graduated from the Institute of Painting, Sculpture and Architecture named after Repin of Academy of Arts of the USSR (Leningrad), faculty of theory and history of art, specialty "art critic" in 1977. In 1979, as an artist designer, he joined the State Hermitage Museum, Exhibition and Design Department (EDD) which was headed by V.A. Pavlov. Since 2003 up to present time he is a Head of EDD

Light & Engineering
Vol. 27, No. 4, pp. 17–24, 2019
https://doi.org/10.33383/2018-024

STUDIES ON GERMICIDAL BENEFIT OF ULTRA VIOLET RAY UPON OLD PAPER DOCUMENTS

Anubrata Mondal and Kamalika Ghosh

Jadavpur University, Kolkata, India
E-mail: kamalikaghosh4@gmail.com

ABSTRACT

In the ever-changing world, cultural heritage, especially through documents, plays an important role in a civilized developing country. The documents specially made of paper are organic products and more prone to bacterial formation. From most of the heritage archives, it has been informed/observed that bacteria destroys the important documents. The conservations of these articles are essential. From the point of view for good lighting system design, one can utilize a photobiological effect of light, i.e., UV range of the light source is killing bacteria too. Experimentation has been carried out on different paper documents with different intensities of UV contents from light sources. The bacteria content in a sample at the initial stage as well as after UV treatments with different intensities have been noted, analyzed, and furnished in this paper. The process shows a successful result as per expectation. If this methodology can be implemented for the conservation of paper archives, it will give a fruitful result for the conservation of our cultural heritage, which is very much valuable for the development of a society.

Keywords: archives, bacteria, conservations, heritage, lighting, swap test

1. INTRODUCTION

Bio deterioration can be defined as "any undesirable change in the properties of a material caused by the vital activities of living organisms" [1, 2], as distinguished from changes produced by "chemical, mechanical, and physical influences". Biological agents that produce deterioration are referred to as bio deteriogens, and these range from microorganisms like fungi to higher plants. Since organic materials, which are most vulnerable to biological attack, are used in many traditional artefacts also, and since the high heat and humidity in weaken organic materials and favour the growth as well as the reproduction of bio deteriogens, that faces critical problems in protecting its cultural collections from bio deterioration.

Preservation [3, 4] of historic materials, particularly of organic materials like textile, papers, wood, palm leaf, birch leaf etc. is a matter of serious concern and thorough investigation to prolong the useful lifespan of physical items that hold outstanding records of the past wisdom. Light, both natural and artificial, is one of the environmental factors that need to be controlled in achieving this goal for the preventive care of such important historic repositories in national archives, heritage building as well as libraries and museums. Nowadays, it is well known that microorganisms are responsible for the deterioration of archival artefacts of cultural heritage etc. Two main factors responsible for the proliferation growth of microorganisms on archival objects, especially on paper, textiles, wood, palm leaf, birch leaf [5, 6] infestation are due to the chemical nature of the substratum and the environmental conditions, such as the availability of nutrients, favourable temperature, humid condition etc. Therefore, it is necessary for a lighting engineer to find out ways and means for destroying microbes like fungi, algae, bacteria etc., by the application of light. An ef-

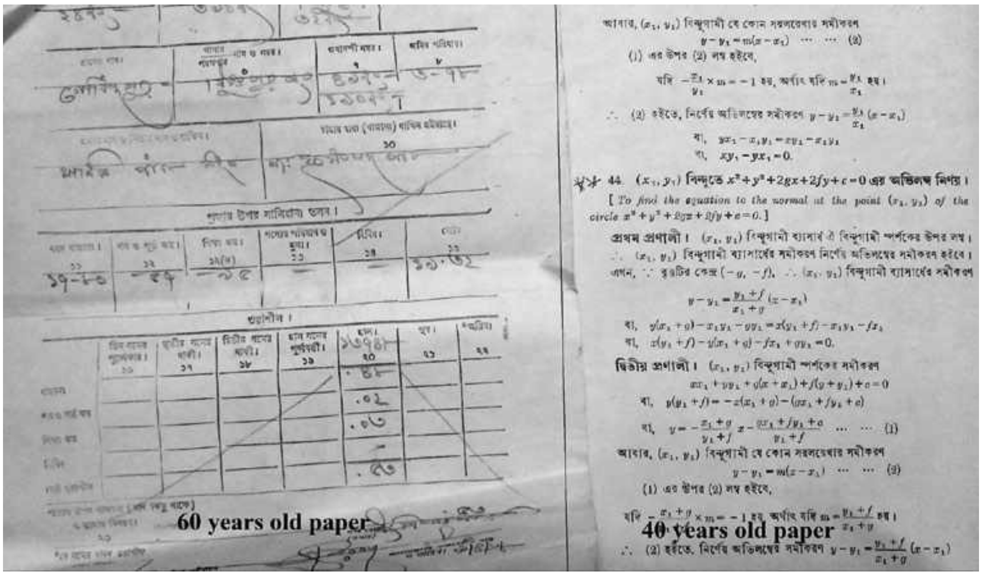


Fig. 1. Collected paper samples

fort has been made using UV radiation, which is available in artificial light sources especially mercury vapour type light sources. This paper attempts to give a brief idea about how UV radiation destroys or controls microbes like fungi, algae, and bacteria with specific kind, intensity, and exposure time.

2. EXPERIMENTAL STEPS [7, 8]

- Collection of old artefacts like paper from Heritage Sites;
- Collection of market available UV lamps with different intensities;
- Preparation of Czapack-Dox media for growing bacteria and fungi;
- Collection of bacteria and fungi infested handmade and machine-made form paper and textiles materials using swap test method before UV exposure, i.e. initial stage, and identification and counting of the concentration of bacteria in the sample;
- Keeping the old subject in Laminar Flow Meter under UV exposure of various intensities for a certain time;
- Collection of bacteria and fungi from paper and textiles after treating with UV radiation in the same manner;
- The final comparison of the bacteria and fungi concentration from heritage artefacts before and after UV treatment.

Table 1. Classification of UV Radiation with Ranges

Class of UV	Range of UV
UV-A	400 nm – 315 nm
UV-B	315 nm – 280 nm
UV-C	280 nm – 100 nm

3. COLLECTION OF OLD ARTEFACTS FROM HERITAGE SITES

At first, two types of paper handmade/machine-made samples have been collected from heritage sites, which are above forty and sixty years old respectively (Fig. 1). These pieces of paper may contain signatures and official records of the circumstances surrounding particular moments and events, and it could be a heritage capsule of the period.

4. COLLECTION OF UV LAMPS WITH TWO DIFFERENT INTENSITIES

Sun is the natural source of light with a wide band of spectrum broadly classified into a Radio wave, Microwave, Infrared, Visible, Ultraviolet, X-rays, and Gamma rays. In these particular wave spectrums, Ultraviolet ray (UV) is electromagnetic radiation with the wavelength shorter than that of visible light, but longer than x-rays. It is in the range between 100 nm to 400 nm (Table 1).

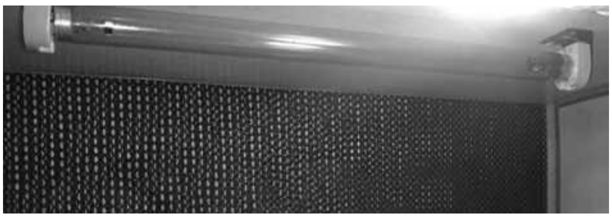


Fig. 2. Experimental UV lamp

Fig. 3. Laminor flow meter and autoclave

In this experiment, the measured values of UV irradiance of two different lamps (Fig. 2), which have been employed to minimize the concentration of bacteria from old artefacts, are **612 μW/m²** and **306 μW/m²** respectively.

5. NECESSARY MINOR/MAJOR INSTRUMENTS THAT ARE USED TO CARRY OUT EXPERIMENT

5.1. Laminar Flow Meter

It is incorporating a UV lamp in the laboratory-based equipment used for the germicidal operation (Fig. 3). Typically, in a laminar flow or biological safety cabinet, the UV lamp is activated, while the cabinet is not in use, to keep the interior of the work zone clean and decontaminated.

5.2. Autoclave

An autoclave (Fig. 3) is mainly used to sterilize surgical equipment, laboratory instruments, pharmaceutical items, and other materials. It can sterilize solids, liquids, hollows, and instruments of various shapes and sizes. Autoclaves vary in size, shape, and functionality. A very basic autoclave is similar to a pressure cooker: uses the power of steam to kill bacteria, spores, and germs resistant to boiling water and powerful detergents.

5.3. Incubators

An incubator is a device used to grow and maintain microbiological cultures or cell cultures. The incubator maintains optimal temperature, humidity, and other conditions such as the CO (CO_2) and oxygen content of the atmosphere inside. In this experiment, the incubator has been used for the growth of collected bacteria from the test sample at the specified condition.

5.4. Lamp Parameters

Two different lamps, which have been employed to minimize the concentration of bacteria from old artefacts, are used for this experiment purpose (Table 2).

Table 2. Lamp Parameters

Parameter	Low Intensity Lamp	High Intensity Lamp
Type	T5 Slim Line	T5 Slim Linkable
Power consumption, W	4	8
Distance, ft.	2	2
Colour temperature, K	2700	6400
UV irradiance at distance, μW/m²	306	612
Voltage, V (AC)	220–240	220–240
Lifetime, hours	7500	8000

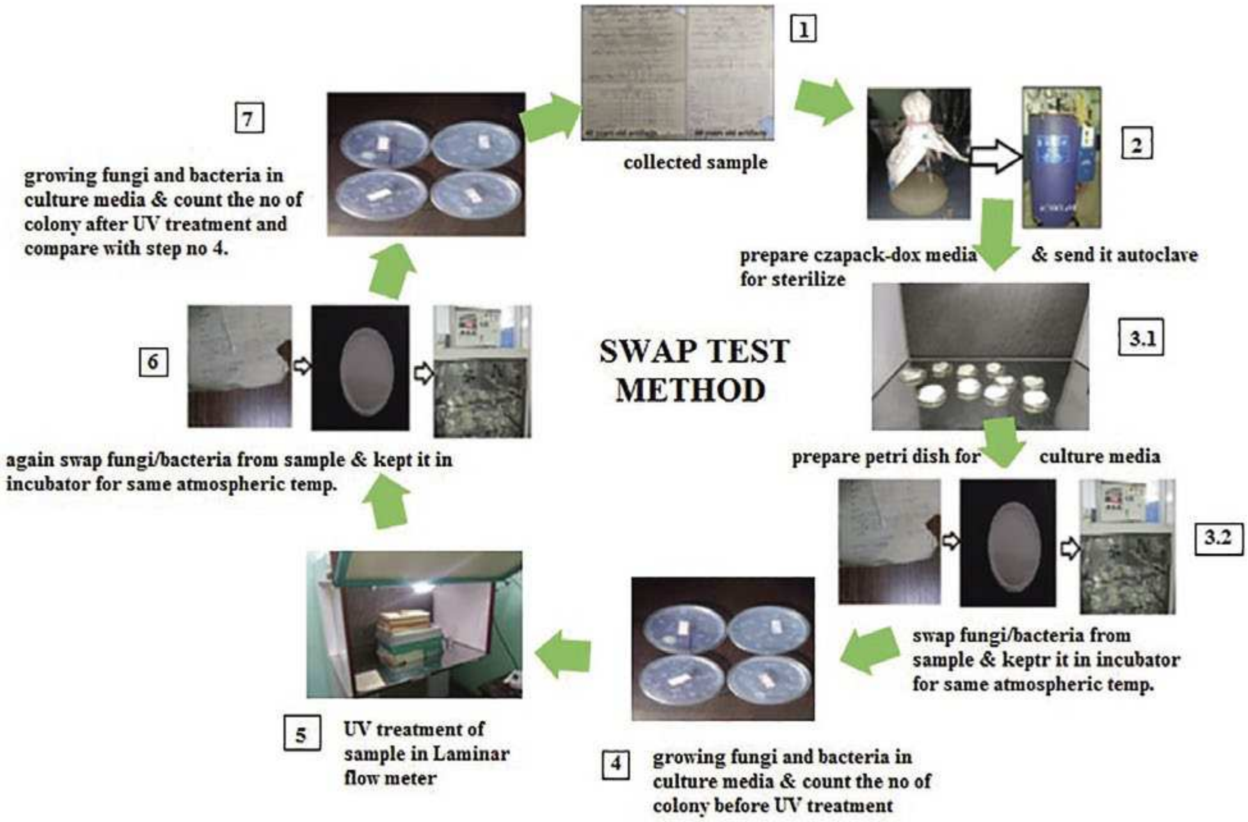


Fig. 4. Swap Test procedure according to order

6. ADOPTED METHODOLOGY FOR REDUCING BACTERIA AND FUNGI FROM OLD ARTEFACTS [9, 10]

The stages of the so-called Swap Test were the following (Fig. 4):

1) At first, samples were collected to carry out the experiments;

2) After collecting samples, czapack-dox/Agar media was prepared and sterilized by the autoclave machine at 121°C for 15 minutes to remove existing bacteria and fungi within the plate before usage and now pour this agar media in a Petri dish, where bacteria and fungi were grown in favourable circumstances;

3) Bacteria and fungi were swapped from the samples and these swapping fungi and bacteria were kept into the agar plate in the incubator to maintain continuous controlled atmospheric temperature (28°C) for the duration of 5–6 days;

4) After 5–6 days bacteria and fungi grew up in the Petri dishes or agar plates, and the number of colonies grown in the agar media was counted;

5) Then these samples were treated under UV radiation in the laminar flow meter for three hours and four hours respectively, and the samples were kept at 2 ft. distance from the UV source;

6) After UV treatment it is swapped and kept into another new agar plate again in the incubator to maintain continuously at the same atmospheric temperature (28°C) for 5–6 days;

7) At last, after 5–6 days bacteria and fungi grew up in a new Petri dish, and the number of colonies was counted again. Thus, the number of colonies after the UV treatment was compared with the number of colonies before the UV treatment. It was counted whether the colonies had been reduced or not after the UV treatment.

7. ANALYSIS OF THE EXPERIMENTAL RESULTS (SWAP TEST) [11, 12]

The experimental results of the sample A (60 years old papers) are shown in Table 3, Table 4. The experimental results of the sample B (40 years old papers) are shown in Table 5, Table 6.

Several attempts have been made to destroy the bacteria in the affected sample through the non-destructive method, i.e. without destroying the subject artefacts. Lighting engineers' effort has been made

Table 3. Original and Microscopic View of Bacteria with the Number of Colony before UV Treatment for the Sample A

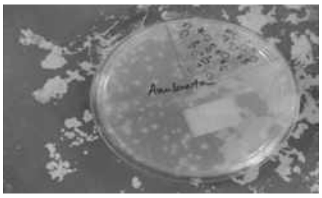
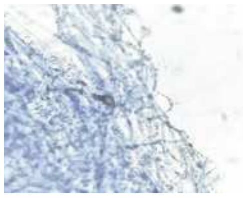
Number of colony (bacteria) before UV treatment	Original view of bacteria	Microscopic view of bacteria
Petri dish 1: 10		
Petri dish 2: 60		

Table 4. Original and Microscopic View of Bacteria with the Number of Colony after UV Treatment for the Sample A

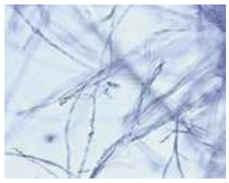
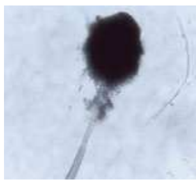
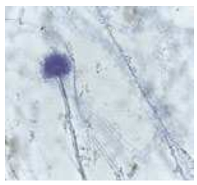
Petri dish 1					
Observation time, hours	**Irradiance of lamps $\mu W/m^2$**	**Dose, mJ/cm^2 [1, 2]**	**Number of colony (bacteria) sample A after UV treatment**	**Visual observation of bacteria**	**Microscopic view of bacteria**
3	612	1.836	4		
	306	0.918	5		
Petri dish 2					
6	612	3.672	17		
	306	1.836	29		

Table 5. Original and Microscopic View of Bacteria with Number of Colony before UV Treatment for the Sample B

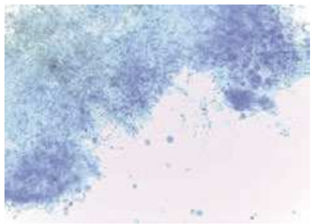
Number of colony (bacteria) before UV treatment	Visual observation of bacteria	Microscopic view of bacteria
Petri dish 3: 5		
Petri dish 4: 15		

Table 6. Original and Microscopic View of Bacteria with Number of Colony after UV Treatment for the Sample B

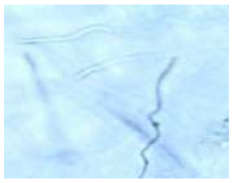
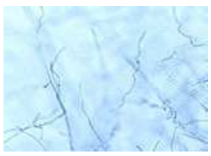
Petri dish 3					
Observation time, hours	**Irradiance of lamps, $\mu W/m^2$**	**Dose, mJ/cm^2 [1, 2]**	**Number of colony (bacteria) sample B after UV treatment**	**Visual observation of bacteria**	**Microscopic view of bacteria**
3	612	1.836	2		
	306	0.918	3		
Petri dish 4					
6	612	3.672	4		
	306	1.836	7		

Table 7. Analysis of Bacterial Colonies

Sample	Petri dish No.	Initial number of bacterial colonies	Intensity of UV lamp	Duration, hours	Dose (mJ/cm^2) [1, 2]	Final number of bacterial colonies	Reduction (%)	Observations
A	1	10	612	3	1.836	4	60.00	Colonies reduction is only 10 % while duration remains the same and intensity is doubled
A	1	10	306	3	0.918	5	50.00	
A	2	60	612	6	3.672	17	71.66	By increasing the duration of time with higher dose, further 11.66 % improvement
A	2	60	306	6	1.836	29	51.66	Not much effective with lower intensity
B	3	5	612	3	1.836	2	60.00	Colonies reduction is only 20 % while duration remains the same and intensity is doubled in case of lower initial concentration
B	3	5	306	3	0.918	3	40.00	
B	4	15	612	6	3.672	4	73.33	By increasing the duration of time with higher intensity, further 10 % improvement
B	4	15	306	6	1.836	7	53.33	Not much effective with lower intensity

to apply proper light sources. The UV content of the lamp has successfully reduced the number of bacterial colonies in the affected subject, without affecting the subject.

The comparison of the number of bacterial colonies before and after UV treatment is shown in Table 7. It has been observed for these studies that as the intensity and duration increases, the effectiveness of reduction for bacteria's colony increases.

8. CONCLUSION

The experimental work dealt with a photobiological effect of light, i.e., killing of bacteria through the application of UV ray. In this experimentation, a UV-B lamp has been used with varied intensity and duration. As per earlier studies/report, UV–C is very much dangerous to use, UV-A is less effective, and UV-B is mostly used for germicidal applications in microbiological laboratories. The results show that the destruction of bacteria response properly as per the stated dosing. Lighting engineers' effort has been made to offer an overall good solution for conservation as well as suitable lighting [12] for proper documental archives with a lighting solution i.e. through UV, not using any sort of chemical, which usually damages the archives. However, experimentation has been carried out at the reasonably low intensity of light considering ambient lighting and UV level in museum hall. Occasionally at the certain interval, the archives may be taken for treatment with high intensities, that is through the laminar flow meter or equivalent devices, which is not easily possible to keep in a museum.

9. ACKNOWLEDGEMENT

The authors are thankful to Dr. Joydeep Mukherjee, Associate Professor and then Director and Dr. Subarna Bhattacharya, Assistant Professor, School of Environment Studies at Jadavpur University for allowing to use their laboratory facility and their kind cooperation while carrying out the experiment for this work.

REFERENCES

1. Kowalski W. Ultraviolet Germicidal Irradiation Handbook UVGI for Air and Surface Disinfection // Springer Heidelberg Dordrecht London New York, 2009,501 p.

2. Bolton J.R. Ultraviolet Applications Handbook Third Edition (Updated) // Bolton Photosciences Inc., 2010.

3. Elottol M.A., Bahauddin A. A Competitive Study on the Interior Environment and the Interior Circulation Design of Malaysian Museums and Elderly Satisfaction // Journal of Sustainable Development, Vol. 4, No. 3, 2011, pp. 223–234.

4. Maev R. Gr., Green Jr. R.R., Siddiolo A.M. Review of advanced acoustical imaging acoustical imaging techniques for nondestructive evaluation of art objects // RNDE, No. 17, 2006, pp. 191–204.

5. Berger G.A., Russell W.H. Interaction between Canvas and Paint Film in Response to Environmental Changes // Studies in Conservation, Vol. 39, No. 2, 1994, pp. 73–86.

6. Sayre E.V., Majewski L.J. Technical Investigation of the Deterioration of the Paintings // Studies in Conservation, Vol. 8, No. 2, 1963, pp. 42–54.

7. Guidelines for Control and Prevention of Termite Infestation in Archives and Libraries // New Delhi: National Archives of India, 1991.

8. Jeyraj V. Care of Archival Materials // Thanjavur Saraswati Mahal, No. 395, 1995.

9. Repair and Preservation of Records // National Archives of India, New Delhi, 1988.

10. Kizlasov L.R. Arheologicheskie issledovaniya na gorodishe Ak-Beshim v 1953–1954 gg [Archaeological research on the site Ak-Beshim in 1953–1954] // Trudi Kirgizskoy arheologo-etbographicheskoy ekspedicii, Vol. 2, Moscow, 1959.

11. McCrone W.C. Microscopical examination of art and archeological objects // SPIE Conference on Scientific Detection of Fakery in Art, Vol. 3315, 1998, pp.1–9.

12. Frank F. Museums and the Green World // LD+A Museum on Display, Vol. 39, No.02, 2009, p. 47–49.

Anubrata Mondal,
M.Tech., Lecturer, Head of the Department of electrical engineering of South Kolkata Polytechnic, India

Kamalika Ghosh,
Ph.D., Assistant Professor of School of illumination, science, engineering and design, Jadavpur University. She has about 30 published articles. She is a life fellow of Institution of Engineers, India and Indian Society of Lighting Engineers

Light & Engineering
Vol. 27, No. 4, pp. 25–30, 2019 *https://doi.org/10.33383/2018-147*

LIGHT IN THE MUSEUM: EXPERIENCES AND CHALLENGES

Lyubov E. Volgina

The State Tretyakov Gallery, Moscow
E-mail: VolginaLE@tretyakov.ru

ABSTRACT

The article is focused on the peculiarities of the lighting in the museum halls, restoration workshops, depositories, the operation of lighting equipment, and the organization of exhibition lighting in the halls of the State Tretyakov Gallery. Initial focus areas in the development of technical specifications for accent lighting equipment have been outlined. The information may be useful to the staff of museums, galleries, etc. engaged in the exhibition activities.

Keywords: light, accent lighting, museum pieces, illuminance/illumination, light resistance

"For an artist or a craftsman, the light is both a blessing and a curse – it is inseparable from the beauty of art, but can physically or chemically do harm," Thomas Brill wrote in his book [1].

This dilemma is a cornerstone in museums, galleries, and everywhere where they store and display collections of any genre and content: artistic, local history, zoological, botanical, decorative and applied art, etc. It is necessary to simultaneously show the collection in the most spectacular representation and to protect the exhibited items from harmful light exposure.

Light in the museum or museum light, lighting of museum spaces: no matter how you call this specific area of lighting engineering, which emerged when the humans began to gather for the descendants the collections of artistic values and artefacts of scientific and research thought of the era. Castles, palaces, public rooms, temples, and universities were adapted for the arrangement of collections. The collections were placed, but how to make the items visible, and at the same time, to protect the collection from light, humidity, fungus, and another adverse impact? Initially, the visit to the Kunstkameras took place mainly in daylight, but over time, the collections became public, and the opening hours of the museums increased, the need for artificial lighting appeared.

In the world there are many museums, galleries, salons, exhibition halls on the one hand, depositories of the items that make up the collections, on the other hand, and restoration workshops, laboratories, conservation service, and many others ensuring the proper condition and preservation of museum pieces and enabling them to be examined by third parties. All this represents the functionality of the museum living organism. The custodians and the researchers develop and prepare the topics of exhibition projects, the restorers prepare museum pieces for the exhibition halls, and the designers architect the exhibition space. The exhibited items are arranged at their places and, unfortunately, most often, only at this stage, the lighting engineers (lighting designers) are invited to create a beautiful and spectacular light atmosphere at the exhibition area.

The responsibility of a lighting engineer is that he makes the final touch before the vernissage. The fineness of the exhibition depends on the lighting installation. Any exhibition can be best remembered by the visitors or can create little stir. It is not only about the uniqueness of the presented items, but also about how they are presented to the audience. Light is the key aspect affecting the perception of the exhibition as a whole.

Fig. 1. Setting accent lighting in the hall of the Tretyakov Gallery

A lighting engineer is required to create interesting light images with an aesthetic, emotional, and psychological impact on the viewer and to ensure the safety of the exhibited items from the influence of the visible part of the spectrum, ultraviolet, and infrared radiation (Fig. 1).

Each museum piece presented in the exhibition hall: flat, volumetric, monochromatic, polychromatic, with a diverse texture of the surface should obtain the proper lighting, directly dependent on the properties of its material.

The lighting of exhibition halls consists of two main components: general (working) lighting and accent lighting. General (working) lighting can include the combined lighting consisting of daylighting and artificial lighting (Fig. 2), or only daylighting or artificial lighting.

Accent lighting is selected after the exhibition space has been assigned: for a permanent exhibition or for a temporary thematic exhibition. Depending on this, various ways of accent lighting are used to ensure good visibility and preservation of museum pieces.

In the last few years, in the regulation of light characteristics in museums, galleries, and utility rooms (depositories, restoration workshops, etc.) there is no legal framework in Russia, as the Appendix B of the GOST 8.586–2001 [2] was cancelled in 2016, and there were only recommendations of the State Research Institute on museum storage [3], which require significant modification. Often, during temporary exhibitions the requirements for the preservation of museum pieces are reduced, the light resistance groups are not taken into account. In pursuit of shine, light, and efficacy, the exhibited items during short-term exhibitions gain greater irradiance, which could gain a long

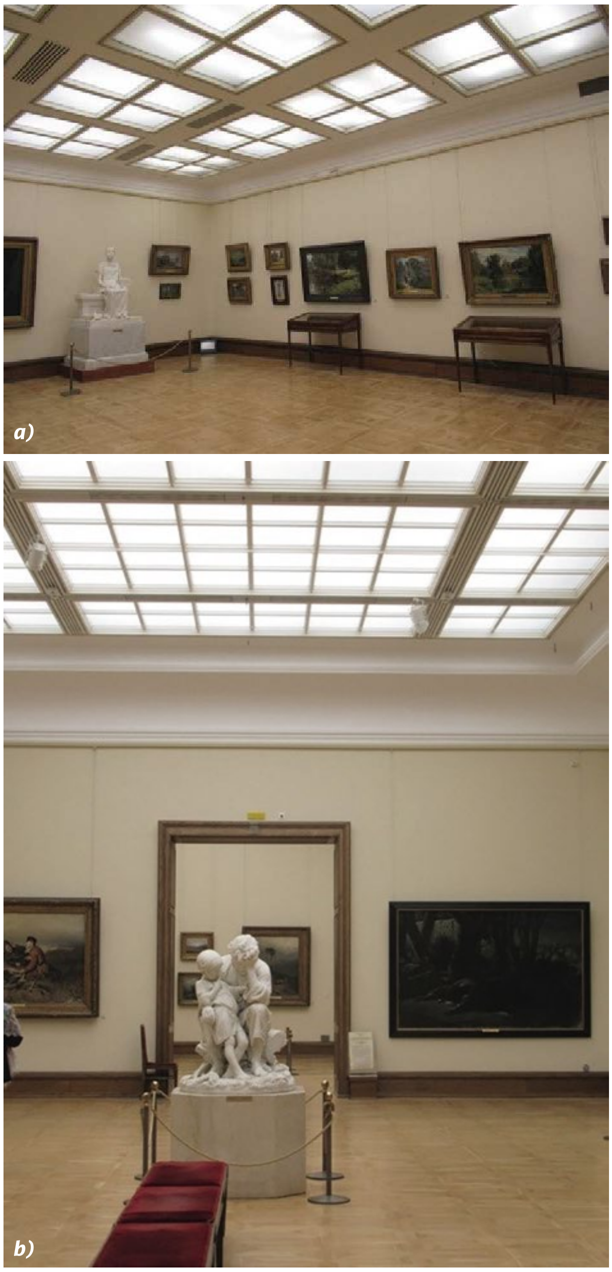


Fig. 2. a) General artificial lighting of Hall No. 35 of the 1st floor, light background; b) general combined (day + artificial) lighting of Hall No.17 of the 2nd floor, light background

Fig. 3. Hall of Graphics. Illuminance of exhibited items at a height of 1.6 m due to accent lighting is 60 lx

Fig. 4. The alternation of "light and dark areas" in the halls of temporary exhibitions creates the effect of "theatricality" of the exhibition space

time being permanently exhibited with lower illuminance levels.

The permanent exhibition of museum pieces in the halls is the representation of identical and equivalent items having equal rights to attract public attention, and the exhibition should not, due to a large amount of information, tire the audience viewing the gallery. Therefore, in the permanent exhibition halls of art museums the accent lighting should be used very carefully and unobtrusively (Fig. 3), so as not to exceed the theatricality of the exhibition (Fig. 4), not to distract the attention of visitors with light effects influencing the emotional state and mood of the audience. Additional accent lighting in such cases may add extra irradiance to the exhibited items, which may worsen the preservation of museum pieces (Fig. 5).

The temporary exhibition is a representation of items united by one concept or idea, which creates a significant impression and has an emotional impact on the visitors of the exhibition.

The other extreme in the light design of exhibitions is the use of accent lighting only without general uniform lighting, and this exhibition lighting technique provides powerful lighting and psychological effects. The use of this lighting technique, in any case, for an art museum with a large collection placed in the permanent exhibition, is questionable. The viewers get tired of the intense visual work on the combination of "dark background – light object" (Fig. 6). The visitors should be at a close distance from the exhibited items to scrutinize the details of medium and small size paintings or the items of small size, while the visitors in the front row obstruct the view to those standing behind. The advantage of this lighting technique is that due to the "contrast effect" it is possible to reduce the illuminance level of the exhibited items.

In the market of the spotlights for accent lighting, there is a large number of lighting equipment of Russian and foreign production. In the Tretyakov Gallery after the opening of the Engineering Building and the Major Building in Lavrushinsky Lane after reconstruction, as well as in the halls of New Tretyakovka on the Krymsky Embankment, a large number of luminaires of different manufacturers are used, each having its own advantages and disadvantages. Over a long time of their operation, a lot of experience has been gained in installing the spotlights on the busbars fixed on the ceilings of exhibition halls and other structures.

The recommendations for museum staff on the choice of lighting equipment, additional accessories to it, and on the installation of busbars are as follows:

1. Before selecting any luminaire for accent lighting, it is necessary to conduct simultaneous testing of lighting equipment of different manufacturers, visually and instrumentally comparing the results obtained on thematic samples from the museum collection;

2. When testing, it is recommended to measure the flicker of luminaires while adjusting the lumi-

Fig. 5. General and accent lighting of the 2nd floor hall, light background (a); general and accent lighting of the 2nd floor hall, dark background (b)

nous flux, to check the presence of halo around the light spot that hits the item;

3. The light emitted by the luminaires produced by different manufacturers and having the same colour temperature documented may be visually similar, whereas when testing the light distribution of luminaires, the light spots on the white surface may have different shades of white colour. This should be kept in mind when selecting the colours of the exhibition space and the design of the exhibited items;

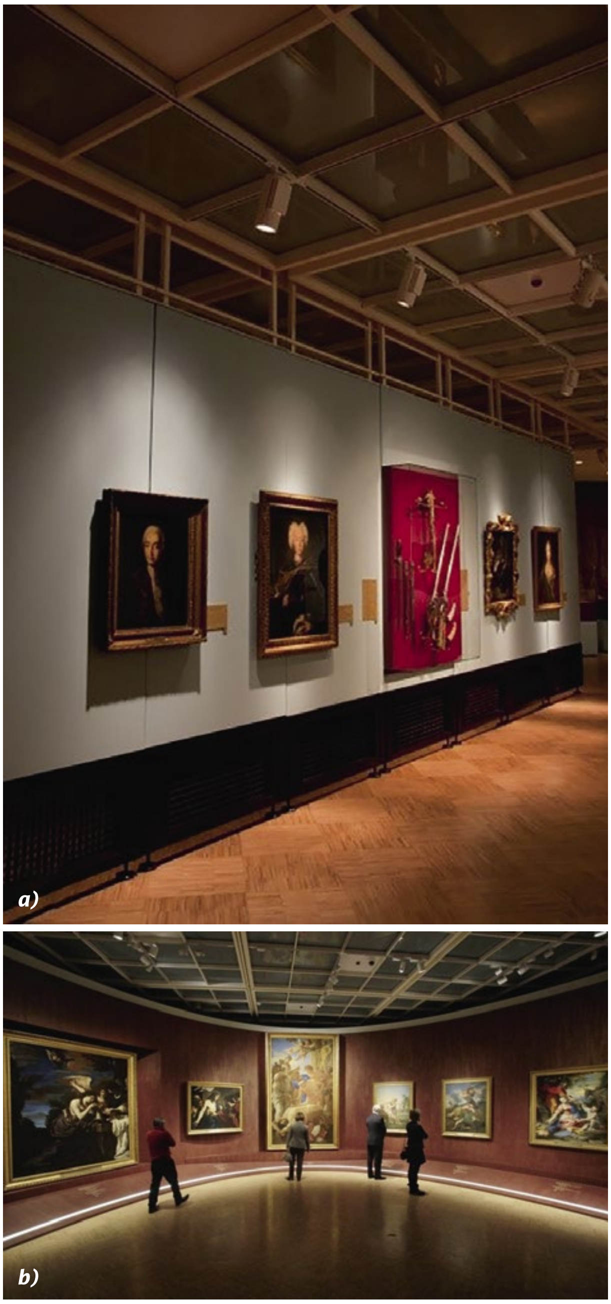


Fig. 6. Temporary exhibition, accent lighting without general lighting of the hall, light background (a); temporary exhibition, accent lighting without general lighting of the hall, dark background (b)

4. It is desirable that the luminaire set includes various lens shades, casher, cells, cross attachments to protect the visitor's eyes from bright light rays, halos, and occasional glare (Fig. 7). The luminaires should be combined with lenses correcting the light beam, framing attachments, oval drawing lenses, etc.;

5. The spotlights should have control over the light parameters: on the luminaire casing or via Wi-Fi, Bluetooth, etc.;

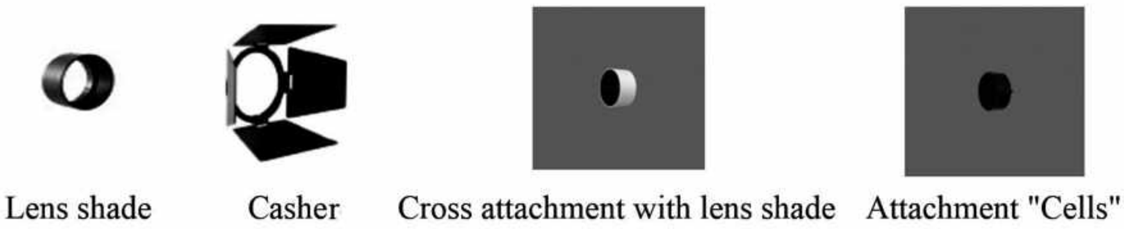


Fig. 7. Variety of attachments for spotlights to protect against halos

6. Modern LED luminaires and spotlights can have different sets of adjustable parameters: luminous flux, colour temperature, expansion angle of beam, luminaire rotation; these are interesting options, which, however, increase the price for quality products, and therefore, when choosing lighting equipment, it is necessary to determine which parameters are really necessary for the setting of accent lighting and to refuse unnecessary options;

7. For high halls and large spaces, the luminaires made on the basis of theatrical spotlights or luminaires for photo studios can be used as accent luminaires (with protective filters, if necessary);

8. After selecting the lighting equipment, it is necessary to determine the location and installation method for the busbar, taking into account the height of the hall, the architecture of the hall, the nature of the collection, the place of museum pieces on the walls, showcases, pedestals, in the centre of the hall, etc.

The installation of museum lighting in the exhibition halls depends on the features of the building in which the Museum and its utility rooms (restoration workshops and depositories) are located. The installation of general and accent lighting in the building adapted to the museum, where the interiors are the objects of exhibition activity, and in the building constructed according to a special project, where all the process requirements of modern museum activities are taken into account, have technical differences in the installation of lighting equipment, especially in the presence of windows and roof lanterns.

One of the essential components of lighting exhibition spaces and restoration workshops is the light sources used for this purpose. The general lighting in these rooms should be close in its colour properties to daylighting. This is an undeniable necessity in art museums, and for the restorers, it is significant that the result of evening work in artificial light would not differ from what the restorer sees in the morning at daylight.

After the phased enactment of the Law “On energy saving and energy efficiency improvement and on amendments to certain legislative acts of the Russian Federation,” due to the gradual displacement of halogen and fluorescent light sources in favour of LED sources, the range of lamps used for the exhibition lighting has decreased significantly. For example, the Tretyakov Gallery was working on the modernization of the Depositary electrical lighting installations. The project selected the line of *REGO* and *REGO LED* luminaires, produced by the *Light Technologies*, which were to replace the Finnish luminaires installed in 1983. The new luminaires were chosen by size, installation method, and, if possible, without increasing the power consumption, to increase the illuminance on the working surfaces (restoration of oil and tempera painting, general lighting not less than 500 lx). The overriding requirement for lighting restoration workshops was to achieve a uniform light distribution on the working surface, excellent colour rendering, and high level of illuminance for high accuracy work. Daylight in these rooms is a significant proportion of the general lighting. According to the results of the comparison between *REGO* luminaires with *LUMILUX DE LUXE T8 OSRAM* series 954 fluorescent lamps of higher colour rendering and *REGO LED* luminaires with different colour temperatures, the luminaires with fluorescent lamps of greater power consumption were selected and installed. The proposed LED lighting options were suitable for household, office, or industrial use, while the museum lighting requires a wider range of affordable LED sources with fixed spectral characteristics simulating the daylight. The following premises were equipped with LED lighting in the Depositary building: offices, corridors, utility service rooms, and storage rooms for museum items, without high requirements for colour rendering, high accuracy visual work.

In conclusion, the priorities in the museum lighting include the following:

1. The examination of museum pieces having different photosensitivity (light resistance) for radiation exposure in the visible, ultraviolet, and infrared regions of spectrum for development of the regulatory framework, which started with the Appendix B of the GOST 8.586–2001 [2], where the issue of parameters standardization of daylighting and artificial lighting in the museum halls, galleries, utility services rooms (storage facilities, restoration workshops, packaging rooms, etc.) was outlined, and it was developed with the participation of the Museum Climatology Laboratory of GosNIIR in terms of light resistance of museum pieces and regulation of lighting and recommendations on organization of the museum space lighting [4], so, the introduction of adjustments in relation to the recommendations of the GosNIIR "Museum storage of artistic values" [3] was started;
2. The development of a methodology allowing to measure lighting characteristics directly in the exhibition halls, on the surfaces of exhibited items of various shapes, sizes, configurations, with using a minimum number of measuring instruments to obtain objective data for operational control of the light environment, and verification of measuring devices in accordance with GOST R8.586–2016 [5];
3. Based on the research and development carried out, taking into account the introduction of new LED sources into the museum lighting practice, create a state standard for standardization of parameters for the light environment in museums;
4. Clarification of the parameters of non-reflective glass, other protective materials (triplex) for the absorption of radiation by the material protecting the collection item from the exposure to all spectral components;
5. Installation or improvement of new, energy-efficient, eco-friendly light sources that replace traditional light sources such as high-power halogen lamps and fluorescent lamps, wich will have spectral characteristics equivalent in colour perception to daylight, and should be present during the working day in restoration workshops and other utility services rooms where high accuracy work is performed, as well as ensure the creation of an individual, unique atmosphere and comfortable visual environment in the museum halls;
6. Establishment of convenient systems of dispatching and control of specified light parameters in the museum premises for permanent and temporary exhibitions.

REFERENCES

1. Brill T.B. Light: Its Interaction with Art and Antiquities // Springer Science & Business Media, 1980, 287 p.
2. GOST R8.586–2001 Gosudarstvennaia sistema obespecheniia edinstva izmerenii'. Sredstva izmerenii' harakteristik iskusstvennogo i estestvennogo izlucheniia dlia obespecheniia sokhrannosti muzei'ny'kh e'ksponatov. Metodika poverki. Prilozhenie B (obiazatel'noe). Normiruemy'e harakteristiki svetovoi' sredy' v muzeiakh [State system for ensuring the uniformity of measurements. Instruments measuring the characteristics of artificial and natural radiation for the safety of museum exhibits. Methods for verification[1]. Appendix B (mandatory). Standard parameters of the light environment in museums], 2001.
3. Devina R.A., Brednyakov A.V., Dushkina L.I., Rebrikova N.L., Zayceva G.A. Muzei'noe khranenie hudozhestvenny'kh cennostei': prakticheskoe posobie [Museum storage of art treasures: practical guidelines] // Tipografiya Ministerstva kul'tury RF, Moscow, 1995, 204 p.
4. Fomin I.B., Zaychikova S. Yu. Tekhnicheskie sredstva kontrolia temperaturno-vlazhnostnogo i svetovogo rezhimov v muzeiakh i pamiatneykakh arhitektury' [Technical means of monitoring the temperature and humidity and light conditions in museums and architectural monuments] // Indrik Publ., Moscow, 2008, 22 p.
5. GOST R8.586–2016. Gosudarstvennaia sistema obespecheniia edinstva izmerenii'. Sredstva izmerenii' harakteristik iskusstvennogo i estestvennogo izlucheniia dlia obespecheniia sokhrannosti muzei'ny'kh e'ksponatov. Metodika poverki [State system for ensuring the uniformity of measurements. Instruments of measurement of characteristics of artificial and natural radiation for safeting of museum exhibits. Verification procedure], 2016.

[1] Replaced by GOST R8.586–2016 [5], in which Annex B is absent

Lyubov E. Volgina,
Graduated from the Moscow Power Engineering Institute with a degree in Lighting and Light Sources (1986). Head of Electrical Equipment Department of the State Tretyakov Gallery

Light & Engineering
Vol. 27, No. 4, pp. 31–42, 2019
https://doi.org/10.33383/2018-148

ILLUMINATION OF PAINTINGS, GRAPHIC ARTS, PRINTED PRODUCTS, PHOTOGRAPHS: PROBLEMS AND POSSIBLE SOLUTIONS

Leonid G. Novakovsky

Pharos-Alef LLC, Moscow
E-mail: pharos-alef@yandex.ru

ABSTRACT

The article analyses the major problems of museum lighting. Possible technical solutions to the mentioned problems relating to each type of exhibited artworks are detailed. The results of the studies used as a basis for these solutions are described.

Keywords: lighting environment, illuminance distribution uniformity, paintings, sculpture, minor forms, glare, interior of palace architecture, fresco, stucco, projection optics, radiation

1. INTRODUCTION

Museum lighting is one of the most complex problems, which requires the application of radically different approaches depending on the type of exhibits.

Moreover, the concept of lighting always depends on the architectural features of a building where exhibits are located.

It is especially difficult to arrange correct lighting in palace museums since the architecture of such buildings was originally designed for another purpose and the lighting equipment contemporary with the time of design and construction fundamentally differs from the current requirements of museum lighting. As a result, a number of seemingly unsolvable problems arises:

– Maintaining of uniform illuminance distribution with significant difference of distances between the exhibits and a lighting device (LD);

– Elimination of highly bright glares on artworks created by light sources (daylighting sources in daytime and artificial ones at night) as well as glares on case glass due to extremely unsuitable built-in lighting and location of built-in light sources;

– Lighting of sculptures in limited exhibition areas not allowing to manage the shadow-forming process.

LDs themselves (chandeliers, wall luminaires, floor lamps, etc.), which are decorations in terms of the interior, often create obstructions for the formation of required light fields accentuating interiors of palace halls, e.g. ceilings with stuccoes or frescoes.

All these problems really seem unsolvable, but invention of new light sources, light emitting diodes (LED), provided they are applied correctly in conjunction with latest achievements in the fields of optics, IT systems, and control systems, allows not only to solve these problems but also to do it without introducing visible changes in the classical interior of a palace.

2. LIGHTING OF PAINTINGS

Preservation of paintings exhibited in museums is provided by means of lighting standards. Unlike production, educational, and other areas where lower limits are specified, for museums, higher limits, which cannot be exceeded in any case, are specified. For each type of exhibits, illuminance values are specified [1]. For instance, it cannot exceed 50 lx for fabric, newsprint paper, and watercolour, 150 lx for oil paintings, and 500 lx for precious metals and jewels.

As for the paintings, it is obvious that these values do not comply with conditions in which they were created, therefore, we see not what was intended by an artist but distorted colours.

Analysis of conditions in which the works were created shows that the range of illuminance values is rather wide. Here's what Leonardo da Vinci wrote about it [2]: "For portraits, you should have a special studio: a long, four-corner yard with width of ten cubits and length of twenty cubits with walls painted black, with a roof stab above the walls and a canvas shade arranged in such a way so that it provides protection from the sunlight. Without extending the shade, you should paint only at the beginning of twilight or when it is cloudy or foggy. This is the perfect light." Reconstruction of these conditions shows that illuminance of the easel may be within the range of (400–600) lx. Van Gogh created a number of his works at night wearing a straw hat and placing candles on its brim and wrote about it [3]: "I often feel that night is much more colourful than daytime." Simulation of such conditions shows illuminance of (15–20) lx. In addition, Van Gogh painted his landscapes at daytime with easel illuminance of (3500–4500) lx.

So, what prevents us from seeing the art from the author's perspective? The thing is that it is necessary to eliminate or minimise aggressive components of the LD spectrum, the ultraviolet and infrared radiations, since the former causes direct destructive impact (dissipation of molecular links) and the latter promotes deterioration of materials by speeding-up chemical reactions by means of temperature rising. The danger of the ultraviolet radiation is enhanced by its so-called cumulative effect, i.e. accumulation of results of such impact.

This all is relevant in case of daylighting or using LDs with conventional light sources: incandescent lamps, tungsten halogen lamps or metal halide lamps but becomes irrelevant after transfer to LED light sources [4].

Application of fluorescent light sources is not preferable too both because of the significant flicker of the luminous flux and relatively low value of colour rendering index (CRI) caused by spectral lines of radiation [4]. However, conventional light sources harmful to art objects have been being changed by widely spread and rather powerful white LEDs with ultraviolet and infrared parts of the spectrum reduced to values safe for all types of colourants or fully eliminated as shown in Fig. 1.

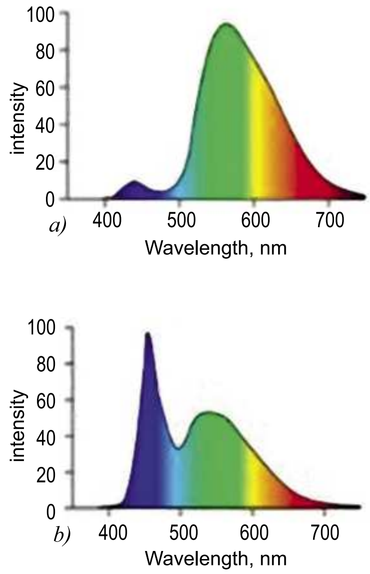


Fig. 1. Spectrum specifications of LED with various correlated colour temperature: a) warm white LED; b) cold white LED

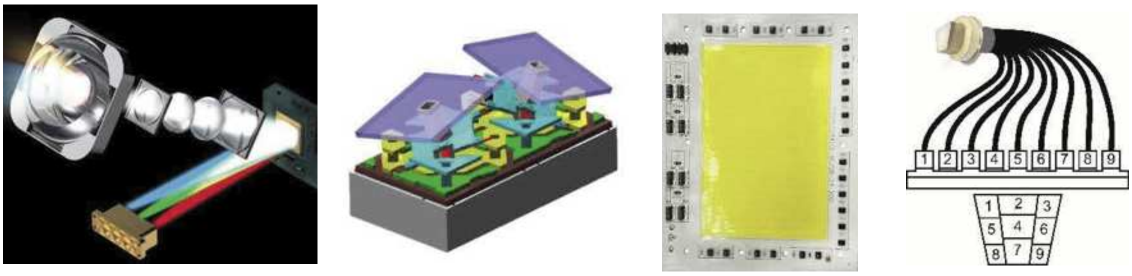
It is obvious that preservation of exhibits is a very important problem and specification of new requirements to storage and exhibition conditions of fine art objects due to the appearance of seemingly safe light sources is a problem, which requires serious studies. In its turn, development of the regulatory framework should allow approaching museum lighting problems in a more flexible way with the consideration that each piece of art, whether it be a painting, a sculpture, a fresco, a mosaic, an installation, etc., is a unique object requiring an individually chosen method of lighting. The only common moment here is the requirement to provide uniformity of illuminance distribution and maximum CRI value, compliance with which is one of the most serious problems of museum lighting.

All the other parameters should comply with the conditions as of the moment of creation of the object as much as possible, subsequently, they may differ greatly, i.e. they should be variable. These parameters are:

– Absolute values of illuminance which may vary, in particular, due to the different distance of observation, for example, of a fresco, a mosaic, or a painting;

– Colour temperature of the resulting radiation, which may vary due to different conditions and daypart in the course of creation;

– The necessity to eliminate glares caused by light sources and interior elements, which may vary due to different lighting conditions;

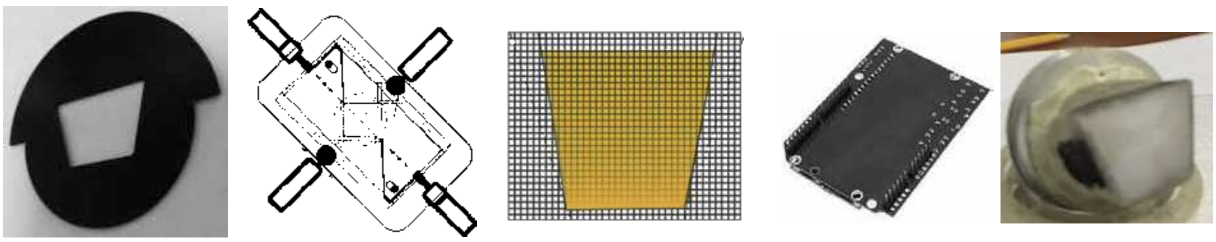


a) *b)* *c)*

Fig. 2. Alternative technical solutions for provision of uniform distribution of illuminance: a) *DMD+DLM* technology; b) a set of LED matrices with differential control of active elements; c) fibre-optic image converter with flexible cables and differential input

a) *b)*

Fig. 3. Lighting of paintings with conventional overhead LDs: a) overview of a gallery; b) vertical illuminance distribution over a painting



a) *b)* *c)* *d)* *e)*

Fig. 4. Devices for provision of required contrast level between an illuminated object and a background: a) removable aperture; b) an aperture controlled remotely; c) remotely controlled matrix; d) liquid-crystal plate; e) fibre-optic image converter

– Contrast level, i.e. the ratio between luminance values of the object and its background.

Thus, correct lighting of a piece of fine art requires solving of a number of the problems listed in Table 1, which shows that it is possible only with conceptually new approaches to design of luminaires and formation of special light environment for each specific exhibit. That is why museum lighting is considered the most complex nowadays.

It is obvious that the mentioned challenges can be solved within a uniform technical solution, i.e. one structure of a LD. It is also clear that LDs may be based on different technical principles depending on specific application conditions. That is why this article examines key technical solutions for beating these challenges and questions of their integration with structures of existing LDs.

3. ARRANGEMENT OF UNIFORM ILLUMINANCE DISTRIBUTION ON A PAINTING SURFACE

As noted above, the achievement of the high degree of illuminance distribution uniformity

Table 1. Known Methods of Resolving Problems of Paintings Lighting

Problems of lighting	Conventional methods
Increase of illuminance level up to the one complying with the conditions at the moment of creation with absolute preservation of paint layer	No solution
Provision of uniform illuminance with relatively close location of light sources	No solution
Provision of variable colour temperature with maximum possible CRI	No solution
Elimination of glares caused by light sources in different lighting conditions	Replacement of a luminaire to a lower position
Contrast management with different sizes of a lighted object	Management of the shape of light beam
Universal design at relatively low price	Design and technological solutions

on a painting surface is one of the museum lighting major problems, therefore, it is one of the main tasks in the design course of a LD providing such uniformity.

Analysis of the technical capabilities of the solution has shown at least three ways to solve this task:

– Application of the *DMD+DLM*[1] technology [5, 6], development of fibre-optic image converters with differential input;

– Application of LED matrices with differential control of active elements.

The operation principle of these technical solutions is explained in Fig. 2.

Among the listed methods, the *DMD+DLM* technology is the most universal one (Fig. 2a). It is based on the simultaneous formation of both a light beam with a pre-defined shape and luminous intensity distribution in this beam by means of a set of micro mirrors with two-axis control.

Another method, as much universal as the previous one, is the application of LED matrices with differential control of active elements [7–9] shown in Fig. 2b.

This method is distinctive with application of a multi-matrix containing separate mini-matrices with dimensions of 1.34×1.34 mm united in groups, each of which, depending on the light distribution area and uniformity degree requirements, contains 6, 5, or 4 mini-matrices with individual power supply of each group, thus providing the required degree of illuminance distribution uniformity on the surface of an illuminated picture.

Another advantage of such a matrix is the structure of the aluminium-oxide board, which is a nanoporous framework with increased thermal conductivity (≥120 W/K×m as compared with 3 W/K×m of conventional aluminium boards), which makes it unnecessary to use a radiator, ventilator, or another cooling system, which is extremely important for operation in a museum environment.

The third quite simple illuminance distribution adjustment method is the application of a fibre-optic image converter [10] (Fig. 2c) with the shape of its output end reflecting the luminaire lens focal plane projection shape of the illuminated object and which is assembled of separate fibre-optic bunches with focused LED radiation of necessary capacity supplied on their input end.

Luminous flux adjustment of each of these light sources allows not only to get a high degree of illuminance uniformity but also to control the illuminance level within a wide range.

4. PROVISION OF THE REQUIRED LEVEL OF CONTRAST

In different museums, it is quite possible to face situations when a light spot formed by a luminaire can be seen around a painting (Fig. 3). Analysis of this method of lighting has shown that it not only irritates sight but also usually causes significant illuminance nonuniformity of a painting (Fig. 3b) and relatively small contrast between the lighted object and its background. Such method causes an increase of illuminance level of the painting, which in some cases causes "shining" of a frame, which bothers perception even more.

These negative effects can be reduced by means of the luminous flux formation with a pre-defined shape and size with the simultaneous control of the background luminance, for instance, by means of:

[1] *DMD* is a *Digital Micromirror Device. DLM* is a *Distributed Lock Manager*

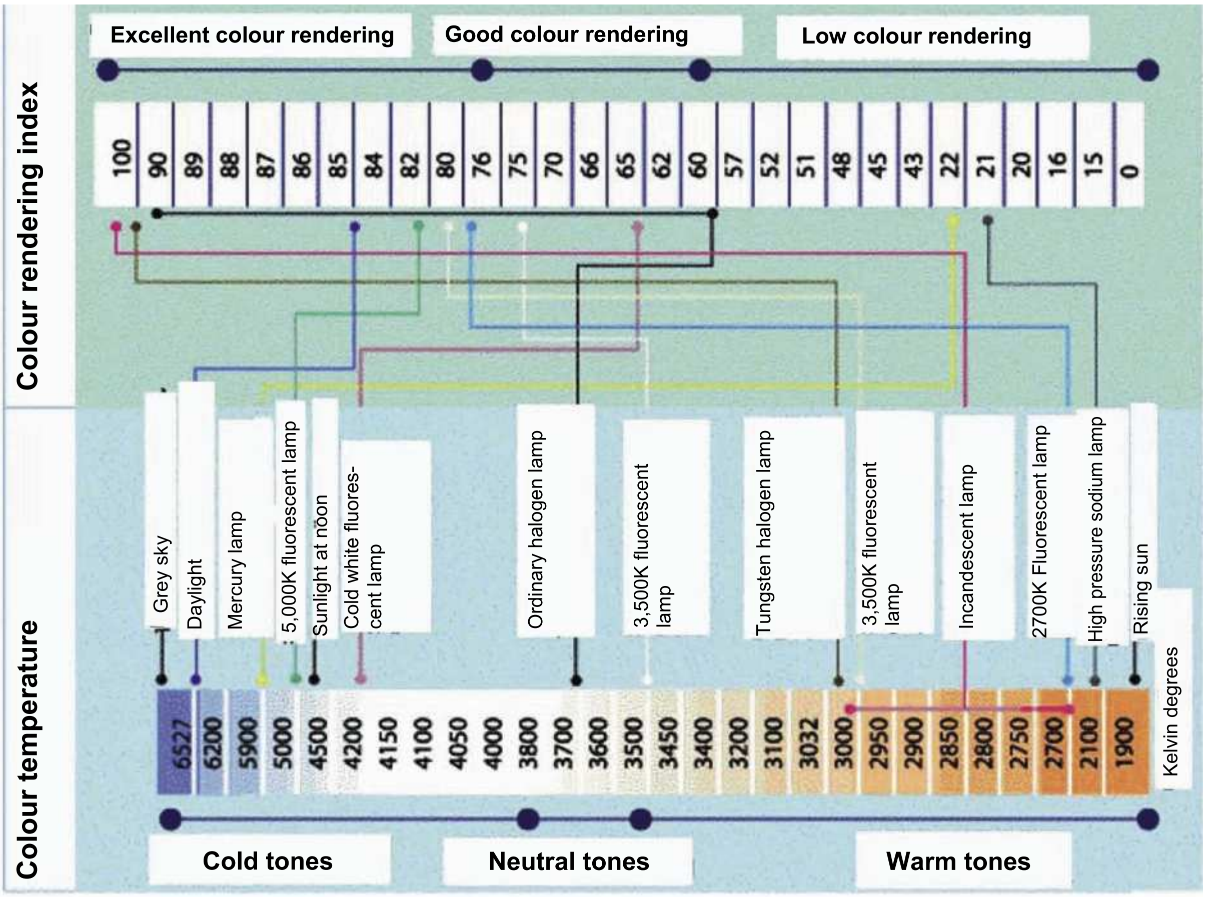


Fig. 5. Scheme of colour temperature and CRI of different light sources

– Projection-type apertures replaced depending on the shape and size of the illuminated object (Fig. 4a) or controlled remotely by means of an electric drive (Fig. 4b);

– Matrices (Fig. 4c);

– Liquid-crystal plates (Fig. 4d [11]);

– Fibre-optic image converters (inside the LD with increased CRI requirements and requiring an optical mixer for mixing radiation from various spectrum of the light sources) (Fig. 4e).

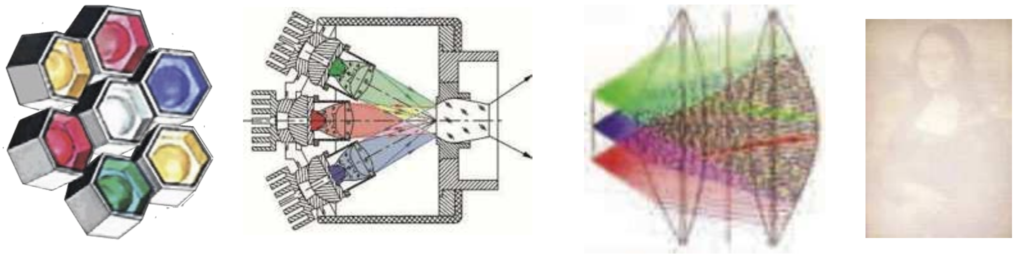
5. PROVISION OF MAXIMUM POSSIBLE VALUE OF CRI AND COLOUR TEMPERATURE

When conventional light sources were used (incandescent lamps, gas discharge, and fluorescent light sources), the maximum possible value of CRI was reached usually by selecting a design of a particular LD. Naturally, as we can see on a scheme shown in Fig. 5, the number of variants of the maximum possible value of CRI was rather limited. The situation is made worse by the fact that the options providing required values of CRI turn out to be non-applicable due to other parameters, in this case, due to the unacceptably high share of the infrared component in the radiation of these LDs.

The appearance of LED makes the situation totally different as it allows to get high values of CRI in case of reliable mixing of radiation with different chromaticity. Application of a fibre-optic image converter [12] shown in Fig. 6 as a mixer may be taken as an example of the technical solution for this task as, simultaneously with the mixing of radiation from seven monochrome LEDs, it forms the shape of luminous flux required for solving a specific task. In this case, CRI of 95 is reached.

With another option [13], if it is necessary to reduce the length of a LD, a thin fibre-optic bead with the thickness of just 3 mm can be used and, working in conjunction with a two-component projection optical system and a diffusive plate, it allows to get CRI of 96–98.

In addition, an alternative option to provide high values of CRI equal or exceeding 95 is the application of complex phosphor.



a) *b)*

Fig. 6. Options to achieve high values of CRI: a) a set of 7 monochromatic LEDs of 5 colours with a fibre-optic image converter; b) a set of 34 LEDs of 5 colours with a fibre-optic bead and a diffuse filter at radiation output

a) *b)*

Fig. 7. Lighting of paintings in an enfilade: a) daytime; b) night time

6. ELIMINATION OF GLARES CAUSED BY LIGHT SOURCES AND INTERIOR ELEMENTS

The most frequently encountered problem of museum lighting causing discomfort for visitors is the availability of glares created by daylighting sources and artificial ones at night time, which is easy to show (Fig. 7). This effect is especially significant in palace museums where paintings located in enfilades, which are relatively narrow halls with large windows and LDs installed overhead, will always "shine" under an influence of light sources.

Glares are inevitable for paintings located on mounts installed at an angle to windows (Fig. 8a) and even more for pieces of art located in cases or behind protective glass**.** Even Raphael did not manage to avoid it (Fig. 8b).

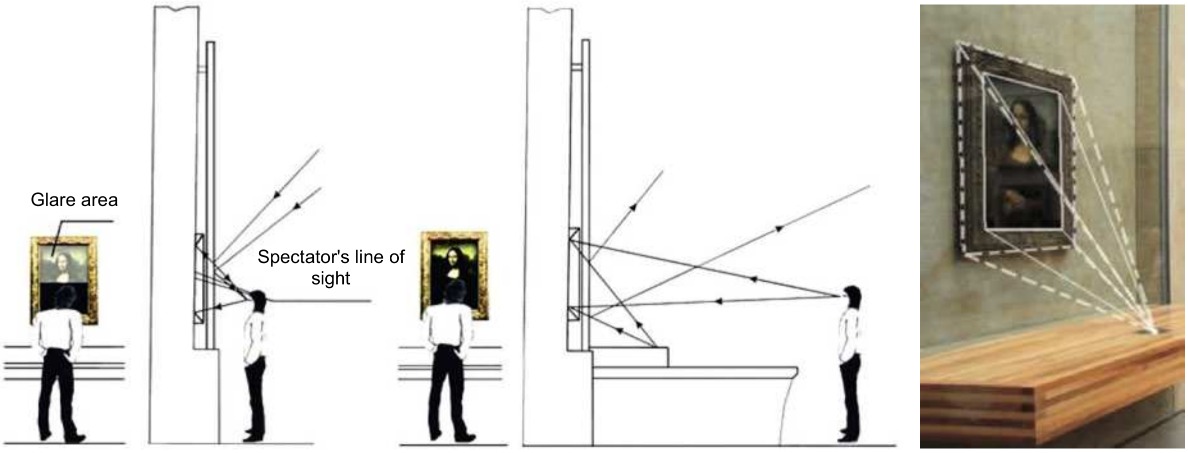
It is obvious that overhead artificial lighting can be avoided neither, especially in palace museums, and since the luminous flux is not sufficient for lighting of paintings, additional special LDs are required with their power supply via busbars spoiling palace architecture. However, the most important thing is that, due to optical laws, they form rather

a) *b)*

Fig. 8. Glares on paintings located perpendicular to a window: a) without protective glass; b) with protective glass

a) *b)* *c)*

Fig. 9. Examples of overhead lighting of paintings with special LDs



a) *b)* *c)*

Fig. 10. Ray path in the process of glare formation:
a) with overhead lighting; b, c) with lower lighting

bright glares on exhibits preventing the normal perception of the latter (Fig. 9).

The solution eliminating this effect shown in Fig. 10 is obvious: it is necessary to change the direction of radiation from light sources, which has been first implemented for the lighting of Mona Lisa in the Louvre [12].

The analysis of ray path shown in Fig. 10 shows that with overhead lighting (Fig. 10a), the position of a glare on the portrait may take almost a half of the surface of a picture depending on the position of the spectator whereas with lower lighting (Fig. 10b) there are no glares at all.

The glares on objects exhibited in cases are eliminated by means of compensating opposing diffuse beam (Fig. 11) providing the value of luminance on the protective glass equal to the value of luminance from outer light sources or even exceeding it. Herewith, taking into account that the external illuminance forming glares constantly change due to the changes of external factors, it is necessary to make this system self-adjusted, i.e. provide it with illuminance and colour temperature feedback sensors. According to the analysis, this allows either to get rid of glares or to sufficiently reduce their impact on the perception of pieces of art.

The values of illuminance on protective glass created by glare-forming light and by opposite beam compensating this glare as well as of illuminance on the surface of the lighting object are shown in Table 2.

7. LIGHTING OF LARGE WORKS AND MULTIFIGURED COMPOSITIONS

The lighting of large works (larger than 1.5 m) usually requires the application of several LDs united into one system. In this case, complications are caused by the connection of LDs as overlapping of non-controlled light beams causes non-uniformity of illuminance in the resulting distribution of light. Another obvious obstruction for qualitative lighting of works with dimensions exceeding 4.0×3.0 m is the inevitability of glares in case of overhead

Table 2. Illuminance of Elements of an Image Case and Eyes of a Spectator

Illuminance on the protective glass, lx		Illuminance, lx	
From external light sources	From the opposing light beam	At distance of 0.5 m from an object	On an object
200	450	140	250
100	450	120	200
50	2910	670	300
50	2300	420	250
50	1140	270	150
50	360	80	80

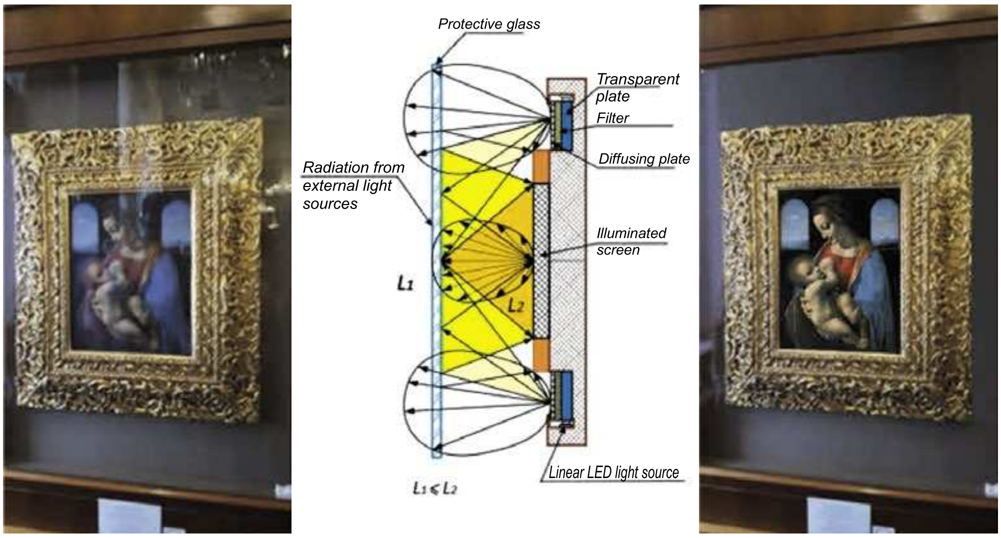


Fig. 11. Lighting with an opposing light beam

installation of LDs and rather large dimensions of a lighting installation almost excluding a possibility of lower installation of equipment due to the significant reduction of exhibition area.

The specified problems are possible to be solved with the application of LED matrix sets with the differential control of active elements as light sources. In this case, LDs are installed as shown in Fig. 12a and 12b so that the edges of light spots from neighbouring LDs with lower luminous intensity (Fig. 12e) overlap each other on the surface providing uniform distribution of illuminance all over the surface of a painting and total elimination of glares.

8. SYNTHESIS OF TECHNICAL SOLUTIONS IN SPECIAL LDS FOR LIGHTING OF PAINTINGS

The first attempt to implement a part of the above mentioned technical solutions in a united LD was made in 2005 in the course of the reconstruction of the Gioconda hall in the Louvre for the lighting of Mona Lisa, which required the development of a special LD (Fig. 13).

The LD contains seven monochromatic LEDs (green, red, blue, orange, and white) with their radiation focused on the input end of the fibre-optic image converter acting simultaneously as a colour mixer and a contouring element and then going to the remote-controlled round aperture and projecting optical device.

The detail description of the design of this LD proposed and implemented by Pharos-Alef LLC is given in [12]. The specified LD was constantly working for 8 years without changing its specifications.

Its modernisation relating to the value and uniformity of illuminance distribution was made in 2013 in the course of the Louvre Efficient Lighting project.

The modernised LD contains 34 single-chip and multi-chip LEDs, an optical mixer consisting of a collimator, an aperture, a fibre-optic mixer, a dif-

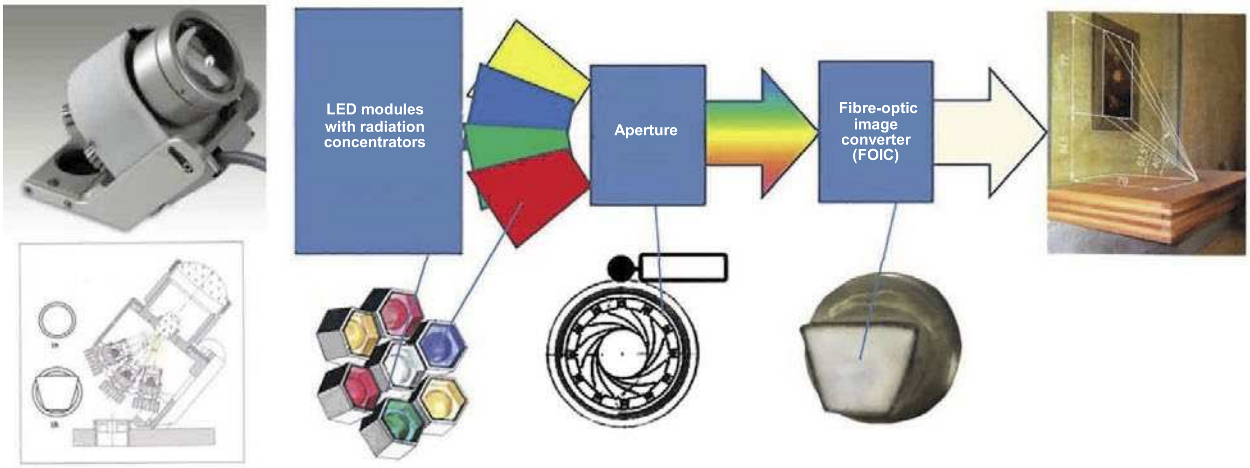


Fig. 13. The design and elements of the LD for lighting of Mona Lisa (2005)

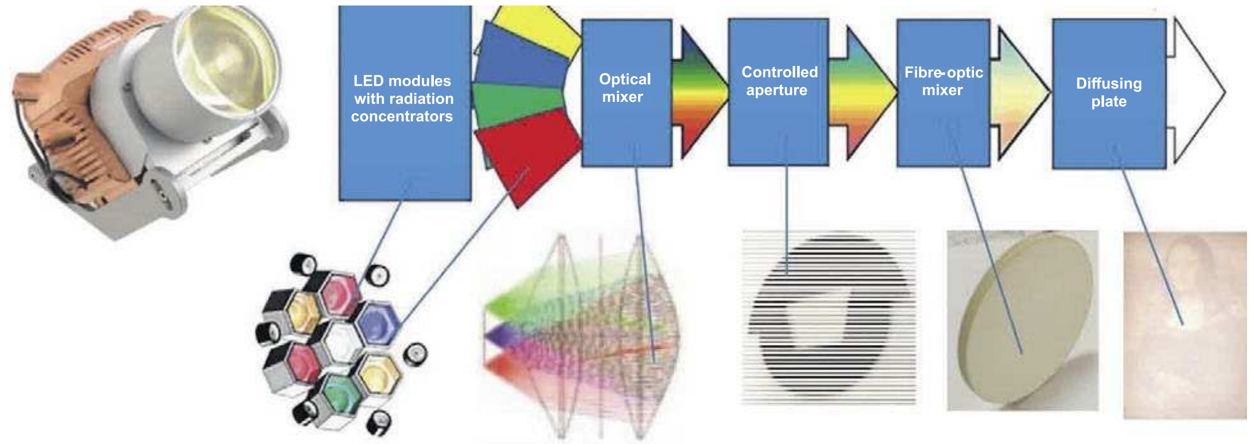


Fig. 14. The design and elements of the LD for lighting of Mona Lisa (2013)

a) *b)*

Fig. 15. Lighting of Lorenzo Lotto's Christ Carrying the Cross: a) with a traditional method of mixing of artificial and natural illumination; b) with the proposed LD

fusing plate, and a projecting aspherical lens (not shown) (Fig. 14) [13].

As a result, it was possible to eliminate distortions of the light beam spot on the illuminated object specific for ordinary lenses and to increase CRI from 95 to 98.

This modernised LD described in [13] in detail has been working in the Louvre since June 2013.

Not so long ago, an attempt was made to update and to simplify this LD making it universal, applicable for operation with objects of different shape and size, and for this purpose, a multi-matrix was

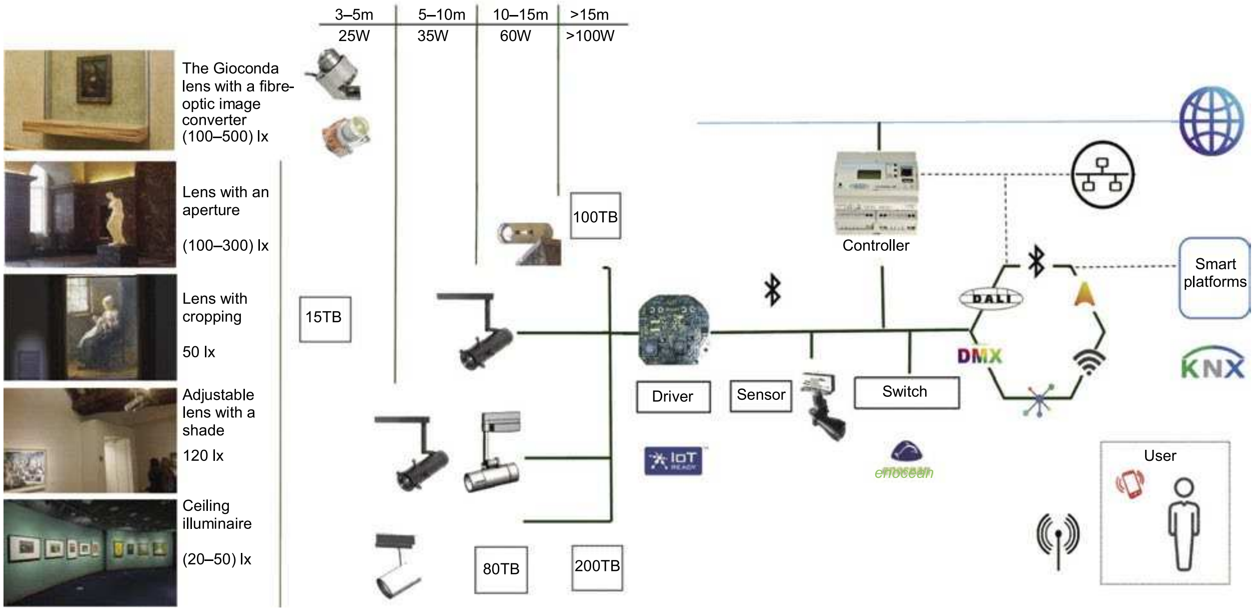


Fig. 16. Major specifications of LD for lighting of paintings and its control system scheme

used as a controlled aperture and a device providing uniform distribution of illuminance on the surface of a painting. To reach high values of CRI, the multimatrix contains LEDs with complex phosphor providing CRI equal to 93–95. As a result, a LD providing solutions to the listed problems was developed and its testing confirmed its practicability (Fig. 15).

As it was already noted in section 6, there is a capability to use another method of paintings lighting with the application of an opposing light beam formed by a diffusing structure with luminous flux end input. Such a method allows not only to provide uniform lighting with radiation of required chromaticity at a sufficient illuminance level but also to reduce the impact of glares significantly.

However, the tests showed that this method has limitations only for objects located behind glass at a distance of at least 3 cm.

Therefore, for solving the specified problems, in cooperation with *Sklear* (Germany), Pharos-Alef LLC has developed a series of such LDs and an adjustable control system for them. Major specifications of these LDs and the structure of the control system are shown in Fig. 16.

9. LIGHTING OF WATERCOLOURS, TEMPERA, GRAPHIC ARTS, AND TEXTS

Alongside with the lighting of paintings, the lighting of graphic arts and text objects (almost everything made on paper) has its special aspects related to their storage, exhibition, and perception. These special aspects basically relate to the susceptibility of paper to accelerated deterioration under the influence of light. It is obvious that maximum impact is caused by ultraviolet and infrared parts of the spectrum, which, as we have seen, can be eliminated. Herewith, as practice shows, the condition of a medium and therefore the piece of art, in general, are to some extent influenced by other parts of the spectrum, which makes curators not only reduce the illuminance value down to 50 lx [14] but also shorten the exhibition time by covering objects with light-proof fabric.

The majority of graphic works of all possible techniques are exhibited upright on walls. At the same time, a small format of graphic works and examination of small features of the images requires relatively small distance between a spectator and an object which in most cases is protected with glass. As a result, the spectator sees his/her reflection in the glass, which significantly prevents the perception of the exhibited piece of art. In addition, everyone is convinced, though not without reason, that this "inevitable evil" can be improved only with the application of expensive non-reflective glass. This method works to a great extent, but, unfortunately, not always. The analysis of causes of the spectators reflection in front of exhibits and capabilities of contemporary light sources shows that non-reflective glass is almost useless at high values of

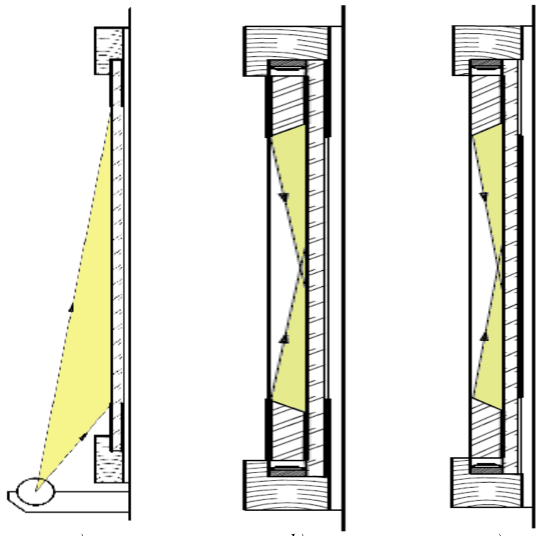


Fig. 17. Schemes of lighting of graphic works and photographs: a) lighting from below with an external LD; b) frontal lighting of an object with a dark mat; c) frontal lighting of an object with a light mat

luminance of daylighting and artificial light sources causing glares. As shown in section 2, this problem can be resolved alternatively by increasing contrast, which can be achieved in several ways:

– The lighting by means of a lower LD up to limit of luminance on the paper;

– Frontal lighting of an object against a non-lighted mat background;

– The lighting of an image and a mat with differently directed radiation.

It is obvious that in any case radiation incidence angles should be as high as possible for the energy impact minimisation of its refracted part.

Implementation of these methods of a LD taking special aspects of graphic art lighting is shown in Fig. 17a (lighting from below) and 17b (an increase of contrast). This effect is expressed even more with the lighting of a dark image and a light mat with differently directed radiation as shown in Fig. 17c.

10. CONCLUSION

The problems of museum lighting listed in the article should not be considered comprehensive in any case as it doesn't describe such important questions as LDs made as parts of palace architecture, methods of harmonisation of technical means preserving pieces of art, and other aspects of museum lighting environment formation with a wide range of architectural solutions existing. The proposed methods of solving these problems are not to be considered comprehensive either. They just demonstrate capabilities of recently created tools for the implementation of tasks in other related areas.

REFERENCES

1. Devina R.A., Brednyakov A.V., Dushkina L.I., Rebrikova N.L., Zayceva G.A. Muzei'noe khranenie hudozhestvenny'kh cennostei': prakticheskoe posobie [Museum storage of art treasures: practical guidelines] // Tipografiya Ministerstva kul'tury RF, Moscow, 1995, 204 p.

2. Da Vinci L. A Treatise on Painting // Folio, 2013, 224 p.

3. Van Gogh V. Pis'ma [Letters] // Iskusstvo Publ., Moscow, 1966, 653 p.

4. Bugrov V.E., Vinogradova K.A. Optoelektronika svetodiodov. Uchebnoe posobie [Optoelectronis of LED. Study Guide] // NRU ITMO, Saint-Petersburg, 2013, 172 p.

5. Hornbeck L.J. Digital Light Processing and MEMS: an overview // Advanced Applications of Lasers in Materials Processing/Broadband Optical Networks/ Smart Pixels/Optical MEMs and Their Applications, 1996, pp. 7–8.

6. Younse J.M. Projection Display Systems Based on the Digital Micromirror Device (DMD) // SPIE Conference on Microelectronic Structures and Microelectromechanical Devices for Optical Processing and Multimedia Applications, Texas, 1995, Vol. 2641, pp. 64–75.

7. High thermal conductivity PCB solutions manufacturing since 2010 // RUSALOX.

8. Naysh M., Rufitsky M., Suchkov M., Ossin A., Zolotov A., Antilin E. Teploprovodiashchiie kommutatcionnie podlozhki [Thermally-Conductive Commutation Bases] // Poluprovodnikovaya Svetotekhnika, 2012, No. 4, pp. 78–79.

9. Astakhov A.A., Karimbayev D.D., Misyunas A.O., Khristikov V.G. Optomozatsiia teplovykh rezhimov v kostruktsiiakh svetovykh priborov na poluprovodnikhovykh istochnikakh sveta [Optimisation of Heat Modes in Structures of Light Devices Applying Light-Emitting Semiconductor Devices] // Reports of TUSUR, 2011, No. 2, Vol. 24.

10. Satarov D.K. Volokonnaia optika [Fibre Optics] // Mashinostroyeniye Publ., Saint Petersburg, 1973, 280 p.

11. Vermeersch B. Full wireless flexibility of the accent lighting within the museum environment // 1st Inter-

national Science and Practical Conference "Light in the Museum", Saint-Petersburg, 2018. URL: https://nts-svet.ru/wp-content/uploads/2018/04/svet_v_muzee/2_8_B_Vermeersh.pdf

12. Miras J.-P., Novakovsky L.G., Fontoynont M. Lighting of Mona Lisa: New Lighting Solutions // Svetotekhnika, 2005, No. 5, pp. 28–33.

13. Novakovsky L., Fontoynont M., Miras J.-P., de Vecchi P., Chanussot J., Angelini M., Marty C., Duchêne G., Makita K. Mona Liza v novom svete [Mona Lisa in the New Light] // Poluprovodnikovaya Svetotekhnika, 2013, No. 4, pp. 64–67.

14. GOST 7.50–2002 Konsetvatsiia dokumentov. Obshchiie trebovaniia [Document conservation. General requirements], 2003.

Leonid G. Novakovsky,
Ph.D. in Technical Science. Graduated from MPU in 1969. Director of Pharos-Alef LLC

Light & Engineering
Vol. 27, No. 4, pp. 43–52, 2019 *https://doi.org/10.33383/2018-149*

ARCHITECTURAL LIGHTING IN MUSEUMS

Nikolay I. Shchepetkov

Moscow Architectural Institute (State Academy), Moscow
E-mail: n_shchepetkov@inbox.ru

ABSTRACT

The role of light, mainly daylight, in the museum interiors is considered in three areas of its dominant usage: **light for architecture, light for an exhibited item, and light as an exhibited item.** This is predetermined by the architectural concept of the museum, due to the creative position of the architect, the author of the project creating a spatial composition of a museum building or complex with one or another daylighting system. Architectural form making is directly related to the nature of the exhibition lighting solution. Examples are given, mainly, from a varied foreign practice of modern museum construction on the projects of famous architects of the 20th-21th centuries in three classified areas.

Keywords: architecture, light, museum, exhibited item, visitor (viewer), architect

Museum and light are inseparable concepts, and this applies to any light in each museum. However, this connection is universal: in any room and open space, the activity of the seeing person is driven by the light. However, in the vast typology of world museums, this dynamically developing topic is particularly diverse and not known in all its scope even to a small circle of specialists. First, the museum typology in buildings, under the open sky, under the ground and under the water, large and small, mono- and polyfunctional, old and new is extremely branched, and this is probably the most complex in structure and content typology among public sites. It is reflected in the original architectural solutions of museums and museum complexes. Secondly, in museums both simple and ingenious methods, systems, and techniques of day, artificial, and mixed (combined) lighting, general and accentuating, direct, diffused and reflected, white and chromatic, static and dynamic, with passive or programmable control and mode of operation, with elements of interactive lighting of a visitor in the exhibition labyrinths are widely used. In all cases, the purpose of creating and function-

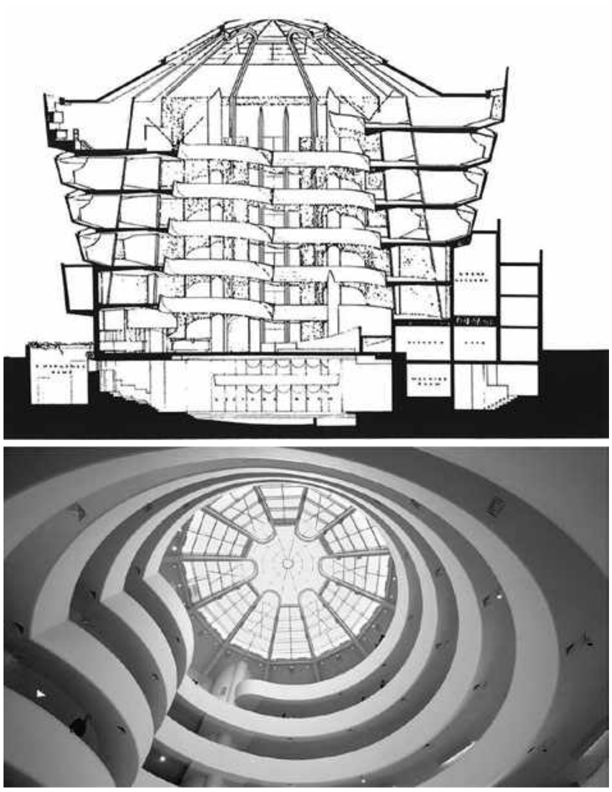


Fig. 1. Guggenheim Museum, New York (F.L. Wright, 1937). The sectional view of the building and the atrium interior in daylight

ing of the museum is to organize effective interaction of two components: the architectural and spatial environment with the items displayed in it and the visitors.

There are three evaluation categories of the interaction of light, mainly daylight, with architecture and exhibited item: **light for architecture, light for exhibited item, and light as exhibited item.** Moreover, daylighting in all cases acts and is considered as a powerful form-making and informative factor in architecture and as the principal means of creating emotionally imaginative expressiveness through examples of museum interiors. Of course, this classification is conditional, because the one group items to some extent have features of another, but gives grounds for formal analysis of exhibition light solutions.

The first group includes museums, where people, voluntarily or not, focus on architecture, the architectural space organization, plastic and colour decor, as the most remarkable thing in the interior or the interior ensemble. Architects, creators of such buildings, in most cases consciously give priority to architectural forms, rather than to the contents of the museum represented by the collection of exhibited items, permanent or temporary. For mobile exhibitions of different art genres, where universal exhibition halls and mobile, mostly artificial, lighting are needed, this priority is understandable, but the architect's desire to express himself is usually prevails: the previous tendency to design the museum buildings in the traditional academic style (for example, the Pushkin State Museum of Fine

Fig. 2. Museum of Art of the 21th century in Rome (Z. Hadid, 1999–2009). Interior with mixed lighting

Arts) was replaced in the middle of the 20th century by an increasingly active search for new spatial compositions and original figurative solutions. This was driven by the avalanche-like growth of various private collections occurred in the post-war period in Western countries. "New museums are living, developing, "open" systems, and they should be matched by architecture that has… structural flexibility and mobility" [1]. For the architect, it is obvious that "In any other sphere of design professional consciousness and values, ideology and creative experience are not manifested with such frankness as in museums" [1]. In our country, due to historical particularities, post-war museum construction was carried out mainly on memorial subjects, and many museums were established in existing buildings with their originally different function, so the daylighting systems in them are far from ideal for exhibitions.

Fig. 3. The interior of the Museum of Modern Art in China (Coop Himmelblau Studio, 2016). Super-sophisticated structural shapes in the upper daylight

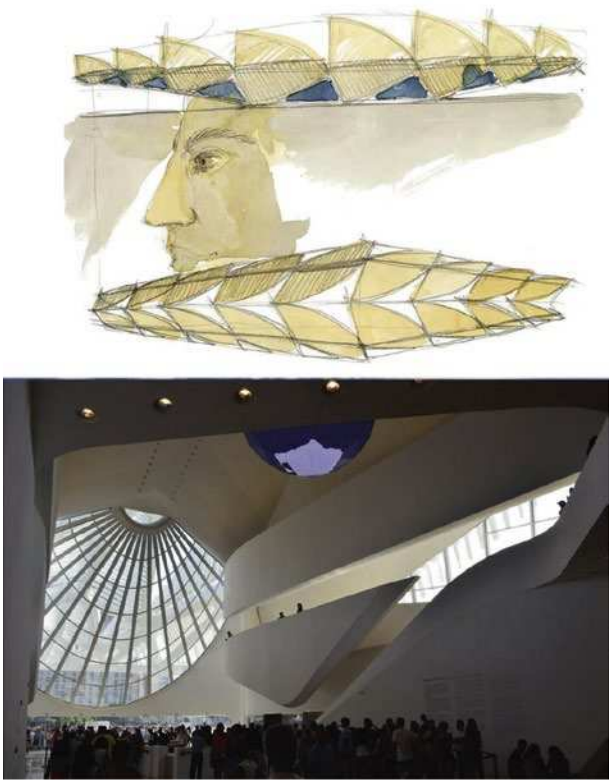


Fig. 4. Museum of the Future in Brazil (S. Calatrava, 2016). Searching for shape – building sketch and day interior

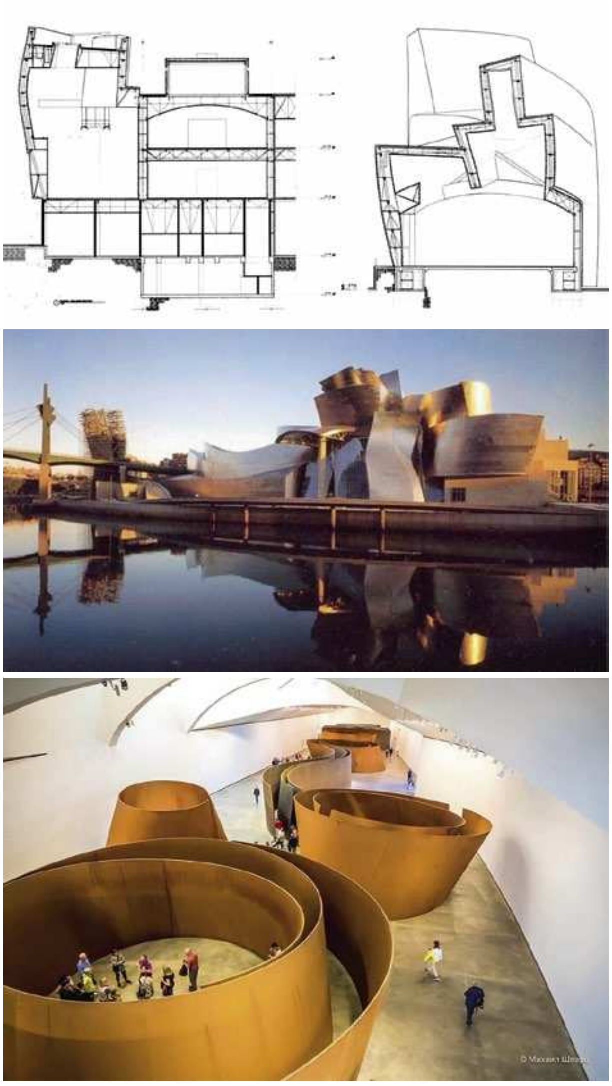


Fig. 5 Guggenheim Museum in Bilbao (F. Gehry, 1995). Appearance, sectional views and interior in natural light

One of the pioneers of the new, completely original spatial planning of the building was F.L. Wright, the creator of "organic" architecture, built the New York Guggenheim Museum in 1937. The continuous spiral ramp adjacent to the outer wall of the building round in the plan rises seven levels around the central atrium with the upper daylighting. Spiral, not very convenient for visitors (feet get tired on an inclined surface), as if "wound" on the ephemeral air volume in the form of slightly narrowing to the top cylindrical daylight space, creating various and spectacular viewpoints at different levels. The exhibited items of changing exhibitions, suspended on the walls with negative inclination (paintings), as well as exhibited on the ramp (sculptures), attract the visitor's secondary attention; the primary attention, especially on the first visit to the museum, is focused on the interior architecture (the exterior image of the building is not less impressive). This is one of the first, most refined and memorable images of the museum, where the trend, technique and style prevail. This is the **light for architecture** (Fig. 1).

In all kinds of variations, this style is reflected in the work of most practising foreign architects of both world renown and less famous, who consider it a great luck to get the order to design a museum that can increase their popularity. In such museum interiors, the visitor, first of all, is amazed by the peculiarity, complexity, expressiveness of architectural forms and spaces, and the extravagance of daylighting techniques and then draws attention to the exhibited items, which are often not visible in the pictures (Fig. 2–4). At the same time, the extravagance of lighting is often forced: if the building is conceived by the author as a complex sculpture, in the external bizarre forms of which the shells with rooms are "crammed", then heir lighting techniques are forced to become sophisticated, which determines the individualized light-spatial and light-plastic effects in interiors (Fig. 5). The light manifestly "works" on architecture and is quite indifferent to the exhibition.

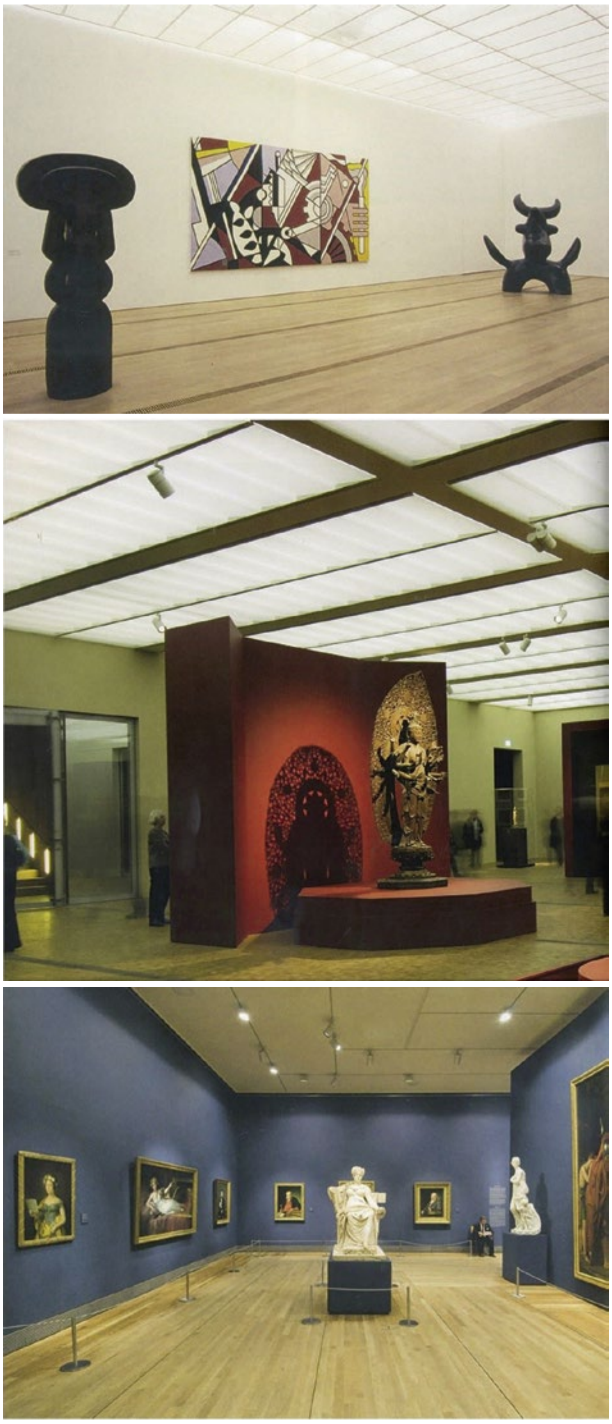


Fig. 6. "Filling" general lighting for flat, silhouette and voluminous exhibited items in halls with light and dark finish of walls and ceiling and different types of lighting installations

Formally, the core museum value is still the exhibited items. Therefore, the primary obligatory task of the designer and the museum specialist is to show them to the visitor in the best light, either literally or metaphorically. This is the second area of the "work" of museum lighting – **light for the exhibited item** – is usually realized by all

Fig. 7. Halls with different luminance adaptations due to combinations of different intensity and different types of artificial lighting systems and different finishing of interior surfaces

means of daylighting, artificial, and mixed lighting in different proportions. Man-made artificial lighting systems have much less impact on physical (not figurative!) form-making in the interior architecture, and in the presentation of the exhibited items are of mass, often crucial importance both in the evening and in the afternoon. There are three techniques of organizing the interaction of any light with the exhibited item:

- General, as a rule, abundant lighting of the exhibition space;
- "Targeted", accent, individual lighting of the exhibited item;
- Combined lighting.

It should be kept in mind that at all techniques the artificial lighting can be selectively controlled over the entire range of characteristics: by specularity and contrast, which determine the shadow formation on the exhibited items, architectural forms, faces, and figures of visitors; width and intensity of light beams forming the light distribution in the interior space and a bright composition in the field of

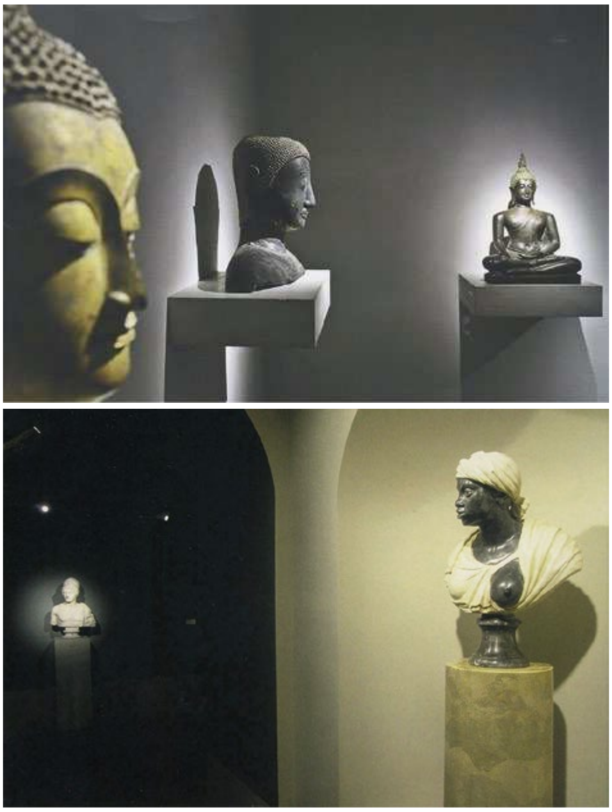


Fig. 8. Accent artificial lighting of voluminous exhibited items in halls with different wall finishing

Fig. 9. National Gallery of Germany, Berlin (Mies van der Rohe, 1968). Exterior and interior of the daytime exhibition space with mixed lighting on the ground floor

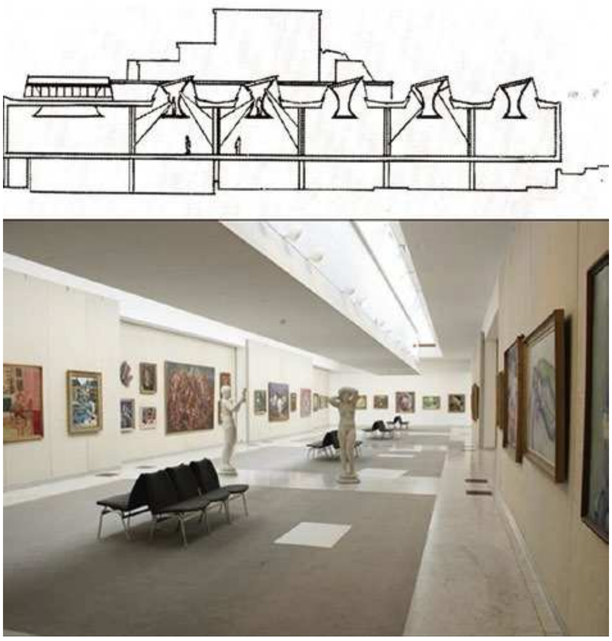


Fig. 10. Museum of Art in Alborg, Denmark (A. Aalto, 1958–1972). Transformation of direct sunlight into diffused light by means of lanterns of complex shape. Section and view of the day interior

view; radiation spectrum and lighting kinetics that affect the visitor's emotions. General lighting – daylighting, artificial or mixed, completely "filling" the interior with a certain intensity, focus from the top or top and side, and barely noticeable non-uniformity – is most universal and neutral in relation to the exhibited items, preferably flat or silhouette. In this case, the perception of the interior and the exhibited items largely depends on the finishing of the surfaces, especially the background walls (light or dark) and the ceiling, which determine the conditions of visual adaptation and contrast of exhibited item and background (Fig. 6–7).

These indicators are even more obvious with the local accent, usually artificial lighting: the dark environment enhances the luminance contrasts, which dramatizes the exhibition. Planar-exhibited items are less sensitive to accentuating light, the spot of which can cover them with a halo or, through modern optical devices, exactly coincide with their area. It is through this technique that the exhibited items are presented most effectively (Fig. 8).

In most of the exhibition rooms, the general (artificial and daylighting) plus accent (usually artificial) lighting, and at the same time, the ratio of general and local, reflected and direct, diffused and directional lighting with different scalar and vector values varies widely. In all cases, interior decoration, their colour scale is of importance (Fig. 8).

In the exhibition halls ensemble alternating according to a certain scenario of different lighting

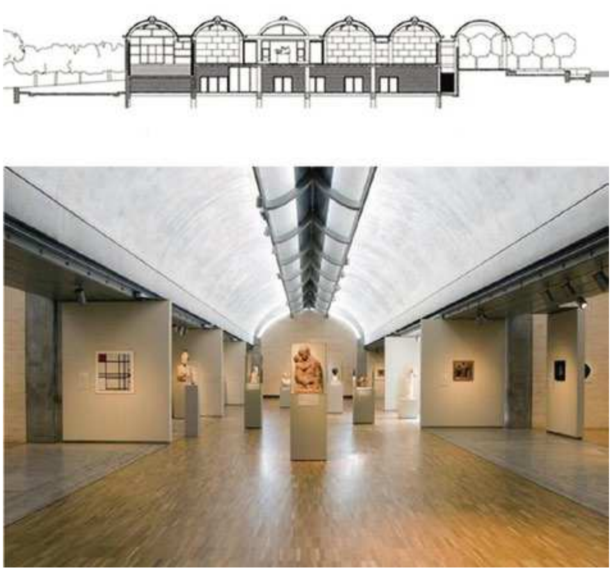


Fig. 11. Kimbell Museum in Fort Worth, Texas (L. Kahn, 1966–1972). Vaulted reflective roof and linear suspended light scattering device turn bright sunlight into a soft diffuse light in the exhibition halls. Section, day interior

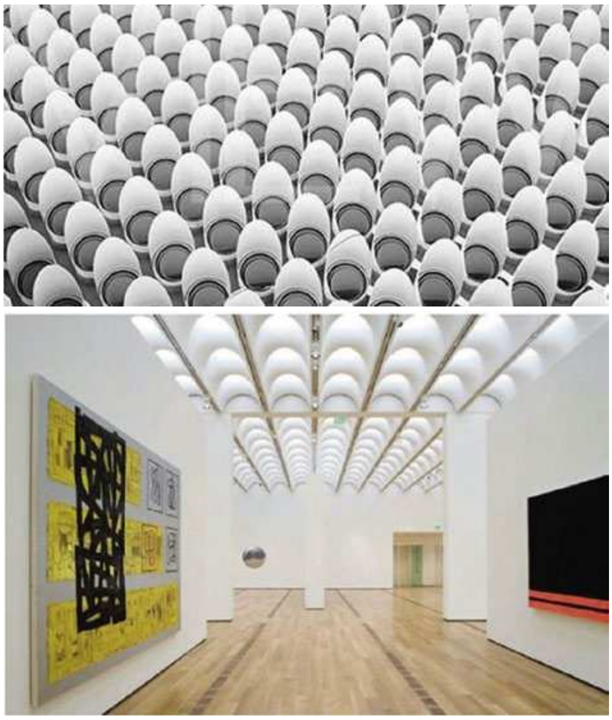


Fig. 12. Museum of Art in Atlanta. (R. Meier and R. Piano, 1980–1983). Section and view of the "carpeting" of the exhibition hall with clear-stories and day interior

techniques can in itself create a self-valuable lighting ensemble. This ability for daylighting is predicted by the architect in the project design, in accordance with his creative philosophy of attitude to light as a form-making factor, and the occasional "flaws" in lighting can be corrected by artificial light.

The trend of more respectful and attentive attitude to the exhibited item is demonstrated in the museums created by the leaders of the functionalism of the 20th century (Fig. 9–11), from which there was a style branch of minimalism in modern architecture, and the universals working in different styles (Fig. 12). Their architecture does not so much "hog the cover", abandoning its own exclusivity and focusing the daylighting to the exhibition, thus creating optimal conditions for perception exhibited items. It, at the will of the author, as if sacrifices the own expressiveness, delegates part of the light expressive potential from architecture to exhibited items, builds the visitor's attention in space, time, and hierarchical content of these items in the proper construction of the exhibition light composition.

The German National Gallery in West Berlin can be considered the flagship museum of this focus, with a powerful architectural image but extremely minimalist architecture in the interior, not distracting the visitor's attention from the exhibited items, and a system of mixed (side daytime plus ceiling

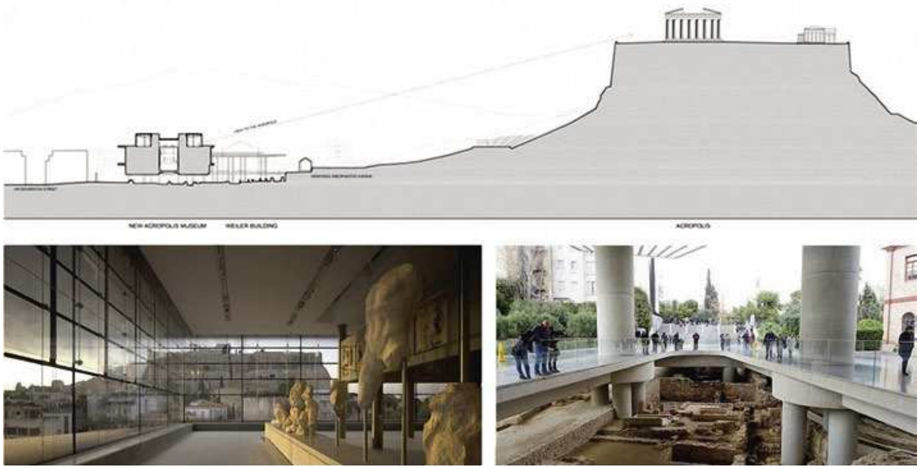


Fig. 13. Acropolis Museum in Athens. (B. Tschumi. 2009). Combined lighting of spacious exhibited items (natural side light and upper artificial light) with landscape and background views of the Acropolis and the Parthenon. Situation section and exhibition halls

Fig. 14. Holocaust Museum, Berlin (D. Libeskind, 1989–2001). General view and daylight interior lighting

artificial) lighting on the ground floor and artificial lighting in the underground floor (Fig. 9). L. Kahn, the adherer of sunlight, for the purposes of museum lighting created original vaulted reinforced concrete coverings with a clear-story in the vault crown, the direct light of which is transformed into a diffused, reflected by the vault and scattered by a linear suspended light scattering device (Fig. 11). A. Aalto, a singer of soft northern light, invented quite complex volumetric plastic forms of covering halls to turn blindly rigid for museum premises sunlight into a safe dispersed one (Fig. 10). R. Meier and R. Piano "shattered" unsuitable for exhibition, bright sunlight in Atlanta with a complex and obviously expensive "carpet" system of numerous shaft clerestory above the exhibition hall. The parameters of clerestory with skewed lens shades were determined by the full-scale lighting modelling on the large layout of the hall in the conditions of real sunlight (Fig. 12). As a result, the exhibition hall in the daytime is abundantly filled with homogeneous, free, high-quality diffused light, available for any exhibited items at any point of the hall.

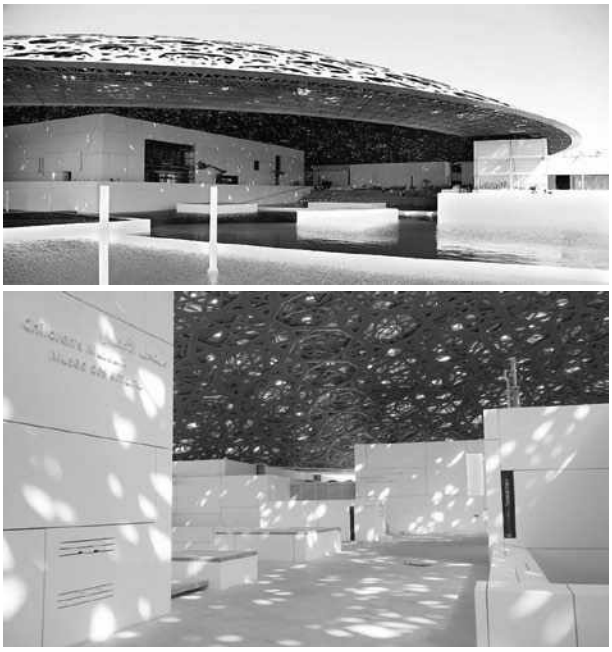


Fig. 15. Louvre Museum, Abu Dhabi (J. Nouvel, 2017). Multilayer mesh structure of dome roof in conditions of dominant sunlight provides infinitely diverse "Brownian" movement of numerous twinkles in different exhibition pavilions under it

The exhibited items often require a reasonable combination of daylighting with artificial light. In particular, these are the artefacts of archaeology and lost architecture, which were once perceived in the conditions of regional natural lighting. The number of such museums and the interest in them is growing all over the world. International contests for the project of the Acropolis Museum in Athens in 1976–1999 and a number of other architectural contests on similar topics offered a variety of approaches to the presentation of exhibited items: ground, semi- and underground. The realized Acropolis Museum demonstrates the exhibited items – preserved fragments of sculptures and architectural plastics on the facades and interiors of

Fig. 16. Modern Jewish Museum, San Francisco (D. Libeskind Studio, 1998–2008). Exterior evening appearance and daytime interior with continuous play of moving sunlight in space and bright spots on the sloping walls and floor

Fig. 17. Colourful artificial light in the installations of J. Turrell: Crater Roden Museum, Arizona

ancient pieces – in side daylighting through the facade stained glass windows and additional upper artificial lighting. At the same time, the contest program requirement and the obligatory element of this museum exhibition is the view of the Acropolis and the Parthenon from some exhibition halls (Fig. 13).

The most intriguing and unpredictable is the third area in the museum exhibitions: **the light as an exhibited item**. The light is always present in the process of presenting the exhibition and architecture to the audience. This is a fundamental, but rarely recorded by numerous analysts, a phenomenon that should be taken into account in any assessment, whether it be architecture or any other works of art, and in any lighting. In some museum interiors, this phenomenon consciously or intuitively becomes a reality, i.e. the exhibition subject (in all cases the light makes real the surrounding figural and spatial world).

The architectural and artistic role of daylighting in the internal space of buildings, including museums, is discussed in the rare in our science, successfully defended in 2018 thesis [2] with multiple fragmentary presentation and the author's interpretation of the conceptual points of view of famous architects on this subject. It is clear that their opinions are purely individual and subjective, and there are few specific coincidences among different authors, except for the general obeisance to the role of light in creative philosophy and practice. These are not scientific theses, but rather, unsystematised professional reflections on always enough timeserving base of own, adapted to reality design methodology.

In the third type of museums, the central exhibited item is the light itself, its effects in the exhibition space in an explicit or veiled manner becomes the focus of the museum visitors. In some cases, a radical change in the structure of the light space due to the unusual focus and the "pulsating" amount of light from light openings irregular in the pattern and location in the rooms of different shapes and scales, alternating during the movement

Fig. 18. Colour as an exhibited item – the *Design Wing* Museum in Shanghai (2016) and the Museum of the 20th century in Florence (2014). Dominance of bright saturated colour over the material form of its "carrier"

of the viewer through the ensemble of museum interiors, depend on the emotional assessments of the viewer (Fig. 14). D. Libeskind said about his museum: "Light is something that penetrates through a sharp angle when you come to understand something about the past, which also speaks about the future. Suddenly you see the light in a completely different way and yourself too." [3]

In other cases, a chaotic host of sunbeams and twinkles, slowly and fancily moving in space and sliding on complicated interior surfaces, is able to fascinate the viewer, provoke him to meditate if he is not in a hurry (Fig. 15–16). These effects can create an appropriate architecture in daylight, primarily sun light, especially if it uses special optical systems: coloured glass, which changes the spectral composition of daylight, glass prism decomposing the white light into a rainbow spectrum, hollow light guide translating "live" daylighting to the desired point of the interior, controlled mirrors, reflective screens and lenses, directing or focusing daylighting in the desired place, special masks creating a shadow pattern conceived and changing in sunlight, etc.

However, it should be recognized that the possibilities of global daylight managing in museums and elsewhere are not absolute, simple and require certain knowledge and talent. It is relatively easier to control man-made electric light. On its basis, new trends in architecture and art were born and gradually developed: light architecture, light design (*light art*), light shows, and light music. Cinema is a purely light art, and there are cinema museums. Implemented temporary and permanent lighting installations and performance, light shows and stage lighting, media and interactive lighting systems in interiors, city and plein air are also in some kind museumized. The artificial light as the central exhibited item in such cases is much more obvious than the daylight.

Although this article is mainly focused on daylighting in museums, I want to show the entirely expressive possibilities of light by the example of artificial lighting: already mentioned cinema in which only the light create a virtual visual world, which we believe as the present. J. Turrell, one of the most famous American lighting designers, creates by the colour illumination the three-dimensional installations stunning in the purity and beauty, temporary and permanent, as museum exhibited items. "In order to comprehend the splendour of "pure light", he frees his works from the materiality of the subject world by emphasizing the materiality of light and giving it the form. Released from the burden of materiality, his works, based on projected light and fuzzy shadows of blurred images, are no more similar to painting or sculpture" [2]. In a number of installations, "closing the audience from the outside world, he leaves the only focus – a window into the sky, contemplating which they could "participate in divine events." The endless movement of the ethereal colour sky from dawn to sunset, with its dramatic changes in saturation and shades from pale blue to cobalt, from dark ultramarine to deep purple and velvety black, encourages perception and allows to experience the feeling of being on the planet" [4] (Fig. 17).

Of course, in this case, when visiting such an exhibition, the visitor should have patience and time to feel, appreciate, or share these experiences.

Finally, the object of admiration can be the pure colour of items as a qualitative characteristic of any light from primary or secondary sources, when the shape of items, including coloured glass, is lapidary and in itself does not attract much attention (Fig. 18). This phenomenon of our visual perception (admiration of pure colour) is successfully used by textile production, architecture, and design (colour of environment elements), abstract painting.

REFERENCES

1. Revyakin V.I. Muzei mira [World Museums] // Inform Express Publ., Moscow, 1993, 244 p.
2. Nasybullina R.A. Arhitekturno-hudozhestvennaia rol' estestvennogo sveta v formirovanii vnutrennego prostranstva zdanii' v sovremennoi' arhitekture [Architectural and artistic role of natural light in the formation of the internal space of buildings in modern architecture] // Thesis abstract of the Ph.D., Architecture, N. Novgorod, 2018.
3. Libeskind D//.Newsweek, 2018 URL: (http://enrope.newsweek.com/Daniel-libeskind-talks-about-his-childhood-bullies-nazi-germany-and-jewish-321345?rm=eu. (reference date 25.05.2018)
4. Plummer H. The Architecture of Natural Light //. London: Thames and Hudson Ltd., 2012, 256 p.

Nikolay I. Shchepetkov,
Dr. of Architecture, Professor. Head of the Department of Architectural Physics of Moscow Institute of Architecture. Laureate of the State Prize of the Russian Federation (for architectural lighting of Moscow). Member of the editorial board of L&E Journal

Light & Engineering
Vol. 27, No. 4, pp. 53–58, 2019 *https://doi.org/10.33383/2018-150*

LEDS IN MUSEUMS: NEW OPPORTUNITIES AND CHALLENGES

Anna G. Shakhparunyants, Eugene I. Rozovsky, Anatoly Sh. Chernyak, and Pavel A. Fedorishchev

VNISI named after Vavilov S.I., LLC, Moscow
E-mail: rozovsky@vnisi.ru

ABSTRACT

The national and international requirements for the lighting of museum pieces are presented based on the results of researches carried out in the second half of the 20[th] century and which should be actualized in connection with the introduction of LED lighting into the museums. In addition, the spectrum diversity of the LED sources needs to address the issue of changing the approach to the assessment of museum lighting, in particular, the transition to the new colour rendering indices (Fidelity Index and Gamut Index) according to the CIE, and the use of energy and/or photonic values in addition to light values.

Keywords: museum lighting, preservation of museum pieces, perception of exhibited items, LED lighting, colour rendering indices, light, energy, and photonic values

Light plays a primary role in human life and activity: at present, the functions and goals of light have gone far beyond ensuring visibility and related safety. In our opinion, the theme of lighting of museums in recent decades has been unfairly ignored by the lighting engineers. Thus, in the Svetotekhnika journal – without exaggeration, the main print medium on lighting engineering in Russia – in the last ten years no more than five articles, one way or another concerning the museum lighting and mainly telling about the experience of lighting design (e.g. [1]) have been published. A number of articles by foreign authors, in particular [2, 3], consider the theoretical principles of lighting the museum items focusing on the issues of colour rendering and visual perception of paintings.

Display of museum pieces, as well as their storage in museum collections, necessarily involves the certain light environment created by daylighting and/or artificial lighting. The museum light environment has several essential functions: provision of the opportunity to see the exhibited items for museum visitors, provision of working conditions with the exhibition and museum collection for the staff. In addition, the museum light should be as safe as possible for museum pieces, while playing an informational and artistic role in the exhibition, as well as ensuring the safety of visitors and museum staff. The inquiry of museum custodians conducted in 2014[th] by Pacific Northwest National Laboratory of the United States has shown that in the case of LED lighting, while energy efficiency is an important criterion in the choice of the light source, ensuring the preservation of museum pieces and exhibition aesthetics [4] have an unconditional priority.

Creating a light environment in the museum space is a complex and demanding challenge, since it is necessary, on the one hand, to ensure the full viewing and perception of the museum pieces and the creation of a sufficient level of visual adaptation and light comfort for people, and on the other hand, to minimize the harmful effects of optical radiation on museum pieces. At present, in fact, three aspects are involved in the search for the optimal solution for creating a light environment. These are:

– The museum custodian or other museum staff responsible for both the preservation of museum pieces and the lighting of the hall and exhibited items in terms of the role of light in exhibition perception, accents, etc.;

– Lighting designer, who is responsible for ensuring the performance of artistic, navigational, and informational tasks set by the museum custodian, with the existing technical capability;

– Lighting engineer, who should be focused on the principle of "do no harm" and the compliance of technical parameters of the lighting installation with regulations and requirements to ensure its safe and effective operation.

Undoubtedly, the priority opinion should be the opinion of the museum representatives, and that is why the key aspect of the concept preparation of creating the light environment in the museum is the constant interaction of lighting designer with the customer, the search for common ground. In turn, the task of the lighting designer and the design engineer is to develop a lighting installation complying both with aesthetic requirements of the customer and safety requirements including physicochemical safety of museum pieces using modern technical means and lighting techniques.

The essential attribute of a high-quality lighting installation in the museum is the largest possible prevention of harmful and sometimes destructive effects of optical radiation, both ultraviolet and infrared, and visible, on museum pieces. In Russia, in terms of sensitivity to the effects of optical radiation, the museum pieces are divided into three categories, which are listed in Table 1. In accordance with these categories, lighting requirements are established, which are currently non-regulatory. At the same time, if we talk about Russia, most of these recommendations were developed in 1980–1990s years, and in principle, the known Russian regulations on the lighting of museums are very few [5–8]. The most cited publication on this subject prepared by the CIE was issued in 2004 [9], and given the pace of development of lighting (first of all, LED) technology in recent years, it can be assumed that the recommendations do not fully correspond to the modern possibilities of lighting engineering. The lighting requirements contained in these documents, which are compared in Table 1, make it possible to estimate the levels of lighting that provide not only the opportunity to exhibit museum pieces but also the relative safety of these pieces.

These documents were developed quite a long time ago, and all of them, including the CIE publication, considered as a light source mainly traditional lamps (incandescent lamps and, in part, fluorescent lamps and high-pressure lamps) and practically did not consider the LED sources.

At the same time, lighting devices (LD) with LEDs have already firmly entered all spheres of our life, where they are widely used. The museum lighting was not an exception, where the LEDs are being implemented, although it concerns more the foreign museums. Thus, according to the above-mentioned survey [4], in 46 museums surveyed in only two years (2009–2011) the share of the used LED devices increased from 0 to 40 %. However, more than a half (51 %) of museums surveyed still use incandescent lamps as the main lighting source. Nevertheless, the trend of increasingly intensive use of LEDs in museum lighting is undeniable and explained by the possibilities offered by LEDs. By allowing to vary not only the illuminance level, as it happens, for example, when using halogen incandescent lamps (however, with changes in the correlated colour temperature), but also spectral distribution of lighting, the LED devices can significantly facilitate the performance of exhibition and aesthetic tasks at a constant level of illuminance, which affects both the perception of museum pieces and their safety.

It should be noted, however, that it is now widely felt that in the case of LED sources the quality of lighting can no longer be measured only by traditional indicators, including correlated colour temperature and general colour rendering index. In our days, the CIE consider the introduction of new colour rendering indicators: the *Fidelity Index* and the *Gamut Index* [10]. The value of these new criteria for colour rendering evaluation was confirmed, inter alia, by a study conducted by the Technical University of Ilmenau and *OSRAM Opto Semiconductors*, which showed that there is a strong correlation between the Fidelity Index and the perceived colour difference and colour shift, and between the Gamut Index and the colour saturation [11].

Another topical issue related to the introduction of LED into museum lighting is the need for a more adequate quantitative assessment of the optical radiation effect on museum pieces. So far, light values have been used for such an assessment, which was explained by the relative immutability of the spectral distribution in the museum lighting.

Thus, today it is necessary to estimate the following light values:

Fig. 1. General view of Hall No. 277 "Art of France of the 17th century" (a) and luminance distribution across the room (b)

- Illuminance;
- Exposure;
- Colour rendering;
- Luminance distribution in the view field.

The corresponding surveys of the halls of the State Hermitage and the State Tretyakov Gallery were carried out by the VNISI named after S.I. Vavilov, as a result of which the levels of illuminance and luminance distribution were measured [12] (Fig. 1).

At the same time, the diversity of possible spectra of light sources used in museums makes it possible to remember that light values do not allow to judge the effect of radiation on the material of museum pieces. For this, obviously, it is necessary to use energy or even photonic values, such as the radiation flux in W, irradiance in W/m^2, the photon flux of radiation in photons per second, and photon illuminance or photon flux density in photons per second per m^2. The introduction of additional metrics for the evaluation of museum lighting is a controversial issue and requires both rethinking the available data and additional research.

As a result, the regulation of the museum lighting, which, in addition to the mandatory exclusion of UV and IR radiation, is currently limited to non-regulatory requirements to the lighting in lx and to exposure in lx·hour, should be supplemented by the requirements for both other photometric and colourimetric lighting parameters (correlated colour temperature and colour rendering indices) and for energy or photon parameters (energy or photon illuminance in W·m^{-2} and energy or photon exposure in J·m^{-2}) and possibly spectral distribution of radiation. The relevant requirements will have to be introduced into the standards for luminaries, possibly developing a separate standard or a preliminary standard GOST R60598–2-… "Luminaries. Part 2. Specific requirements. Luminaries for museum lighting".

It is necessary to take into account the fact that in addition to the objective (quantitative) assessment of lighting there is also its qualitative assessment based on the perception of illuminated items by people, which in terms of museum items is crucial. In this part, LED devices provide unique opportunities that have already been used in many museums. As an example, the lighting of Leonardo da Vinci's painting "Mona Lisa" in the Louvre, which was developed by Faros-Alef LLC experts led by L.G. Novakovsky [13], and the lighting of the Sistine Chapel in the Vatican [3]. It was suggested that the light should display the colours of the paintings, which, as far as possible, are similar to the original ones. This means that since most paintings created before the end of the 19th century were created in daylight, the spectral distribution of the light source with T_c of 3,500 K, which is usually preferred by museum custodians, should be optimized so that the colours of the paints illuminated by the light source are similar to those of the paints illuminated by the light source with T_c of 6,500 K. The best approach, in our opinion, would be to create a standard series of LED luminaries with colour temperatures, in the range between 3,000 and 6,500 K, and to use a luminaire with adjustable colour temperature to choose the most suitable lighting for a particular exhibited item. Moreover, the museum custodians should have the last word.

It should also be noted that already today modern photometric equipment allows us to measure all parameters of lighting devices necessary to make a decision on whether to use a particular or another

Table 1. Lighting Requirements

Items	Source		
	[5]	[8]	[9][*]
Items insensitive to light: metal products, ceramic products; minerals (except photosensitive), jewels, glass, enamels	Illuminance is not standardized (rarely more than 300 lx required) UV and IR are not standardized (general comment on inadmissibility)	(200–500) lx UV: (20–300) μW/lx IR: (30–40) mW/lx	< 200 lx Annual exposure < 600,000 lx·hour UV and IR are not standardized (general comment on the inadmissibility of UV and the need to limit IR)
Painting works, varnishes, wood, ivory, glue paint	< 150 lx Paintings annual exposure < 650,000 lx·hour UV and IR are not standardized (general comment on inadmissibility)	(75–150) lx UV: (20–50) μW/lx IR: (30–70) mW/lx	< 50 lx Annual exposure < 150 lx·hour UV and IR are not standardized (general comment on the inadmissibility of UV and the need to limit IR)
Items especially sensitive to light: watercolours, drawings, fabrics, clothing, manuscripts, zoological and botanical collections	< 50 lx UV and IR are not standardized (general comment on inadmissibility)	(30–50) lx UV: (20–30) μW/lx IR: (30–120) mW/lx	< 50 lx Annual exposure < 15 lx·hour UV and IR are not standardized (general comment on the inadmissibility of UV and the need to limit IR)

[*] The CIE classification involves the separation of materials into four groups of light resistance (insensitive, low-sensitive, medium-sensitive, and high-sensitive), with the last two of the Russian classification forming a group of especially sensitive to light museum pieces

device in the museum. Modern measuring devices ensure the monitor the required parameters of museum lighting devices, namely:

- Luminous flux and luminous intensity distribution;
- Spectrum of radiation;
- Correlated colour temperature;
- Colour rendering index;
- Other photometric, colourimetric, and electrical parameters of the lighting device.

In addition, progress in measuring instruments and telecommunications allows us to provide the most significant museum pieces, and in the long run all of them, with illuminance/irradiance sensors, with their readings transferred to a single centre for monitoring the illuminance/irradiance, and exposure levels, and taking timely measures to ensure the preservation of museum pieces.

Unfortunately, few museums in our country have engineering and technical personnel with the necessary knowledge and experience to organize such monitoring, so there is a certain risk for the museums to get lighting products of inadequate quality, and even unsafe.

It is obvious that even having the necessary instruments to monitor the lighting parameters, the requirements for which are enshrined in the current (though obsolescent) regulations, today it is impossible to make an adequate evaluation of lighting installations with LED in museums, and the existing guidelines and recommendations require extensive analysis and possible revision, both in the part of the exhibition illuminance level, and in the part of the permissible exposure for a certain period of time.

In addition, it is necessary to organize a systematic survey and monitoring of the museum lighting parameters during the operation of the lighting installation, which, in our opinion, should include:

- Periodic measurement of the level of UV radiation falling on museum pieces, E_{UV}, μW/m^2;

- Periodic measurement of the level of IR radiation falling on museum pieces, E_{IR}, mW/m^2;
- Periodic measurement of the illuminance level of museum pieces, E_{LI}, lx;
- Estimation of the light exposure of museum pieces, $E_{LI} \cdot t$, lx·hour.

Knowledge of the levels of irradiance and illuminance of the E_{UV}, E_{IR}, and E_{LI} will allow us to take measures to reduce the corresponding parameter (replacement of UV or IR filters, reduction of illuminance level), and the knowledge of the light exposure will allow us to make a reasonable decision on limiting the time of display of museum pieces.

Moreover, it is worth noting that the monitoring of these parameters should be carried out strictly in accordance with the measurement methods, which are not currently standardized, not allowing to give a "legal" opinion on the condition of a facility, even when the necessary equipment and the experience of measurement operators are available.

Proceeding from this, we see as a priority the development and release of a modern regulatory document: an industry standard for lighting engineering or an appropriate guide for museum custodians, taking into account the introduction of modern light sources and technologies and incorporating techniques for lighting parameters measuring. Within the conference "Light in the Museum" held in April 2018 in St. Petersburg the representative of the Ministry of Culture of the Russian Federation declared the intention of the government to create an appropriate regulatory framework.

This task will be facilitated by the R&D "Analysis of current regulatory documents studies in order to develop the standard for the museum lighting. Basic procedure setting and research work program on the standard development", which is currently being conducted under the authority of the Ministry of Culture. The data obtained from a detailed analysis of the modern scientific and technical base will help to identify controversial and poorly studied areas, to determine the feasibility and areas of new research necessary to obtain a complete picture of the museum lighting and its peculiarities, in order to develop a standard or recommendations containing scientifically sound, modern, and adequate regulatory requirements for museum lighting.

The underlying rationale of the research is:

- Diversity of LED sources in terms of photometric, spectral, and colourimetric characteristics;
- Insufficient knowledge of the of visible light effect (as well as UV and IR radiation) on the preservation of museum pieces;
- Lack of national and interstate standards on lighting and exposure of museum pieces;
- Lack of research into existing museum lighting systems and their lighting characteristics.

REFERENCES

1. Lyakisheva I.V. Pervoe v Rossii muzei'noe dinamichnoe osveshchenie svetodiodami [The first Russian museum dynamic lighting by LEDs] // Svetotekhnika, 2010, No. 3, pp. 57–58.
2. Degtyarev A.S., Raktovich N.A. Osnovny'e printcipy' osveshcheniia vy'stavochnogo prostranstva v muzeiakh sovremennogo iskusstva [Basic principles of illumination of exhibition space in museums of modern art] // Potential of intellectually gifted youth – development of science and education: Materials of the VI International Scientific Forum of Young Scientists, Students and Schoolchildren, Astrakhan, 2017, pp. 297–300.
3. Shanda Ya. Chto takoe tochnost' vosproizvedeniia tcveta v muzei'nom osveshchenii [On Accuracy of Color Reproduction in Museum Lighting] // Svetotekhinka, 2014, No. 5, pp. 23–27.
4. SSL Adoption by Museums: Survey Results, Analysis, and Recommendations. URL: https://www.energy.gov/sites/prod/files/2015/02/f19/gateway_museums-report_0.pdf
5. Revyakin V.I., Olenev A.A. Rekomendatcii po proektirovaniiu muzeev [Museum Design Recommendations] // Stroyizdat, Moscow, 1988, 44 p.
6. Rekomendatcii po proektirovaniiu iskusstvennogo osveshcheniia muzeev, kartinny'kh galerei' i vy'stavochny'kh zalov [Recommendations for Design of Artificial Lighting in Museums, Galleries and Exhibition Halls] // VNIPI Tyazhpromelectroproekt im. F.B. Yakubovsky, Moscow, 1992, 91 p.
7. Devina R.A., Brednyakov A.V., Dushkina L.I., Rebrikova N.L., Zayceva G.A. Muzei'noe khranenie hudozhestvenny'kh cennostei': prakticheskoe posobie [Museum storage of art treasures: practical guidelines] // Tipografiya Ministerstva kul'tury RF, Moscow, 1995, 204 p.
8. Prikaz Minkul'tury' RF ot 8 dekabria 2009 g № 842 "Ob utverzhdenii ediny'kh pravil organizatcii formirovaniia, ucheta, sokhraneniia i ispol'zovaniia muzei'ny'kh predmetov i muzei'ny'kh kollektcii', nahodiashchikhsia v muzeiakh Rossii'skoi' Federatcii". (otmenyon Prikazom ot 11.03.2010 № 116) [Order of the Ministry of Culture

of the Russian Federation No. 842 of December 8, 2009 "On approval of uniform rules of organization, accounting, preservation and use of museum pieces and museum collections located in museums of the Russian Federation" (cancelled by the Order No. 116 of 11.03.2010)].

9. CIE157:2004 Control of Damage to Museum Objects by Optical Radiation // CIE, 2004.

10. Blattner P. New CIE Color Fidelity Index // Report at the 1st International Scientific and Practical Conference "Light in the Museum" ("Svet v muzee "), Saint-Petersburg, 2018. URL: http://nts-svet.ru/wp-content/uploads/2018/04/svet_v_muzee/2_2_P_Blattner.pdf

11. Biske K., Hartwig W., Schirz K., Wilm A., Horst K. TM-30–15 i obshchii' indeks tcvetoperedachi MKO Ra: issledovanie tcvetoperedachi bely'kh SD s liuminoforom [TM-30–15 and the general colour rendering CIE R_a index: Research of colour rendering of white LED with luminophor] // Svetotekhnika, 2018, No. 2, pp. 40–45.

12. Chernyak A. Sh., Kuznetsova A.B., Bartseva A.A. Izmereniia parametrov osveshcheniia zalov i e'ksponatov Gosudarstvennogo E'rmitazha i Gosudarstvennoi' Tret'iakovskoi' Galerei [Measurement of lighting parameters of halls and exhibited items of the State Hermitage and the State Tretyakov Gallery] // Svetotekhnika, 2018, special issue "Light in the Museum", p. 45–49.

13. Novakovsky L., Mirat J.-P., Chanussot J., Marty K., Katsuaki M. "Mona Liza" v novom svete ["Mona Lisa" in a new light] // Solid-State Lighting magazine, 2013, No. 4, pp. 64–68.

Anna G. Shakhparunyants,
Ph.D. in Technical Science. Graduated from MPEI in 1986. General Director of VNISI named after Vavilov N.I., president of the Russian national committee of the CIE

Eugene I. Rozovsky,
Ph.D. in Techinical Science (1984). Graduated from MPEI in 1971. Leading researcher of VNISI named after Vavilov N.I. Senior Scientific Editor of L&E Journal. An expert from the Russian Federation in TC34 IEC "Sources of light and related equipment"

Anatoly Sh. Chernyak,
Engineer. Graduated from MPEI in 1962. Head of the Laboratory of lighting and light devices of VNISI named after Vavilov N.I.

Pavel A. Fedorishchev,
graduated in 2007 from the Faculty of history, political science and law of the Moscow State Regional University. Head of the international cooperation group of VNISI named after Vavilov N.I.

Light & Engineering
Vol. 27, No. 4, pp. 59–65, 2019
https://doi.org/10.33383/2018-151

IMPLEMENTATION OF EXHIBITION LIGHTING CONCEPT AS MEANS OF ARTISTIC EXPRESSION THROUGH EXAMPLE OF "RUSSIAN INSOMNIA" EXHIBITION

Karsten Winkels

Svetoproekt, LLC, Moscow
E-mail: winkels@svsrv.ru

ABSTRACT

The article focuses on the disclosure of the artistic possibilities of the exhibition lighting through the example of the "Russian insomnia" exhibition. The key techniques in creating a museum exhibition, increasing the influence of lighting on the viewer, are highlighted. A process of creating a lighting project for an exhibition is presented in successive stages. The first stage is the development of the exhibition concept, which arranges the exhibited items in four halls. The second stage is the setting of artistic lighting tasks for each hall and the search for their solutions. The third stage is the technical implementation of the project.

Keywords: exhibition lighting, theatrical exhibition, concept, object d'art, artistic tasks, game of shadows

1. INTRODUCTION

The exhibition lighting is an essential means of artistic expression of exhibitions and collections of museum pieces. Its principal task is to create the conditions for the complete and emotional perception of the objet d'art by the audience. The lighting is intended to reveal and complement the artistic images embedded in the objet d'art, as well as to focus the viewer's attention on it. If the painting or sculpture is illuminated improperly, the museum visitor will most likely pass it by.

The ability of light to influence the emotional state was noted in ancient times. A good example is stained glass windows in Gothic cathedrals and other religious buildings. Converting natural lighting into multicoloured mosaic, the stained-glass windows brought life-affirming harmony into the mood of believers.

2. SPECIFICITY OF EXHIBITION LIGHTING AS A MEANS OF ARTISTIC EXPRESSION

Having been engaged in the design of exhibition lighting for a long time, I noticed that under certain conditions the role of lighting for the audience perception is increasing.

The first condition is the dynamism and interactivity of the museum exhibition. We are talking about theatrical exhibitions, in which objects d'art are united by a single concept and storyline. In this case, the spectator turns from a passive observer into an active participant of the events and comes into contact with the artistic space of the exhibition. And the light is perceived as an integral part of this space, not just as a lamp, which should be lit.

The second condition is the combination of light and sound. Our perception of the surrounding reality is arranged in such a way that we feel the light effects sharper and in relief, if they occur in conjunction with the sound effects.

Finally, the third and essential condition is the lights and darks as an element of the exhibition concept. This involves the lighting of objects d'art to be dimmed. The lights and darks involve the viewer in interaction with objects d'art, because their movements create additional shadows. At the same time, the shadows should organically intertwine into the artistic space of the exhibition and in any case not distract the viewer. The ability to create the dancing shadows gives the vast space for the creativity of the lighting designer. Both static and dynamic shadows acquire independent artistic significance.

3. GENERAL INFORMATION ABOUT THE "RUSSIAN INSOMNIA" EXHIBITION

In 2011, I was lucky enough to take part in the creation of the "Russian Insomnia" exhibition project, with its concept meeting all three of the above criteria. It was an interactive exhibition displaying the image of insomnia's impact on the creative person. The exhibition had a clearly developed storyline, which will be further described in more detail. Music, poems and various noises were used as one of the instruments of influence on the viewer. Considering the subject of the exhibition, the lighting of the exhibited items should have been dimmed, which allowed to create the dancing shadows.

The purpose of the exhibition was to show insomnia as an essential element of the inner world of the creative person. The collection image of the Artist suffering from insomnia was created through the sculptures, photographs, sound effects and lighting. The project concept derived the features of the theatrical performance and quest. According to the plan, the viewer moves through the four halls of the exhibition, participating in the story presented.

There are two actors: the viewer and the Artist, embodied through various expressive means. Night comes, and the Artist can't sleep. A variety of thoughts occur to him, he experiences various events, and the viewer feels all this together with him. In fact, all artistic images conveyed in sculptures, photographs, sound and light effects are the experiences arising in the Artist's head. The audience is involved in this emotional experience.

A special place in the concept is given to the poems about insomnia by Russian poets. In the thematic collection, the works of A.S. Pushkin ("Poems composed at night in insomnia"), A.A. Fet ("In the midnight silence of my insomnia…"), O.E. Mandelstam ("Insomnia. Homer. Tight sails…"), A.A. Akhmatova ("Insomnia"), D.S. Samoylov ("Insomnia"), B.L. Pasternak (Marburg), B.A. Slutsky (Conscience at night, during insomnia…) are used, as well as other poems creating the atmosphere of sleepless night. The poems sound in the four halls of the exhibition, develop the dynamics of the plot and make the viewer feel that the Artist communicates with him.

In my opinion, the Artist's image is close to the lyrical hero of the poetry by I.A. Brodsky. Loneliness is both a source of inspiration and a great suf-

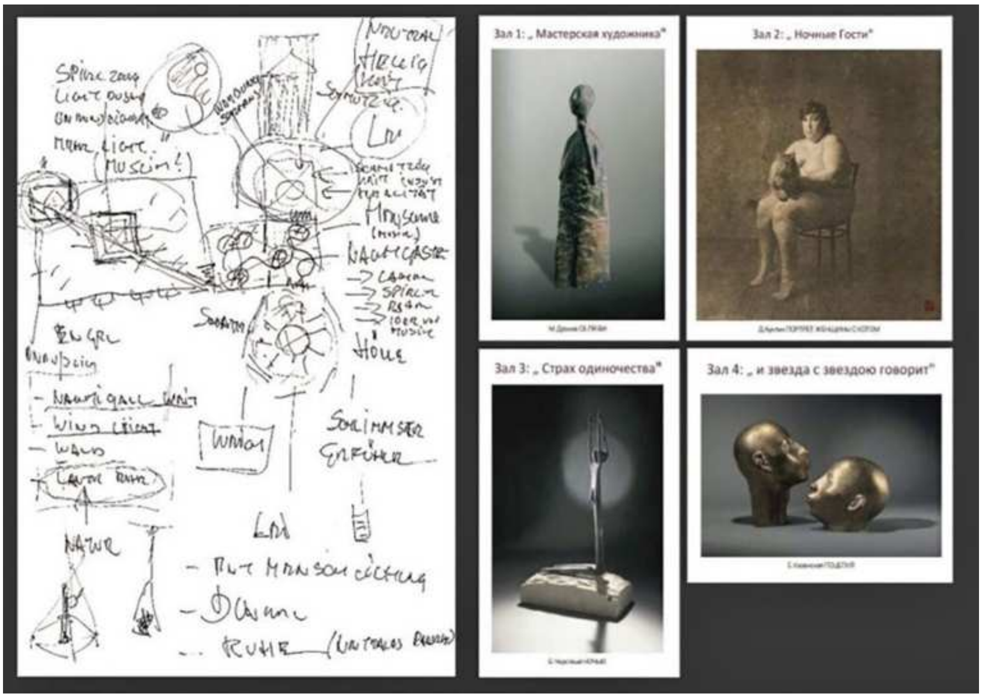


Fig. 1. Sketch on paper and description of the exhibition halls

Fig. 2. Hall No.1 "The Artist's Studio"

Fig. 3. Hall No. 2 "Night Guests"

fering for him. He is tormented by the longing for communication, but in any event he takes the role of an indifferent observer. On the one hand, he believes in his mission as a creator, and on the other hand, he is constantly hesitant that he is losing time and will soon lose his talent. This Artist is full of contradictions.

4. GETTING STARTED ON THE PROJECT: DEVELOPMENT OF FOUR HALLS CONCEPT

By the beginning of my work on the exhibition project, the exhibited items were already collected, but it was necessary to unite them with a backbone idea. I decided that in order to make the plot more dynamic, the narrative should be more linear so that the viewer could perceive and experience it as a real life. After a searching study of the sculptures and photographs intended to be used as exhibited items, I developed a concept that consistently revealed the four stages of insomnia and their impact on the Artist. Each stage correlated to one of the four halls, while the moving from one hall to the next one meant a transition in time (Fig. 1).

The first hall ("Artist's Studio") symbolized the creative process of the Artist, smoothly passing from twilight to night. It is known that for creative people evening and night hours often are periods of greatest productivity. Sometimes Mozart wrote music scores in one night, Gogol created his best works at night, and Van Gogh specially set candles on his hat to work in the dark. The purpose of the first hall was to show the archetypal image of the Artist, who is so absorbed by the process of creative search that he forgot everything. His mood is perfectly conveyed by a quote from Brodsky's poem "Loneliness": "When your loneliness at night spits on humanity."

The second hall (Night Guests) moved the Artist into the world of images inspired by the tired consciousness and insomnia. These images embody his night mares, they serve as triggers that get hidden fears from the corners of his subconscious. In creating this hall, I was inspired by the images of the Forest King spirit (from Schubert's ballad),

Fig. 4. Hall No. 3 “The Horror of Loneliness”

Fig. 5. Hall No. 4 “Return of Light”

the witches’ sabbath (from Goethe’s Faust and Bulgakov’s “Master and Margarita”) and the evil force from Gogol’s “Viy”. The night is thickening, and the Artist is evidently becoming uncomfortable.

The third hall (“The Horror of Loneliness”) speaks for itself. The Artist is overcome by longing, fear falls upon him. He begins to engage in self-analysis, the conscience tortures him. He has doubts about his talent and prospects of his creativity. The sense of loneliness ends the personal breakup of the Artist. This hall is the darkest, in terms of time it refers to the night hours before dawn.

Finally, the fourth hall (The Return of Light) symbolizes the eternal rebirth of life. The dawn brings relief by pulling the Artist out of the tenacious clutches of darkness. The new day brings hope to the Artist and to everything existing.

5. DEFINING ARTISTIC LIGHTING TASKS FOR EACH EXHIBITION HALL

When the concept was approved by my project colleagues, I started creating with the simplest sketches on paper. The lighting tasks had to be defined for each hall, and this is what I have as a result.

Hall No. 1

Lighting should focus the viewer’s attention on the Artist’s involvement in the creative process. He is self-absorbed and awaiting the inspiration. The light should capture this breathless expectation. Everything in the design of the hall is subject to the charisma of the Artist. There’s only his genius here. For the sculptures representing the Artist, the light is clothing, and it should be noted that the sculptures are made of different materials (Fig. 2).

Lighting concept: centre lighting and dark walls (two screens were installed on them).

Hall No. 2

Lighting should convey the mystical atmosphere of the hall. The evil spirit comes to life, incarnating from dreams, and the lighting should help it to impress the viewers. This makes them thinking about the inner emotions. In this hall the Artist welcomes his friends – Night Guests. Some of them are playing cards at a table. Nobody talk, everyone

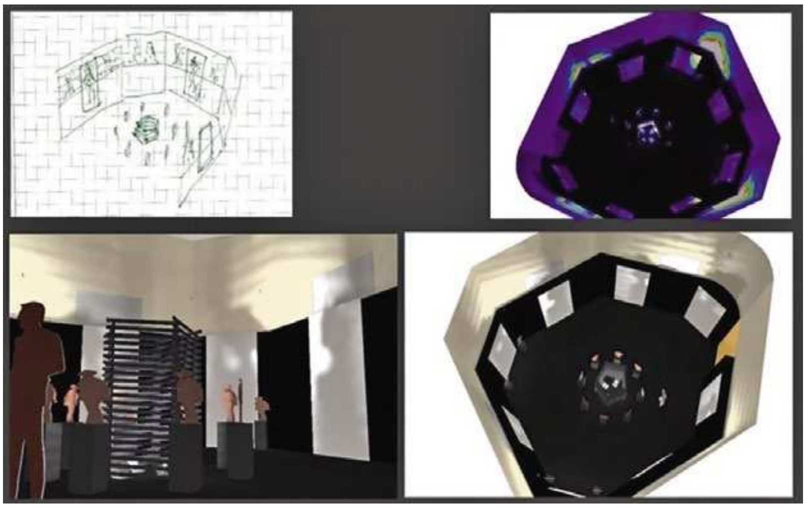


Fig. 6. Technical realization of lighting, Hall No. 3

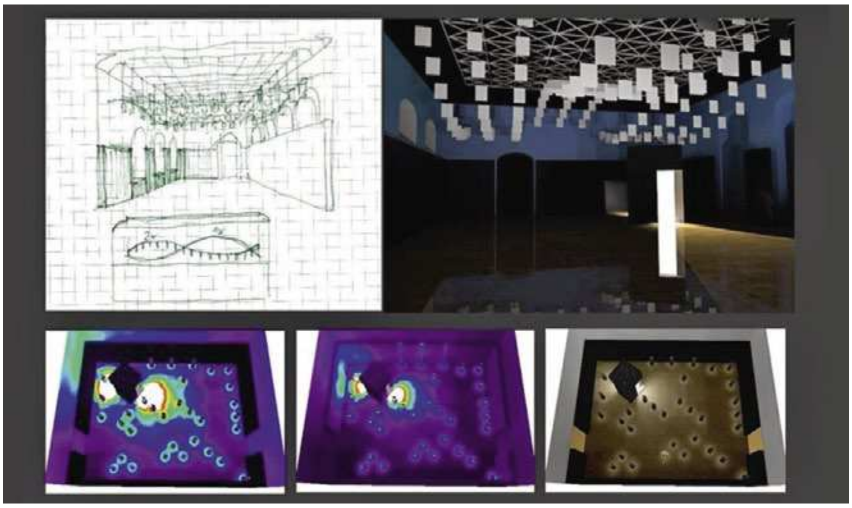


Fig. 7. Technical realization of lighting, Hall No. 4

is focused on the game. The other guests are sitting around a large festive table: laughing, drinking and telling stories – the late dinner. The characters of their stories are incarnating and are sitting at the table like sculptures. In one of the corners, in a large armchair with a headrest, almost in the dark, an old friend is sitting and reading the fairy tales for night visitors, surrounded by mystical figures generated by these fairy tales. Lighting gives a touch of surrealism to what is happening: werewolves and other supernatural beings can't walk under the light of night lanterns. These beings seem to talk with each other and involve the viewers in their conversation (Fig. 3).

Lighting concept: insular lighting (tables, an armchair with a headrest), darkness.

Hall No. 3

This is a hall of terrible feelings and gloomy thoughts, so everything should be decorated in dark colours here. The leitmotif running through this hall is the dancing shadows. The following technical solution has been developed for this purpose: the light source is surrounded by light scattering surfaces as dissolving the light flux and focusing it on the sculptures in a circle, a little further away. The sculpture shadows fall on the wall, becoming the objects d'art. The idea was that at any motion of a viewer, more shadows would appear, "jumping" on the walls as a train of thoughts (Fig. 4). The peculiarity of lighting lies in the fact that the integral image of the sculpture arises only when the viewer approaches it.

Lighting concept: Symbolic "fire" in the centre of the hall. The shadows are dancing on the walls.

Hall No. 4

In this hall, the lighting embodies the gradual coming of the dawn. The light carries hope and an eternal revival to a new life. The following technical solution has been developed for this purpose: illuminated sculptures of angels are arranged on one spatial diagonal, symbolizing the path to an eternal light. At the end of this path there is a black cube

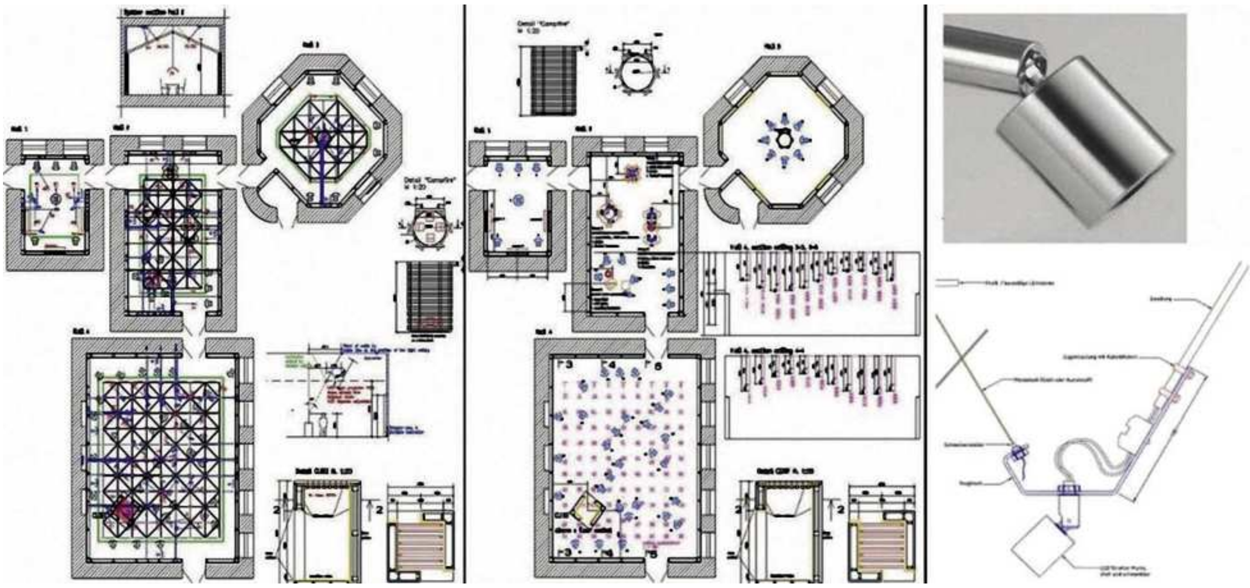


Fig. 8. Lighting Fixtures Layout

with two entrance doors arranged diagonally, with a completely white room of 2.50 x 2.50 m. The ceiling of the cube is made of translucent white polycarbonate, behind which, beyond the eye of the viewers, the fluorescent lamps with a correlated colour temperature 4000 K and a total luminous flux more than 20000 lm (!) are installed. The idea was precisely to make the viewers bodily feeling the light, its infinity. This purifying whiteness relieves from the experiences of a sleepless night and completes the exhibition.

Lighting concept: diagonal lines coming out of the infinite cube (Fig. 5).

Acoustic design

In cooperation with the famous composer Alexander Gerasimov, a thematic sound design was created for each hall.

In the Artist's studio, we hear the noise from the street, the barking of a dog, the distant singing of a night bird, and all this is dominated by the noise of the old clock resonating with the music of Gerasimov. In the second hall, the main themes were the sounds of the card game and the conversations of the guests at dinner. The third hall is filled with a lonely scream, a painful moaning of a man who woke up from nightmares in the darkest hour. The fourth element of sound design is an atmosphere filled with the singing of the first morning birds and a quiet whisper of stars talking to each other in anticipation of a new day. The symbiosis of sound and light create a unique atmosphere for each exhibition hall.

6. TECHNICAL IMPLEMENTATION OF THE PROJECT

The *DIALux* lighting design program was used to determine the optimal arrangement of the sculptures and photographs in each hall. With its help, the sketches on paper were transformed into computer visualization of all four halls (Fig. 6). As a result, full images of all rooms were obtained, showing the real illumination levels, the location of shadows and other key aspects. After some rearrangements of sculptures, the way was found and further implemented. It is important that *DIALux* allowed me to see the predicted result even before the installation of equipment (Fig. 7).

The lighting equipment for the project tasks was made in my *WINKELS CONCEPTS* design office in Germany. Especially for this project in three weeks the design of LED luminaries with a length of only 30 mm and a diameter of 25 mm, the power of 4 W and with a correlated colour temperature of 3000 K, with the LEDs by *Cree* (USA) and five different types of lenses (very narrow, narrow, wide, very wide, with prismatic diffuser) by *Ledil* (Finland)) was developed. Five types of optics were used, depending on the requirements of the geometry of the illuminated space and the specificity of the sculpture material. The design concept of lighting devices allowed us to change the illumination level of each exhibited item, "play" with accents and flexibly adjust to specific artistic tasks (Fig. 8). 80 luminaries were used in total.

Can say, we had two sources of LED illumination for each sculpture in total. Depending on the position of the source relative to the sculpture, a luminaire with a wide or very wide luminous intensity curve was used for the basic lighting, which, if necessary, was supplemented by the luminaire with narrow or very narrow luminous intensity curve to set accents in accordance with the peculiarities of the sculptures. This meant the understanding of the artistic concept, what ideas the author wanted to convey to the audience, and only then – the development of the lighting project. Small sculptures were illuminated by only one luminaire, and some of the large sculptures – by three or four luminaires, depending on the size of the sculptures. We were limited by the possibility to use only LEDs with a correlated colour temperature of 3000 K, so the right choice of optics and the exact arrangement of the light spots were very important for giving expression to the texture of the sculptures. For example, some clay sculptures were highlighted only using a diffuser to emphasize their delicate texture without any excessive reflections of light.

7. CONCLUSION

The participation in the project convinced me that technical possibilities of exhibition lighting allow me to solve the most interesting and complex artistic tasks, and even to create objects d'art. The visitors to museum exhibitions already perceive the lighting as an integral attribute of creative self-expression. The lighting design technologies advances with time, and there is no doubt that new developments will reveal new light resources.

Karsten Winkels
graduated from the Faculty of Architecture and Civil Engineering at the Technical University of Dortmund and from the West German Institute of Applied Lighting Engineering. At present, he is an Art Director of SvetoProekt, LLC, Moscow; Director General of WINKELS CONCEPTS, Dortmund, Germany; winner of many national and international awards in lighting engineering

Light & Engineering
Vol. 27, No. 4, pp. 66–72, 2019
https://doi.org/10.33383/2018-152

MEASUREMENT OF ILLUMINATION PARAMETERS OF THE HALLS AND EXHIBITED ITEMS OF THE STATE HERMITAGE AND THE STATE TRETYAKOV GALLERY

Anatoly Sh. Chernyak, Alyona B. Kuznetsova[1], and Alexandra A. Bartseva

Russian Lighting Research Institute named after S.I. Vavilov (VNISI, LLC), Moscow
[1] E-mail: kab@vnisi.ru

ABSTRACT

The article focuses on the measurement of lighting characteristics of exhibited items in the exhibition halls of the two largest Russian museums – the State Hermitage and the State Tretyakov Gallery. The review of the current regulatory technical documentation for the design and implementation of museum lighting is given, the shortcomings are identified and the proposals for improving the legal framework for the lighting of the exhibited items are made. The measurements were carried out in accordance with existing recommendations, and according to which the lighting was designed in the museums. The principal measured parameters in this survey were UV radiation, illuminance of exhibited items, luminance distribution in the viewer's field of view, correlated colour temperature and the colour rendering index of the light sources. A brief overview of the measurement results of some halls of selected museums is given.

Keywords: lighting of museum exhibited items, exposition, measurements, UV radiation, illuminance, luminance, design recommendations

1. INTRODUCTION

Today, the design of museum lighting (precisely, the lighting of museum pieces) is carried out in Russia as well as throughout the world according to the long-established lighting standards developed in the (80–90) s of the last century in the format of recommendations [1–5].

The specified documents are outdated as they were focused mainly on incandescent lamps and, to some extent, on fluorescent lamps.

The recommended values of illumination on the exhibited items (mainly paintings and graphics) and the exposition accumulated during the exhibitions, were formed, on the one hand, based on the goal to ensure full perception of exhibited items, the general level of light adaptation and light comfort for people, and on the other hand, in terms of protection of exhibited items from harmful effects of optical radiation.

The comparison of the requirements contained in local documents [1–4] indicates a slight discrepancy. As for the publication of the CIE [5], the requirements for illuminance of paintings and the second group of exhibited items by light sensitivity and the requirements for their annual exposition are significantly tightened.

The most complete requirements for artificial lighting in museums were given in the recommendations of VNIIPI "TYAZHPROMELEKTROPROEKT" [2], which used the results of research conducted by Leningrad Department of VNIIPI together with VNIIR with the participation of the Hermitage Museum and the NIISPh. In addition to the illumination standards for exhibited items, they also contain:

– Limitation of the brightness of light sources and lighting devices within the view of observers up to 30° above the eye level by a value of (1000–1500) cd/m^2;

Fig. 1. General lighting of the White Hall of the State Hermitage

Fig. 2. General lighting of the hall No. 37 of the State Tretyakov Gallery (painting of the second half of the 19th century)

– Limitations on the sharp difference of illumination in adjacent rooms (readaptation);

– Requirements for the brightness distribution on the room surfaces within the view of visitors – a difference of no more than 10 times;

– The requirement for the brightness of the ceiling, which should not be significantly higher than the brightness of the walls and exhibited items in a system with the light reflected from the ceiling… and others.

The qualitative characteristics of museum lighting should include correlated colour temperature T_{cc} and general colour rendering index R_a of light sources [6, 7]. It should be noted that when using LEDs, R_a becomes a rather imperfect parameter to evaluate colour rendering, and to assess the adverse affect of radiation on exhibited items it is better use the energy or photon values rather than light ones [8].

In this area, the research works on updating the above requirements for museum lighting are carried out.

The absence of a comprehensive regulatory document on the illumination level and quality of museum pieces and museum premises as a part of the state or sectoral (departmental) standard induced to conduct a study of the existing museum lighting through the example of two iconic museums in Russia – the State Hermitage and the State Tretyakov Gallery in Lavrushinsky Lane.

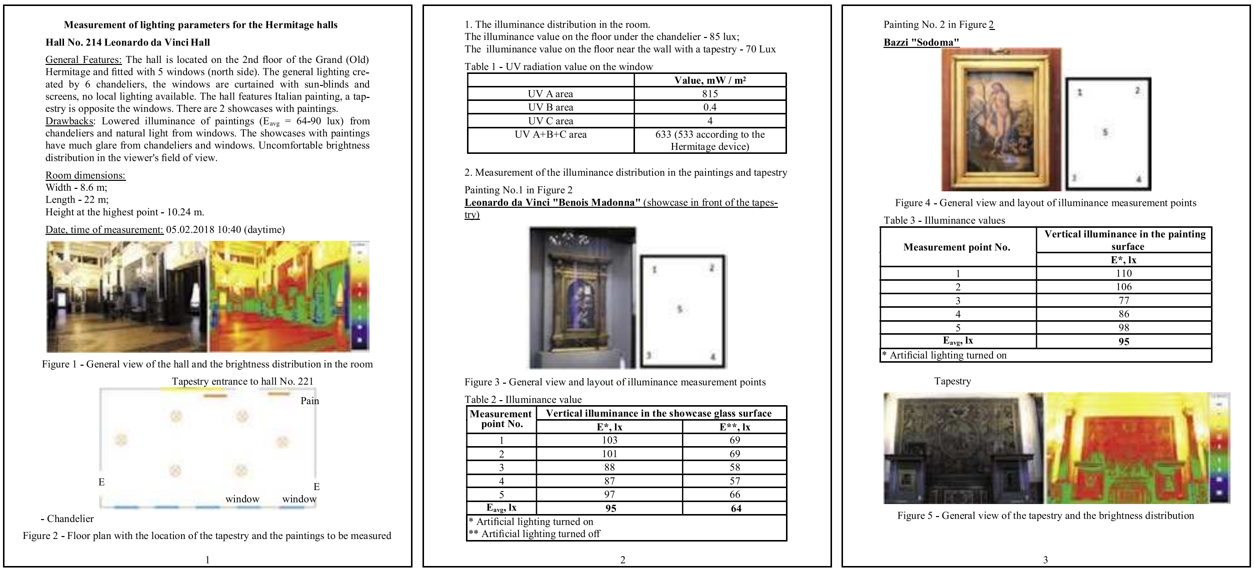
2. MEASUREMENTS

The museums, in which the survey was carried out, differ significantly in the interiors for exhibiting the works of art (mainly, paintings and graphics) and accordingly in their lighting systems. When measuring, the authors followed the lighting requirements, which the experts of these museums were guided by in the design.

If the Hermitage is a complex of palace buildings outstanding in architecture and decor and, therefore, it is a work of art – a valuable showpiece requiring high-quality interior lighting, then the Tretyakov Gallery is specially created for the exhibition of artistic works.

The general lighting of the Hermitage halls (Fig. 1) and, in part, of the paintings is provided by multi lamp chandeliers and floor lamps in addition to natural light through the large windows, while in the Tretyakov Gallery, with its mainly windowless rooms (Fig. 2), it is realized by luminous ceilings with artificial light sources with the addition (on the second floor) of natural light coming through the glazed widow lantern.

Both approaches to museum lighting have their advantages and disadvantages. It is believed that the best impression of paintings is created in natural light, but this light varies both during the day and seasonally. On cloudy days, the Hermitage does require additional illumination, and to exclude glare on the surfaces of paintings, the windows should be curtained. As for the luminous ceiling in the Tretyakov Gallery, which simulates the sky through artificial and natural light or artificial light only, it provides comfortable lighting of the rooms as a whole and uniform and sufficient lighting of paintings, but at the same time has the high power consumption. Thus, the total power consumption of lighting fixtures with fluorescent lamps of hall No. 38 of 190 m^2 with full lighting is 12.1 kW. Switching to LED tubes will mitigate this drawback. At the same time, the Hermitage is a leader and innovator



Measurement of lighting parameters for the Hermitage halls

Hall No. 214 Leonardo da Vinci Hall

General Features: The hall is located on the 2nd floor of the Grand (Old) Hermitage and fitted with 5 windows (north side). The general lighting created by 6 chandeliers, the windows are curtained with sun-blinds and screens, no local lighting available. The hall features Italian painting, a tapestry is opposite the windows. There are 2 showcases with paintings.

Drawbacks: Lowered illuminance of paintings (E_{avg} = 64-90 lux) from chandeliers and natural light from windows. The showcases with paintings have much glare from chandeliers and windows. Uncomfortable brightness distribution in the viewer's field of view.

Room dimensions:
Width - 8.6 m;
Length - 22 m;
Height at the highest point - 10.24 m.

Date, time of measurement: 05.02.2018 10:40 (daytime)

Figure 1 - General view of the hall and the brightness distribution in the room

Figure 2 - Floor plan with the location of the tapestry and the paintings to be measured

1

1. The illuminance distribution in the room.
The illuminance value on the floor under the chandelier - 85 lux;
The illuminance value on the floor near the wall with a tapestry - 70 Lux

Table 1 - UV radiation value on the window

	Value, mW / m²
UV A area	815
UV B area	0.4
UV C area	4
UV A+B+C area	633 (533 according to the Hermitage device)

2. Measurement of the illuminance distribution in the paintings and tapestry

Painting No.1 in Figure 2
Leonardo da Vinci "Benois Madonna" (showcase in front of the tapestry)

Figure 3 - General view and layout of illuminance measurement points

Table 2 - Illuminance value

Measurement point No.	**Vertical illuminance in the showcase glass surface**	
	E*, lx	**E**, lx**
1	103	69
2	101	69
3	88	58
4	87	57
5	97	66
E_{avg}, lx	**95**	**64**

* Artificial lighting turned on
** Artificial lighting turned off

2

Painting No. 2 in Figure 2

Bazzi "Sodoma"

Figure 4 - General view and layout of illuminance measurement points

Table 3 - Illuminance values

Measurement point No.	**Vertical illuminance in the painting surface**
	E*, lx
1	110
2	106
3	77
4	86
5	98
E_{avg}, lx	**95**

* Artificial lighting turned on

Tapestry

Figure 5 - General view of the tapestry and the brightness distribution

3

Fig. 3. Example of measurement report

in the field of aesthetics and museum lighting equipment, having passed the way from candles and incandescent lamps through fluorescent and halogen lamps to the LEDs.

Thus, in far 1949, the lighting of the Hermitage halls with fluorescent lamps was marked by the experts (A.I. Brodsky, B.A. Vvedensky, etc.) as very successful, as the paintings in such light are perceived much better than in natural light. Later, such companies as *Philips*, Tochka Opory, etc. have been working on the modernization of lighting in the Hermitage, and recently the BOOS LIGHTING GROUP International Lighting Corporation has joined them [11]. Out of 60,000 of the total number of light sources used in the Hermitage, 15,000 are LED sources, while the remaining 45,000 are HL, FL, CFL and MHL.

In the Hermitage, the measurements were carried out in 16 halls (the halls of French art of the 17th century, Leonardo da Vinci, Italian art of the Renaissance of the 16th century, decorative and applied art of Venice of the 15th – 16th centuries, French applied art of 17th-18th centuries, ministerial corridor, portrait gallery of Romanov's house, White Hall, etc.), located on the 2nd and 3rd floors, where lighting is arranged in different ways, including the use of floor lamps, directional spotlights, hanging chandeliers, luminous ceilings, etc. In the State Tretyakov Gallery the measurements were carried out in only 9 rooms on the 1st and 2nd floors of the building (painting and sculpture of the second half of the 19th century, painting of the turn of the 19th-20th centuries, the graphics of the 18th – early 20th centuries, the hall of Old Russian art, etc.), which allowed us to cover all lighting techniques used in the State Tretyakov Gallery – luminous ceilings, spotlights, clear-stories. The list of measured parameters and instruments used is presented in the Table.

The results of measurements are included in the reports the example of which is shown in Fig. 3.

The measurements in the Hermitage covered a negligible number of halls and exhibited items, mainly the oil painting. Therefore, it is possible to make only the general estimates of lighting, which is characterized by a large-scale transition to and use of modern lighting devices including devices with adjustment of angular size of light beam, light flux, etc., as well as the involvement in lighting design of specialized enterprises (*Philips*, Tochka Opory, etc.)

Fig. 4. Lighting of Hall No. 169 of the State Hermitage by the Tochka Opory Company

Table. Measured Parameters and Instruments Used

Parameter measured	Instrument name	Instrument appearance
Illuminance on paintings and in halls including semi-cylindrical (cylindrical) illuminance	Luxmeter-flicker meter Ecosphere EcoLight 02 type	
	LMT Pocket Lux 2 Luxmeter with attachment for measuring semi-cylindrical illuminance	
Radiation spectrum of lighting devices, R_a and T_{cc}	UPRtek MK350S Spectrophotometer	
Luminance (distribution in the observer's field of view)	LMK mobile advanced Photometer	
UV radiation	TKA-AVS UV-radiometer	
Temperature (distribution on the painting)	*Testo 882* imaging radiometer	

From the latest works of the Tochka Opory company, it is worth noting the good lighting, made in accordance with the recommendations on illuminace (E_{avg} ~ (145–160) lx) and colour rendering (T_{cc} = 3100 K at R_a = 96). It should be noted the successful implementation of the upward lighting techniques, free from the blinding of lighting devices and glare in the paintings (Fig. 4).

In general, the lighting in the Hermitage is performed professionally both in terms of perception of the exhibited items and their preservation – all windows, in addition to the double curtains, have UV radiation protection films.

The general brightness distribution in the view of observers is quite well implemented. As for the temperature distribution, it was distributed evenly

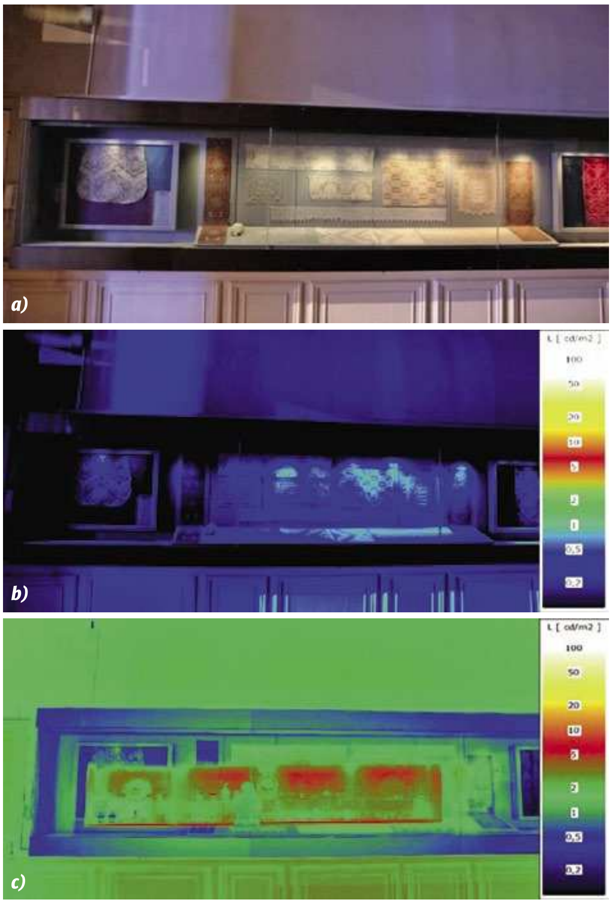


Fig. 6. Lighting of a showcase with a cloth in hall No. 223 of the State Hermitage Museum (decorative and applied art of Venice of the 15th – 16th centuries): a) the showcase photo; b) colour and luminance image of the showcase with the turned off illumination of the opposite showcase; c) colour and luminance image of the showcase with the turned on illumination of the opposite showcase

in all the paintings viewed and did not differ from the ambient temperature in the room, which complies with the requirements for the museum pieces storage.

However, in many cases the museum premises are dark (Fig. 5), the paintings are not sufficiently illuminated, especially in the absence of natural light, the condition of minimizing the brightness of adjacent rooms is not always met. In many halls, the measurement of cylindrical illuminance indicated that the saturation of rooms with light does not comply even with the low requirements for this indicator (not less than 50 lx according to GOST R55710–2013 [9]).

There is also an unsuccessful combination of exhibitions: for example, the showcases of hall No. 223, contrasting in the illumination level (one of them presents glass and bronze (exhibited items insensitive to light), and the other – open-work fabric (extra sensitive exhibited items, the standard illumination is less than 50 lx)), installed opposite each other (Fig. 6).

In the State Tretyakov Gallery the lighting is comfortable, uniform from luminous ceilings, created mainly by luminous ceilings (these halls are the majority), no glare on the paintings. T_{cc} of the ceiling lighting is (4000–4200) K, and there are “over lights” of paintings (Fig. 7): E_{avg} from 180 to 280 and even up to 350 lx, which is quite possible to eliminate by adjusting the light coming from the ceiling and from the exhibition luminaries.

It should be noted that according to the specialists of the State Hermitage and the State Tretyakov Gallery they are guided by the Instruction on the Accounting and Storage of Museum Values in the State Museums of the USSR, which was enacted by the order No. 290 of the Ministry of Culture of the USSR dated 17.07.1985 [10]. According to paragraph 224 of this instruction: “For all kinds of graphics, books, manuscripts, photographs, fabrics, botanical and zoological collections, the level of illuminance should be within (50–70) lx. For all other exhibited items it should be 75 lx.” That is, in technical sense the lighting complies with the requirements, and this once again demonstrates the imperfection of the regulation for museum lighting, as such a low-variation lighting gradation for different light sensitivity groups of the exhibited items (50–70 and 75 lx) hardly makes sense, given, moreover, the error of measurements of average illuminance, which is about 10 %. In fact, judging by the results of measurement of illumination in the surface of oil painting works, both museums were guided by recommendations, including international ones [1, 2, 5, etc.], allowing illuminance up to (150–200) lx.

3. CONCLUSION

Unfortunately, the survey was carried out only for two museums and in a limited volume. It is quite expected that lighting in many other Russian museums may be different, and, therefore, it is advisable to continue these measurements extending them to museums of different categories and exhibitions.

The authors express their gratitude to the management and staff of the energy services of the State Hermitage and the State Tretyakov Gallery for their warm welcome and assistance in carrying out measurements in the exhibition halls of the museums.

Fig. 5. Examples of insufficient lighting in the halls of the State Hermitage: a) Portrait Gallery of the Romanov House; b) Ministerial Corridor

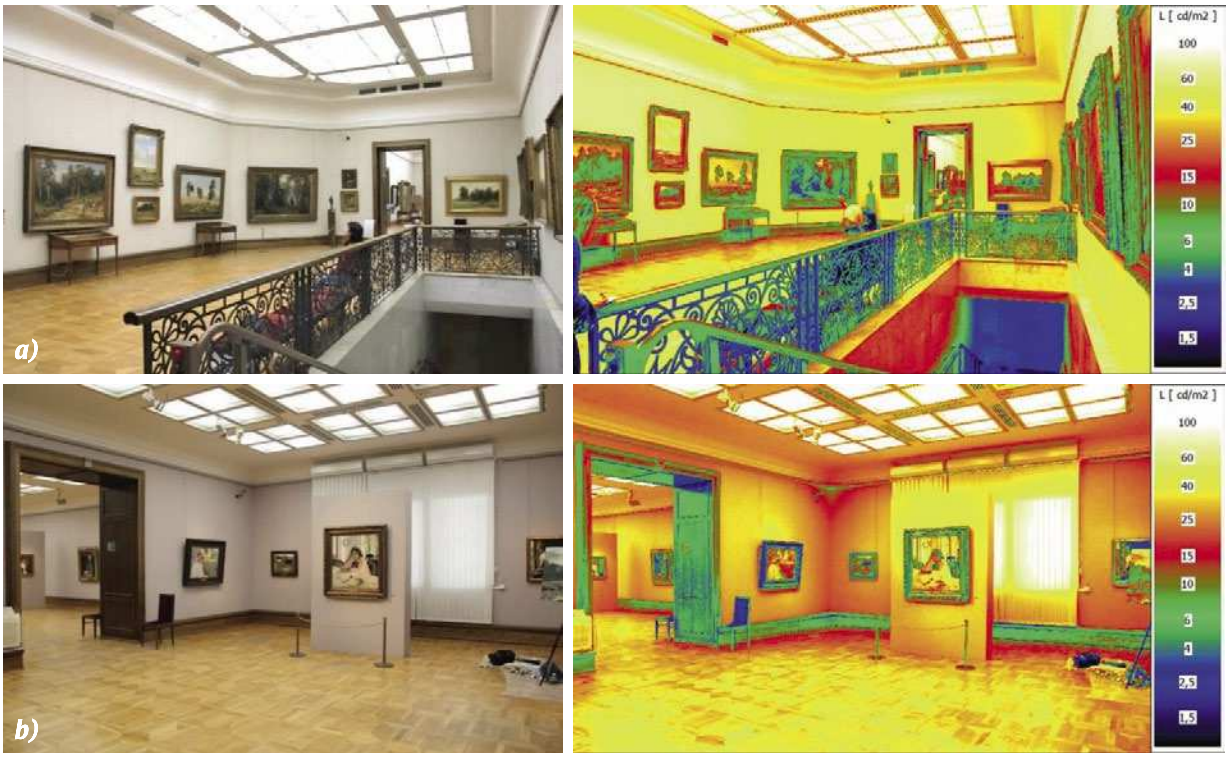


Fig. 7. Examples of lighting of the Tretyakov Gallery halls in photographs and colour luminance images: a) hall No. 25 (painting and sculpture of the second half of 19th century); b) hall No. 41 (painting of the turn of 19th-20th century)

REFERENCES:

1. Recommendations for Museum Design. / CNIIEP named after B.S. Mezentsev, M.: Stroyizdat, 1988, 48 p.

1. Rekomendatcii po proektirovaniiu muzeev. / TCNIIE'P im. B.S. Mezentceva, M.: Stroi'izdat, 1988, 48 p.

2. Recommendations for Design of Artificial Lighting in Museums, Galleries and Exhibition Halls, M.: Tyazhpromelektroproekt,1992, 91 p.

2. Rekomendatcii po proektirovaniiu iskusstvennogo osveshcheniia muzeev, kartinny'kh galerei' i vy'stavochny'kh zalov. M.: Tiazhprome'lektroproekt, 1992, 91 p.

3. Museum Storage of Art Treasures: Practical Guidelines. Moscow: State Research Institute of Restoration, 1995, 17 p.

3. Muzei'noe khranenie hudozhestvenny'kh cennostei'. Prakticheskoe posobie. M.: GosNII restavratcii, 1995, 17 p.

4. Order of the Ministry of Culture of the Russian Federation No. 842 of December 8, 2009 "On approval of uniform rules of organization, accounting, preservation and use of museum pieces and museum collections in the museums of the Russian Federation". Section 59 Light conditions. (Cancelled by Order No. 116 of March 11, 2010)

4. Prikaz Minkul'tury' RF ot 8 dekabria 2009 g № 842 "Ob utverzhdenii ediny'kh pravil organizatcii formirova-

niia, ucheta, sokhraneniia i ispol'zovaniia muzei'ny'kh predmetov i muzei'ny'kh kollektcii', nahodiashchikhsia v muzeiakh Rossii'skoi' Federatcii". Razdel 59 Svetovoi' rezhim. (Otmenen prikazom № 116 ot 11 marta 2010 g.)

5. CIE157:2004 Control of Damage to Museum Objects by Optical Radiation // CIE, 2004.

6. Ya. Shanda, What is Colour Fidelity in Museum Lighting? // Light & Engineering, 2014, V.22, #4, pp.51–58.

7. Novakovsky, L., Mira, J.-P., Shanyusso, J., Marty, K., Katsuaki, M. "Mona Lisa" in a new light // Semiconductor lighting engineering, 2013, No. 3, pp. 64–68.

7. Novakovskii' L., Mira ZH.-P., Shaniusso ZH., Marti K., Katcuaki M. "Mona Leeza" v novom svete // Poluprovodnikovaia svetotekhnika, 2013, No. 3, pp. 64–68.

8. Shakhparunyantz, A.G., Rozovsky, E.I., Chernyak, A. Sh., Fedorishchev, P.A. LEDs in Museums: New Capabilities and Challenges // Svetotekhnika, 2018, Special issue Light in the Museum, pp. 36–39.

8. Shakhparuniantc A.G., Rozovskii' E.I., Cherniak A. Sh, Fedorishchev P.A. Svetodiody' v muzeiakh: novy'e vozmozhnosti i problemy' // Svetotekhnika, 2018, Spetcvy'pusk "Svet v muzee", pp. 36–39.

9. GOST R55710–2013 Lighting of the workplaces inside buildings. Measurement standards and methods.

9. GOST R55710–2013 Osveshchenie rabochikh mest vnutri zdanii'. Normy' i metody' izmerenii'.

10. The instruction on the accounting and storage of museum valuables in the state museums of the USSR enacted by the order of the Ministry of Culture of the USSR No. 290 dated 17.07.1985.

10. Instruktciia po uchetu i khraneniiu muzei'ny'kh cennostei', nahodiashchikhsia v gosudarstvenny'kh muzeiakh SSSR, vvedena prikazom Minkul'tury' SSSR ot 17.07.1985 № 290.

11. Belyakova, M.P. Modernization of Lighting in the Hall No. 277 of the State Hermitage // Svetotekhnika, 2018, Special issue "Light in the Museum", pp.60–62.

11. Beliakova M.P. Raboty' po modernizatcii osveshcheniia v zale № 277 Gosudarstvennogo E'rmitazha // Svetotekhnika, 2018, Spetcvy'pusk "Svet v muzee", pp. 60–62.

Anatoly Sh. Chernyak,
graduated from MPEI in 1962, at present he is a Head of the Laboratory of Lighting Technology and Lighting Devices of VNISI LLC, Moscow

Alyona B Kuznetsova,
graduated from MPEI NRU in 2011, at present she is a Senior Research Fellow of VNISI LLC and postgraduate student

Aleksandra A. Bartseva,
graduated from MPEI NRU in 2013, at present she is an engineer of VNISI, LLC

Light & Engineering
Vol. 27, No. 4, pp. 73–80, 2019
https://doi.org/10.33383/2018-153

RESEARCH OF OPTICAL RADIATION IMPACT ON MATERIALS OF MUSEUM EXHIBITS AND REQUIREMENTS TO MEASUREMENT DEVICES

Sergei S. Bayev[1], Vladimir N. Kuzmin[2,3], and Konstantin A. Tomsky[2,3]

[1] *ITMO UNIVERSIY, Saint Petersburg*
[2] *St. Petersburg State University of Film and Television*
[3]*Scientific and Technical Enterprise TKA (STE TK), LLC, Saint Petersburg*
[3] *E-mail: tka46@mail.ru*

ABSTRACT

LED lighting creates capability of the best representation of museum exhibits and creation of additional light perception effects. It also allows us to use the results of light and colour measurements for adjustment of quantity and quality of lighting. Photometric devices may become permanent assistants in decoration of exhibitions and museum premises. Even more important are photometers for monitoring of acceptable level of illuminance and UV irradiance. With correct evaluation of adverse impact of LED lighting, there is an opportunity to significantly increase the permitted level of exhibits lighting, which is a permanent requirement by designers. The recommendations for standardisation of lighting are based on results of special studies performed with consideration of material light-resistance groups and properties of light sources. Such studies were performed by STE TKA, LLC, and GOSNIIRESTAVRATSII by request of the Ministry of Culture. The article describes major results of this study, which mainly aimed at specification of safe acceptable level of UV irradiation of materials with application of energy-saving fluorescent lamps as well as major characteristics of produced photometers. Similar studies and elaboration of recommendation are required also for LED light sources.

Keywords: illuminance, UV irradiation, wavelength, spectral distribution, light-resistance, acceptable level

1. INTRODUCTION

In the course of development of optical radiation measurement devices for museums, it was found necessary to conduct additional studies for specification of acceptable levels of ultraviolet irradiation alongside with the known data of visible radiation.

It is well-known that continuous impact of radiation on objects causes visible changes of their appearance (colour, brightness, mechanical properties and structure of material). In the first significant scientific publication about impact of visible radiation on fading of watercolours, it was found that the fading effect depends on the level of irradiation and duration of exhibition [1]. The first qualitative dependencies for the processes of changing and destruction of objects were found [2].

Further research and practical works allowed us to specify simple recommendations for museum exhibitions: to limit maximum acceptable illuminance for the most of light-sensitive objects with a value of 50 lx and 200 lx for oil and tempera paintings. This approach was the basis for the museum lighting systems with lighting created by means of natural light or incandescent lamps.

The most of recommendations for museum premises lighting introduced in different countries were based on the value of illuminance in lx and the ratio of UV radiant power of the light source in µW to its luminous flux in lm. Such allowance was correct for thermal light sources (basically incandescent lamps) and became incorrect after appearance of new sources with significantly changed share of ultraviolet radiation, and direct measurements of ultraviolet radiation are required for its determination.

The work by professor Krochmann [3] describes typical museum materials subject to impact of radiation from different light sources. On the basis of these experiments, there was an attempt made to find qualitative standards of exhibit colour change after irradiation with consideration of relative destruction coefficient *D(λ)* (Fig.1).

It was found that impact of optical radiation on museum exhibits depends on:

– Spatial distribution of radiant flux;

– Chromaticity of radiation;

– Relative spectral responsivity of an exhibit, i.e. the degree of its resistance to impact of radiation;

– Duration of irradiation.

The valid CIE recommendations to museum lighting were issued in 2004 [4] and required significant update due to spread of LED light sources in museums.

2. METHODOLOGY OF THE STUDY

The idea of experimental determination of maximum acceptable values of UV radiation is based on determination of the process of changes of optical properties of surfaces of tested materials under UV radiation and its representation in the form of graphs up to previously specified values determined in accordance with selected criteria [5].

The methodology of determination of changes of properties of museum and library collections materials under UV radiation consist of separate methods:

– Method of creation of required level of irradiance with constant monitoring of the values of exposure at which physical and chemical and/or physical and mechanical properties (hereinafter referred to as changes of properties) occur;

– Method of measurement and control of the reached change of material properties;

– Method and procedure of irradiation of specific samples of museum and library materials selected for irradiation;

– Processing of the results of tests of reference and production samples.

Due to individual sensitivity to optical radiation of each material, as many as possible samples of various materials were prepared for the experiment. 83 samples were taken and grouped on 12 boards with proposed high and medium sensitivity to irradiation and were irradiated in different modes by sources with different power and chromaticity. Each sample was divided into 3 parts (Fig. 2) with roughly the same surface properties with the first one of them (the reference sample) was covered with a light-proof shield and the third one being irradiated only with visible light through protective film reflecting the UV region of the radiation spectrum.

The second part of each sample was directly irradiated by the source of UV radiation. The radiant intensity was monitored daily by means of

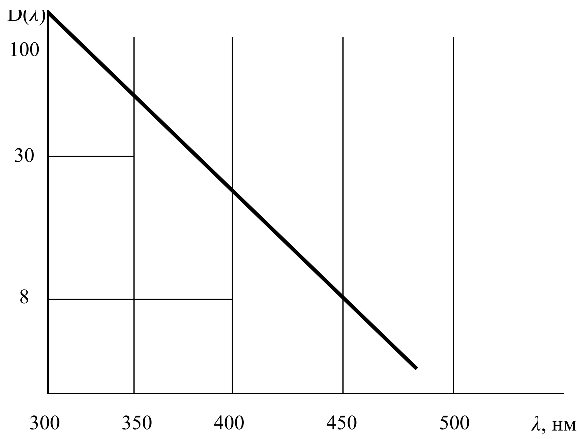


Fig. 1. The degree of harmful effect of radiation depending on wavelength (*D(λ)* = 100 % with *λ*=300 nm)

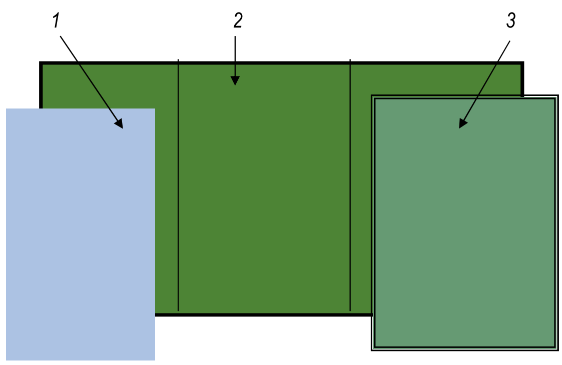


Fig. 2. Scheme of sample preparation for irradiation: 1 – the part covered with a light shield; 2 – an open part; 3 – a part closed with an UV filter

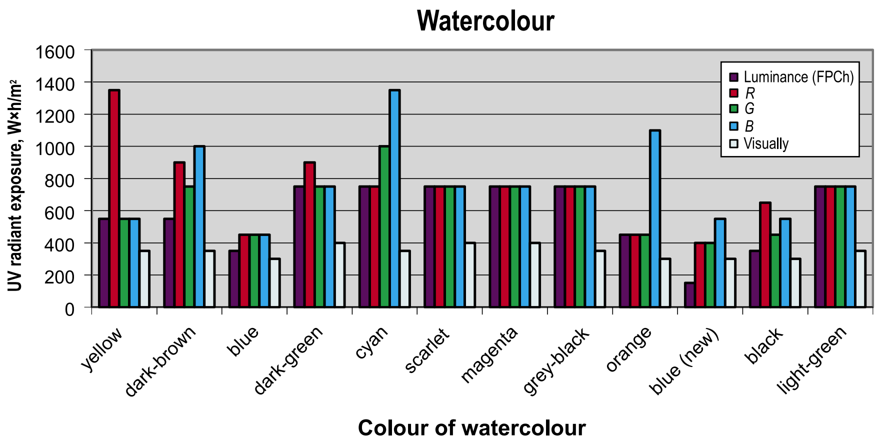


Fig. 3. The values of UV energy exposure causing threshold changes of luminance (more than 2 %) and chromaticity coordinates (more than (5–20)% for watercolours

a photometer in visible and UV regions, and exposure in W·h/m^2 was counted with cumulative sum each (8–9) hours of everyday irradiation. After each everyday irradiation, the optical properties of the samples surfaces were measured. In order to decrease measurement error caused by surface irregularities, these measurements were performed in 3–6 points of each part with averaging of results within each part while illuminating the samples with a special photometric lamp with high-stability radiation spectrum and colour temperature of T_c = 2856 K.

The luminance factor of each part of a sample and *R, G, B* colour coordinates, measured by means of FPCh luminance meter with colour filters made of KS13, ZS11, SS5 glass recommended for three-colour projection in a catalogue of coloured glass, were measured.

The absolute values of colour coordinates for different material types may vary by an order of magnitude and strongly depend on measurement conditions, therefore, they were not used for decreasing irregularities. More correct is comparison between characteristics of irradiated and non-irradiated areas, i.e. determination of change of luminance and chromaticity coordinates of areas irradiated with UV radiation as compared with those of the reference part. That is why, for further processing of measurement results, relative values of changes of luminance and chromaticity coordinates of areas irradiated with visible and UV radiation were calculated in percents of the reference area of each material after each daily irradiation.

The results of measurements for a quite long period of time (until the consequences of irradiation become visible) were tabled and the graphs of dependence of relative change of luminance[1] and colour on the increasing dose of UV radiation accepted by each sample were made in accordance with this table, i.e. the development of the process of change of surface optical properties under irradiation were graphically represented.

For graphical representation and analysis of the changes, the results were processed using special *Microsoft Excel*-based software developed for this purpose.

3. THE RESULTS OF THE STUDY

The selection of a criterion of acceptable value of luminance change was based on the Weber-Fechner law [6], according to which, relative threshold value of "visibility" of luminance change does not depend on its absolute value and is equal to about 2 %. The threshold value of "visibility" of colour change depends on individual aspects of colour perception by each individual (different spectral responsivity) and on illuminance, hue and colour saturation of an object. According to the results of the experiment, the threshold value of visibility of colour change was equal to (4–5) % for well-lighted saturated colours and up to (20–30) % for low-saturated and dark (brown, violet, dark-blue, dark-green) colours.

Using the specified criteria of maximum acceptable changes of luminance (±2 %) and colour (±5 %), maximum acceptable dose of UV radia-

[1] Luminance was measured by means of a photoelectric portable photometer manufactured by ZOMZ, Sergiyev Posad (basic percentage error of the photometer does not exceed ±10 %).

Table 1. Acceptable Level of UV Exposure for Museum Materials

Light-resistance group of materials	Acceptable UV exposure, W·h/m^2
Newspapers	68
Paper	150
Watercolour	1250
Oil paint	1680
Textile	620

tion for each sample at which critical values of visibility of changes of sample luminance and colour had been reached (Fig. 3), watercolours as an example) was determined in accordance with the graphs of surface optical properties changes.

Maximum acceptable doses of UV radiation for material groups (e.g. for watercolours irrespective of colour) were determined by selecting the least value of maximum acceptable doses of all values for all samples included in this group of materials (Table 1). Thus, this value will be known safe for all other materials forming the group.

The maximum acceptable doses with consideration of recalculation factors taking integral transmission of protective film in areas irradiated with light and spectral responsivity of radiometer into account were taken as recommended values of maximum acceptable doses of UV radiation.

The recalculation factor for visible radiation was defined experimentally. Illuminance of one point with and without the film caused by one source was measured by means of an illuminance meter. Transmittance of the film was equal to 0.22, the light getting on the tested samples through the film was weakened by the same value. Hence, this is the factor to be introduced as correction of true value of illuminance of the samples.

The recalculation factor for UV radiation was determined by calculation in accordance with typical characteristic of chromaticity of high pressure mercury lamp DRSh-250 and spectral responsivity of the radiometer. It was equal to 1.14. The same factor should be introduced as correction of true value of irradiance of the samples.

For each type of materials, maximum acceptable doses and intensities for constant and temporary exhibitions and for long-term storage of especially valuable exhibits were specified (Table 2).

The following minimal acceptable values of illuminance/irradiance were taken:

– For UV radiation – as low as reasonably practical;

– For visible radiation – the standards [7] providing safe and emergency ways through museum premises as well as minimal illuminance levels for comfortable examination of exhibits.

The illustration of some results of the study is presented in Fig. 4.

4. PHOTOMETRIC DEVICES FOR MUSEUMS

The performed study was continued by development of a group of photometers for measurement of light environment characteristics in museums. The most required measurements in museum practice are:

– Measurement of illuminance;

– Measurement of UV irradiance;

– Measurement of colour characteristic (colour temperature, colour rendering index, chromaticity coordinates);

– Measurement of radiance (i.e. luminance distribution in a spectator's field of view);

– Measurement of glare.

4.1. Illuminance Measurement

The most widely spread device for measurement of illuminance is reliable and simple illuminance meter. Significant changes in metrology of photometers occurred in the second half of the previous century. In [8], it was shown that application of widely spread illuminance meters based on selenium photoemissive cells and similar devices causes significant (more than 20 %) error when measuring fluorescent light sources. In accordance with CIE recommendations [9], the illuminance meters should be corrected in accordance with spectral luminous efficiency $V(\lambda)$ with high precision. VNIIOFI (All-Russian Research Institute for Optical and Physical Measurements Federal State Unitary Enterprise) has developed the relevant requirements to optical measurement devices and the

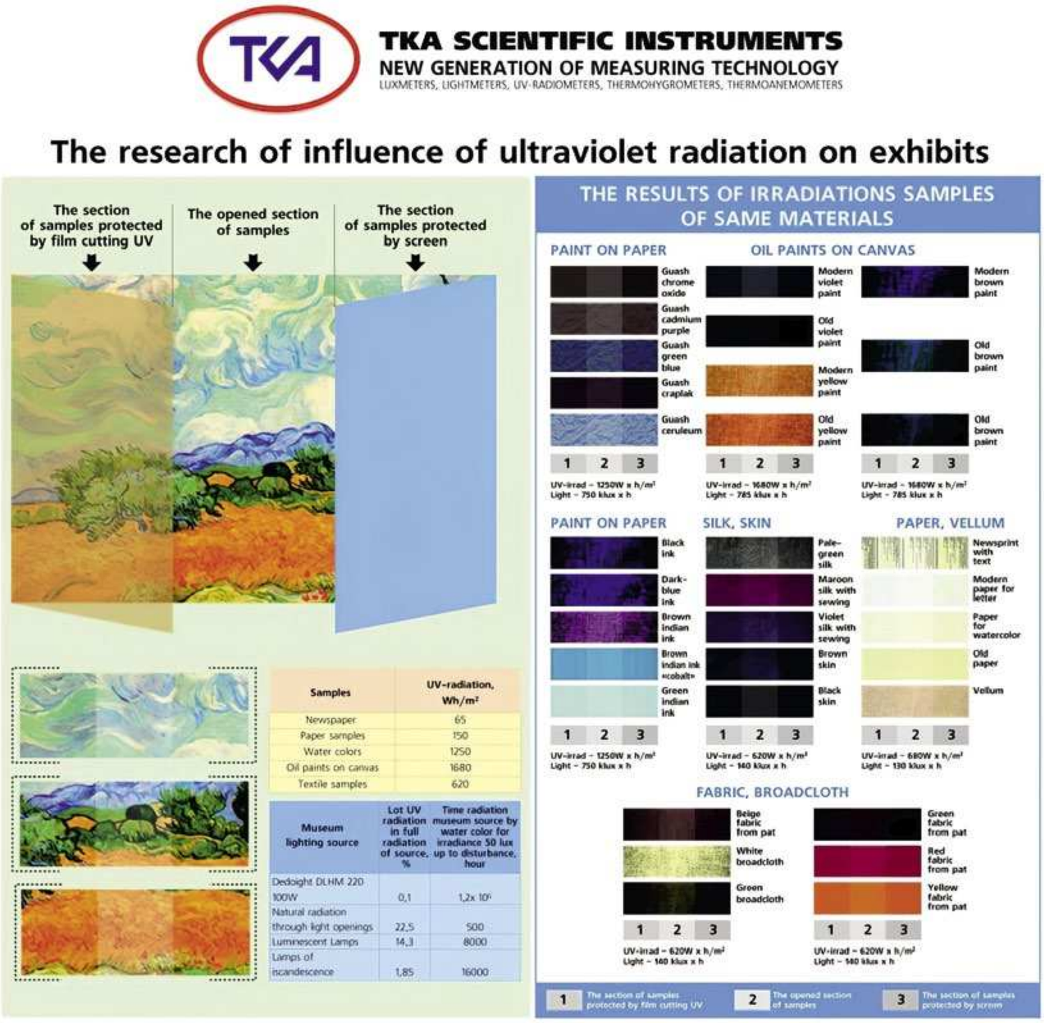


Fig. 4. Visual changes of different materials

first photometer of the new generation which had passed state registration was the combined device TKA-01/3 (Fig. 5) developed especially for museums and libraries.

Depending on the exhibited materials, the level of museum lighting is usually within the range between 30 and 700 lx. However, it is rational to use one device for measurements (monitoring) of illuminance both in halls, corridors and stairs where it can be lowered down to 5 lx and outside the premises where illuminance may reach 100000 lx and more.

Therefore, the measurement range of the museum illuminance meter should be of (1–200,000) lx. Relative measurement error should not exceed 8 %. Most of the produced illuminance meters complies with these requirements: *Hagner* (Sweden), *Minolta* (Japan), TKA (Russia), *Testo* and *Krohmann* (Germany), *Kara Tekniikka Oy* (Finland) and others.

4.2. Measurement of UV Irradiance

Monitoring of the level of UV irradiance is even more important for preservation of museum exhibits. Development of UV radiometers was an especially complicated challenge in terms of metrology. The conventional method of reduction of photometric device characteristics to U-shape ones was not only complicated to be implemented but also, in our opinion, did not assist in obtainment of correct measurement results.

For the purpose of reduction of measurement error, different methods are applied: limitation of radiation source types, introduction of correction factors, etc. Thanks to the reached compromise, we’ve managed to find an opportunity to reduce the total UV radiation measurement error down to 10 % in serial UV radiometers TKA-AVS and Argus.

Table 2. Recommended Maximum Level of UV Irradiance for Materials According to Light-Resistance Groups

Irradiated object	Light-resistance group of materials	UV exposure causing visible change of material colour, W·h/m²	Recommended maximum limit of UV irradiance, mW/m²		
			For permanent exhibitions	For temporary exhibitions	For long-term storage (≥2 years) and for especially valuable exhibits
Newspapers, books	3	68	24	40	3
Photographs	3	60	21	35	2
Grades	3	80	28	45	3
Paper and parchment manuscripts	3	50	18	30	2
Iconography	3	100	35	50	3.5
Watercolour	3	80	28	45	3
Ink (including coloured)	3	60	21	35	2
Chinese ink	3	60	21	35	2
Tempera	3	80	28	45	2
Pastel paint	3	80	28	45	3
Carpets, gobelins, fabrics, clothes, goffering, fur, leather	3	80	28	45	3
Collections of insects, stuffed animals and birds	3	80	28	45	3
Oil paintings	2	150	52	90	6
Objects made of bones	2	400	139	180	14
Wooden accessories, furniture	2	500	174	220	20
Gouache	2	150	52	90	6
Some types of light-sensitive minerals and jewellery	2	1,000	350	350	30

Notes:
1. Limit values of UV irradiance are given for any light sources for everyday 8-hour exhibition.
2. The values given in Table 2 are maximum allowable ones with mandatory reduction if it does not influence the quality of visual perception of an exhibit.
3. If the level of UV irradiance created in premises by means of general lighting exceeds the limit given in Table 2, exhibition should be suspended and measures for exhibits preservation should be taken. Preservation measures may be both technical and organisational.
4. Minimal limit of UV irradiance is not specified but in any case it’s required to aim at the lowest practicable values.

The TKA-type indicators which are quite simple in operation and user-friendly are overlooked.

In the future, according to the new studies and recommendations by CIE, it will be probably necessary to make measurements separately in A1 (315–340) nm and A2 (340–400) nm spectrum ranges. These spectral regions of LED luminaires are supposed to cause the most significant environmental impact.

Among the range of devices, it is worth noting the Khranitel device by TKA with its UV responsivity increased especially for museum purposes and which measures 5 major microclimate parameters.

Fig. 5. Combined device TKA-01/3

Fig. 6. Spectral colorimeter TKA-VD

Fig. 7. Remote luminance meter TKA-KINO

4.3. Measurement of Colour Characteristics

Measurement of light chromaticity may be of sufficient importance for both storage and exhibition safety and better representation of exhibits [10]. A lot of produced models including portable ones are likely to provide measurement of major spectral characteristics of museum lighting. The spectral colorimeter developed for solving of this task (Fig. 6) has required metrology and operational characteristics.

TKA-VD spectral colorimeters are designed for measurement of chromaticity coordinates and correlated colour temperature of light sources in the CIE1931 and 1976 international colorimetric systems, illuminance and luminance. The device is included in the National Register of Measuring Equipments of the Russian Federation. Its new version has enhanced spectral resolution and is capable to send the measurement results to PC and gadgets via Wi-Fi.

4.4. Luminance Measurements

Remote measurement of luminance is provided by the new version of the TKA-Kino luminance meter (Fig. 7). It is a simple and reliable device which allows to measure luminance of a lighted surface just by pressing a button. It can also be applied for evaluation of contrast revealing coefficient[2] used in museum practice and luminance distribution.

Temperature and humidity detectors are widely spread in museums and should be supplemented by illuminance or UV irradiance level detectors with wireless data transfer. There are a number of challenges to be solved in case of museum interest. It is necessary to restore cooperation between developers and manufacturers of measurement equipment and museum specialists.

5. CONCLUSION

The study performed and measurement devices created on its basis may be used for evaluation of museum lighting. But the low state of knowledge of impact of LED lighting on museum materials does not allow to draw conclusions about changing of applicable rules and to sufficiently increase acceptable levels of illuminance and UV irradiance without additional studies.

REFERENCES

1. Saunders, D. The Environment and Lighting in the Sainsburi Wing of the National Gallery // ICOM Com-

[2] Ratio of the lightest part of background or an image to the darkest one applied in museum practice.

mittee for Conservation, 1993, vol.11, Lighting and Climate Control.

2 Thomson, G. The museum environment. 2nd ed. London: Butterworths, 1981.

3 Aydinli, S., Hilbert, G.S., Krochmann, J. Uber die Gefahrdung von Ausstellungsgegenstanden durch optische Strahlung // Leicht-Forschung, 1983, Vol. 5, No. 1, pp. 35–47.

4 CIE157:2004 Control of Damage to Museum Objects by Optical Radiation // CIE, 2004.

5 Ivanov Yu.P., Kuzmin V.N., Tomsky K.A. Museum and library lighting recommendations. Moscow: Department of Museums of the Ministry of Culture of the Russian Federation, 1997, 14 p.

5. Ivanov Iu.P., Kuzmin V.N., Tomsky K.A. Rekomendatsii po normirovaniiu osveshchennosti v museiakh i bibloitekakh. M: Upravleniie museev Ministerstva kultury RF, 1997, 14 p.

6. Fechner Gustav Theodor //In Sachen der Psychophysik// Leipzig, Breitkopf und Hartel – 1877, 248 стр.

7. SP 52.13330.2011 Daylighting and artificial lighting. The updated version of SNiP 23–05–95*.

7. SP 52.13330.2011 Estestvennoie i iskusstvennoie osveshcheniie. Aktualizirovannaia redaktciia SNiP 23–05–95*.

8. Ignatiev V.G., Boos G.V. What to do with U-116 and U-117 illuminance meters? Photometry and its Metrology Equipment science and technical conference, Moscow, 1997, p. 27.

8. Ignatiev V.G., Boos G.V. Chto budem delat' s liuksmetrami Iu-116 i Iu-117?] // Nauchno-tekhnisheskaia konferentciia "Fotometriia i eio metrologicheskoie obespecheniie", M., 1997, p. 27.

9. CIE53:1982 Methods of characterizing the performance of radiometers and photometers. – Bureau Central de la CIE, Paris-France, 1982.

10. Shanda Ya. What is Colour Fidelity in Museum Lighting? // Light & Engineering, 2014, V.22, #4, pp.51–58.

Sergei S. Bayev
graduated from Saint Petersburg State Institute of Cinema and Television in 2015. Nowadays, he is a post graduate student in the Saint-Petersburg National Research ITMO UNIVERSITY

Vladimir N. Kuzmin,
Prof., Dr. of Technical Science. He graduated from Kuban State University (KGU) in 1971 with specialty in optics and photometry. At present, he is the Deputy General Director of Scientific and Technical Enterprise TKA responsible for optics and photometry and Professor of the Light and Engineering basic department of St. Petersburg State University of Film and Television

Konstantin A. Tomsky,
Prof., Doctor of Technical Science, graduated from the North-Western Polytechnic Institute of Remote Education in 1972 with specialty in radio equipment. At present, he is the General Director of Scientific and Technical Enterprise TKA and Head of the Light and Engineering basic department of St. Petersburg State University of Film and Television

Light & Engineering
Vol. 27, No. 4, pp. 81–88, 2019
https://doi.org/10.33383/2018-154

LED MUSEUM LIGHTING: BACK TO NATURAL LIGHT

Andrei V. Aladov, Alexander L. Zakgeim[1], and Anton E. Chernyakov

FSBIS Science and Technology Centre of Microelectronics and Submicron Hetero-structures of the Russian Academy of Science, Saint Petersburg
[1] Email: zakgeim@mail.ioffe.ru

ABSTRACT

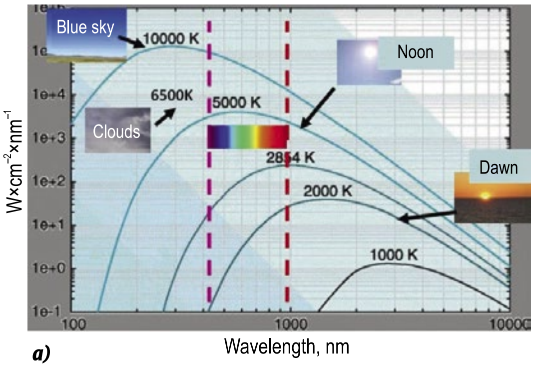
Article overviews prospects of application of adjustable polychrome LED luminaires based on *RGB* mixture principle for museum lighting. Such light sources allow creating of high-quality lighting systems with capability to adjust luminous flux and chromaticity characteristics with a wide range of correlated colour temperatures between 2800 K and 6500 K and high values of all colour rendering indexes: R_1-R_{14}. Application of adjustable LED light sources makes it possible to do artificial museum lighting similar to natural environment at the moment of creating of a piece of art by an artist, hence, to make its perception more precise. Possibility to adjust the correlated colour temperature allows creating individual lighting of paintings in compliance with the genre and subject of a work (a portrait, a landscape, time period, etc.). The article also briefly describes major theoretical, circuit design and software aspects of creation of a dynamically adjustable LED system of museum lighting and gives first examples of its application.

Keywords: light emitting diode (LED), light source, adjustable LED lighting system, *RGB* mixture, luminous efficacy, colour rendering indexes, correlated colour temperature, remote control

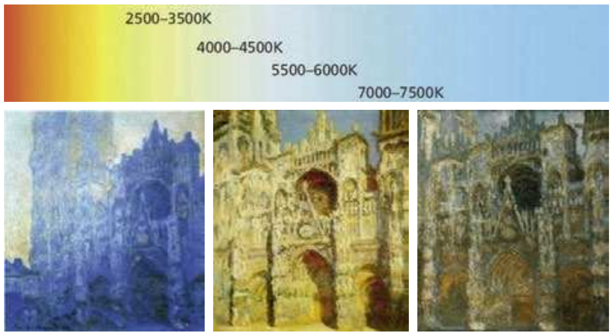
1. INTRODUCTION

The rapidly developing LED lighting systems have been being applied in museums more widely. This process itself, with participation of such great museums as Louvre, Prado, Amsterdam Rijksmuseum and exhibition of such masterpieces as Mona Lisa (Gioconda), Night Watch, etc. with LED lighting, witnesses high quality of existing LEDs and the light created by them [1, 2]. In point of fact, recognition of LED lighting by many museums is related to significant increase of major light engineering indicators of LED as well as to "approaching the consumer" by widening of the product range and increase of convenience of LED luminaires application. As is known, the advantages of LED, which brought them to the lighting market for the first time in the early 2000s, consisted in the absence of IR and UV radiation components, luminous efficacy (LE) comparable with fluorescent lamps, and long service life. But the quality of light was far from perfect. Nowadays, advances in increase of efficiency of LEDs based on *AlInGaN* hetero-structures have surpassed the wildest expectations. The record values of efficiency for blue semiconductor emitting crystals (used as a basis for phosphor white LEDs) are equal to ~85 % [3]. For white phosphor LEDs based on efficient blue LEDs, *Cree Inc.* demonstrated the level of LE reaching to 303 lm/W, which is close to the theoretical level [4]. The LE value of commercial devices is (150–200) lm/W which exceeds all known types of lamps [5].

But the quantitative indicators, illuminance and LE, are not so important for museum lighting as qualitative indicators, primarily the correlated colour temperature (T_{cc}) and colour rendering indexes (CRI). According to contemporary requirements for high-quality lighting, general CRI R_a should be equal to at least 95 whereas special



a)



b)

Fig. 1. Spectral distribution of natural lighting in different time periods and with different weather conditions (a); C. Monet, the Rouen Cathedral series in morning, day, evening (b)

CRIs for saturated colours R_8–R_{14} should be equal to at least 85 [6]. It must be admitted that, thanks to development of phosphor technology and, partially, the semi-conductor radiators as well (which can be not only monochrome but also double-sideband [7]), colour rendering of phosphor LEDs has increased dramatically becoming acceptable for illumination of paintings. But, after becoming more efficient and qualitative than most of fluorescent lamps, in one respect phosphor LEDs are still heirs of fluorescent lamps. That is their radiation is static, the spectrum of radiation is specified during manufacturing and cannot be varied in the course of operation.

Herewith, for a number of applications including museum lighting, capability of dynamic control of spectral and colour characteristics seems to be attractive. Controllability of spectrum (colour) first determined by E.F. Schubert as *smart light* [8] radically widens functionality of light sources (LS), in particular, changing approaches to museum lighting. The degree of controllability may be different, for example, from varying over time within a specific range of T_{cc} to reproduction of a wide range of natural colours, which includes millions of shades [9]. It is possible to imitate natural light with all its transitions from warm to cold hues or, in other words, to turn artificial light into natural one.

Paintings of the Old masters, like most of paintings by contemporary artists, were painted with natural lighting. From the physical point of view, natural light is characterised by wide continuous spectrum close to that of a Planck's radiator (Fig. 1a) providing ideal colour rendering of illuminated objects (all CRIs of the Planck's radiator are equal to 100). The maximum point of the natural light radiation spectrum differs throughout the day from warm hues (at dawn) to cold ones (at noon) and then to warm colours again (in the evening) as well as in compliance with weather conditions (sunny, cloudy, overcast). In terms of colorimetry, it is reflected as variation of T_{cc} between warm hues (T_{cc} ~ (2,000–2,500) K) and cold hues (T_{cc} ~ (6,000–10,000) K). Such variation of lighting to the large extent determines perception of an imaged object by an artist, as exemplified by the Rouen Cathedral series by Claude Monet shown in Fig. 1b.

However, in museums, artificial light is used always or most of the time, until recently it was made by tungsten halogen lamps, mercury fluorescent lamps or metal halide lamps. This light is far from natural one. Although the spectral distribution of incandescent lamps is similar to that of a Planck's radiator, due to low temperature of the filament their spectrum almost does not include the blue range of wavelengths, which, for instance, causes adverse impact on landscapes with sea or sky. The fluorescent lamps are characterised by a selective spectrum of radiation, which make them not acceptable for lighting of paintings due to low CRIs. The listed features of the lamps a priori confirm that their light differs from that at the moment of creation of a painting and perception of paintings by a spectator may not comply with what an artist saw and wanted to express.

Is it possible to create artificial LSs returning natural light? Yes, there is such possibility these days. Its implementation is linked with development of polychrome mono-crystal LED matrixes applying the *RGB* mixture principle. The white light is created as a sum of radiation bands of multi-colour LEDs contained in the matrix, hue (T_{cc}) control is performed by changing the share of any component of the total spectrum.

The theoretical aspects of colour mixture for creation of high-quality white colour as well as the

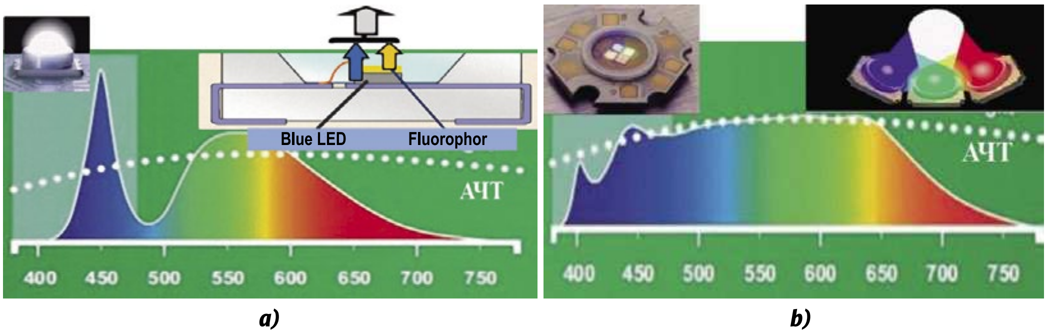


Fig. 2. Typical spectra of radiation of the phosphor white LED (a) and a polychrome multi-crystal LED (b) compared with a spectrum of a Planck's radiator (dashed line)

structure of a controllable LED LS based on this principle and functional diagram of the whole lighting system including remote control and software are briefly described below.

2. SIMULATION OF COLOUR MIXTURE, SELECTION OF COMPONENTS OF THE CONTROLLABLE LS

As mentioned above, nowadays LSs on the basis of white phosphor's LEDs with original blue radiation of a semi-conductor crystal partially re-radiated to the yellow-green area by a phosphor are the most commonly used and their total double-band spectrum is equal to white light (Fig. 2a). Despite the high values of luminous efficacy and colour rendering (LE~200 lm/W; R_a>80) of phosphor LED, their disadvantage is their typical "two-peak" spectrum, due to which some special CRIs R_i are lowered, but the main disadvantage is incapability to change spectrum and colour characteristics in the course of operation of LS.

Controllability (fine adjustment, regulating, and programming) is possible with another scheme of a LED LS, which is based on mixture of radiation in multi-crystal polychrome LED matrixes [10]. The main question here is how many and which semi-conductor radiators spectrum distribution should be mixed to obtain white light with specified characteristics. Let's examine this important question a bit more careful. The contemporary LEDs with specific efficiency fill in almost the whole visible spectrum (except for a little gap close to wavelength ≈550 nm called *the green gap*), and, by selecting of 8–10 monochrome LEDs with relevant power, it is possible to obtain an envelope of the total spectrum similar to that of a Planck's radiator with any T_{cc} (Fig. 2b) [11, 12]. However, for both technical and economical reasons, this approach is suitable only for development of unique (reference) LSs [13] and is not feasible for common practice. Over the last 20 years, a large number of studies had been devoted to simulation and calculation of minimal but sufficient amount of LEDs for creation of white light with specified parameters [14–16]. This question does not have the unique solution and faces the main contradiction between quantitative and qualitative characteristics of white light, LE and R_a (increase of one of these parameters always leads to reduction of the other one). The brief conclusion of the results obtained in these studies is as follows. With typical half-breadth of monochromatic semi-conductor radiators of $\Delta\lambda_{0.5}$ ~ (15–40) nm, obtainment of white light with high value of general CRI of R_a~90 requires mixture of radiations of 4 or 5 semi-conductor radiators with optimal selected peak values at wavelength λ_{peak} relatively uniformly distributed throughout the visible spectrum. Further increase of the number of LEDs adds little to the value of R_a but causes significant decrease of LE. It is significant that even low deviations of peak values of wavelength λ_{peak} of particular LEDs from optimal values may cause sharp decrease of the values of special CRIs R_i.

To solve the task of LED spectra mixture, we used a computational model and software developed by OOO SOFT-IMPACT allowing to find the optimal value using a special objective function while varying lots of parameters [17]. As a result of calculation, the total radiation spectrum is defined and analysed in part of chromaticity coordinates x, y, correlated colour temperature T_{cc}, general and special CRIs, and LE calculations. The model allows to form a multi-parameter objective function and to optimise white light with specified T_{cc} provided that the values of R_a (as well as specific R_i) and LE will not be less than the specified ones.

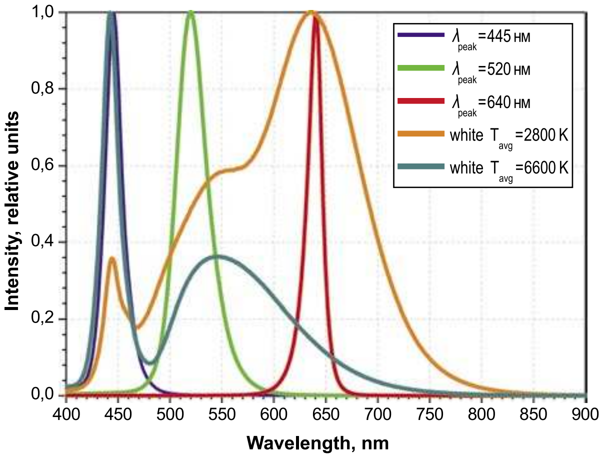


Fig. 3. Spectral distributions of LEDs (3 monochrome and 2 phosphor) used as a basis for colour mixture

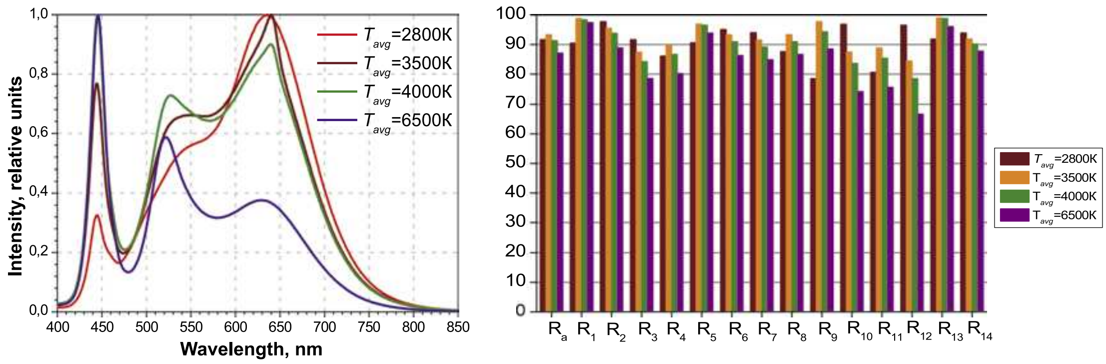
After analysing a number of combinations of polychrome *RGB*, *RGBA*, *RGBW*$_c$, *RGBW*$_w$ type matrices (*R, G, B, A* are monochrome LEDs with red, green, blue and amber colour respectively and W_c and W_w are phosphor white LEDs with cold and warm hues), the variant of a radiator with 5 components was chosen as an optimal one for museum lighting according to the results of computer simulation. There are three monochrome LEDs (two *AlInGaN*-based with λ_{peak} = 460 nm, $\Delta\lambda_{0.5}$ = 22 nm and λ_{peak} = 520 nm, $\Delta\lambda_{0.5}$ = 34 nm) and one *AlGaInP*-based with λ_{peak} = 630 nm, $\Delta\lambda_{0.5}$ = 15 nm, and two phosphor LEDs of warm (W_w) and cold (W_c) hues with T_{cc} equal to 2800 K and 6600 K respectively. The spectra of radiation of the selected original LEDs are shown in Fig. 3.

In the course of white light creation experiments with specified values of T_{cc}, at first the values of output optical power obtained during simulation (optimisation with maximum R_a) were set and then, with direct visual control of colorimetric characteristics, using the *OL 770-LED High-speed LED Test and Measurement System* the values of power of radiators were adjusted individually until better compliance with a point of the Planck's radiator envelope at relevant colour temperature was obtained.

The experimental studies and simulation showed that the selected combination of 5 basic LEDs allows us to create a LS providing high-quality white light with a wide range of T_{cc} = (2800–6500) K, i.e. almost the whole range practically important for lighting. In Fig. 4, the relevant spectral distributions, the values of general and special CRIs at 4 T_{cc} values (2,800; 3,500; 40,000 and 6,500 K) are presented. It is worth noting that at all T_{cc} the major contribution in the total luminous flux is made by phosphor LEDs providing also high values of LE. The blue, green and red monochrome LEDs correct the special CRIs and increase them. As shown in Fig. 4b, in the area of warm and neutral white light, (2,800–4,000) K, there is a situation when $R_a \geq 90$ and all values of special CRIs $R_i \geq 80$. The values of some special CRIs (R_1, R_5, R_{13}) are proximate to 100. The high values of R_9, R_{13}, reaching 95–98, are especially important. These indexes are not taken into account for calculation of R_a but they play an important role in reproduction of bright-red colours and shades of human skin colour.

3. LED SYSTEM OF CONTROLLABLE LIGHTING: THE STRUCTURE, THE KEY ELEMENTS, THE FUNCTIONING PRINCIPLES, AND SOFTWARE

The LED system of controllable museum lighting may include both one LS and a group of LSs depending on the task to be solved, lighting of one painting, a group of paintings, or common illumina-



a) *b)*

Fig. 4. Spectral distributions (a) and values of CRI R_a, R_i (b) for a controllable source of white light with T_{cc} equal to 2,800 K; 3,500 K; 4,000 K; 6,500 K

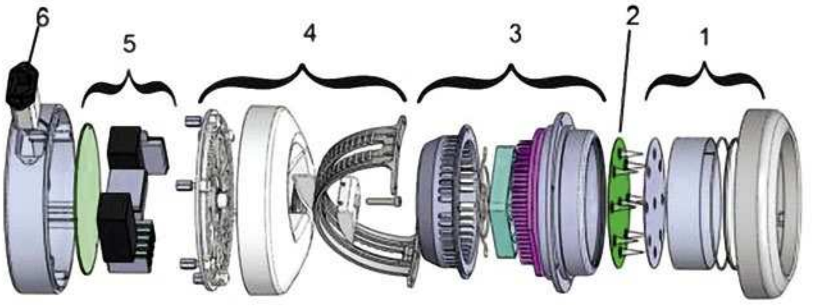
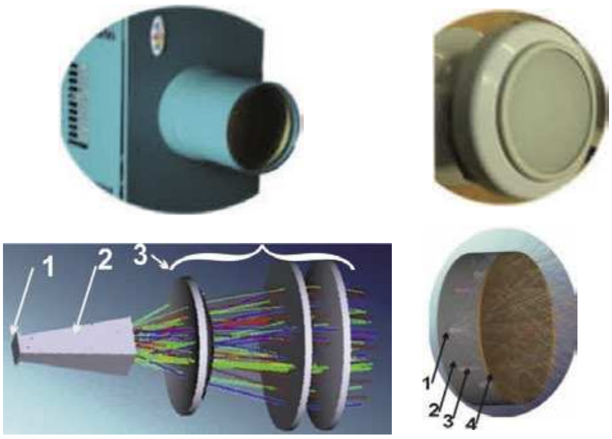


Fig. 5. Diagram of the major units of the controllable LS: **1** – optical system, **2** – LED module, **3** – radiator with a fan, **4** – bottom of the body with a rotary device, **5** – electronic power supply and control unit, **6** – power supply filter

tion of a hall. A separate LS itself is a device containing electronic and optical units.

The structure of LS is shown in Fig. 5. The key element of LS is the multi-crystal polychrome module, which is a board ***2*** with a set of multi--colour LEDs and secondary optics for mixture of radiations. The spectral characteristics of LEDs forming the module were defined in the previous section and, based on the complex of qualities, primarily LE, we selected 4-crystal LEDs *LE RTDUW S2W (R-G-B-*W_c) and *LE CWUW S2W* (W_c-W_w) [18] manufactured by *Osram Opto Semiconductors*. The LEDs are mounted on an aluminium radiator equipped with a fan ***3***. The study of thermal parameters showed that in the heaviest operation modes, the temperature of the active area of LED does not exceed 95 °C (thermal resistance of individual LEDs ~ (4–5) K/W) and none uniformity of heating of the board does not exceed 10 %. To stabilise the thermal conditions (which is required for continuity of spectral and performance characteristics of LED), the board of radiators is equipped with a temperature sensor turning the fan ***3*** on.



a) ***b)***

Fig. 6. Photo and optical diagrams of two types of LS
a) – projection-type LS for lighting of an individual painting (part of a painting):**1** – LED matrix, **2** radiation mixer, **3** – three-element lens;
b) – diffusing-type LS for lighting of spaces: **1** – LED matrix, **2** radiation mixer, **3** – diffuser, **4** – side reflector

The optical system of LS1 should provide high ratio of radiation transmission between LED and the exit aperture, the specified value of spatial distribution of radiation as well as colour uniformity in the far-field and near-field, i.e. good mixture of radiation from several LEDs. The calculations and optimisation of the optical scheme were performed in accordance with the optimal optical systems architecture. Taking the most important art objects lighting conditions into account, the two types of luminaires had been designed:

– The first one with projection lenses creating a bright limited illuminated field used for local lighting of one painting (or a particular area of a painting);

– The second one with diffusing optics providing uniform lighting of the whole room.

The photos of the luminaires and both variants of the optical scheme are shown in Fig. 6. It is worth noting that an important optical element of both systems is the mixer of radiation from separate radiating crystals, which provides uniformity of the colour field at all angles of radiation (over the surface of the illuminated object).

The radiating module itself is located on a rotary device mounted to the bottom of the body ***4*** with the electronic unit ***5*** located inside. It's functional diagram (Fig. 7) includes power supply, transceiver modules for data exchange with the remote control unit (RCU) or the computer via wireless channel, the microcontroller and control units (CU) setting the LED operation modes and, subsequently, their output radiation characteristics. The LEDs form five colour groups (lines, sequential radiators): R, G, B, W_c and W_w connected with five CU units controlling radiant power of each colour group of LEDs according to the level set by the microcontroller.

The LS radiation parameters may be controlled using signals transferred to input of the microcon-

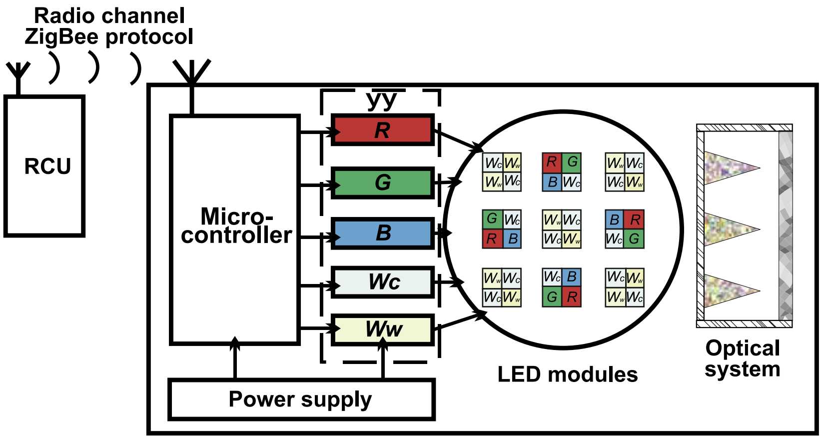


Fig. 7. Functional electric scheme of LS

troller via wireless network (radio channel) from a personal computer or RCU. The microcontroller receives control signals, sets light characteristics of LED groups with different chromaticity and monitors temperature of the LED board. The main task of the wireless network is to transfer relatively small data volumes to short distances, and the network should have minimal consumption implementing various schemes of monitoring and control in the course of solving light engineering tasks [19].

The network in our lighting system is based on *IEEE802.15.4* standard and its *ZigBee* specification [20, 21]. Low signal-to-noise ratio allows the signals to co-exist successfully with alternative sources of radiation at the same frequency (*Wi-Fi*, *Bluetooth*). The standard also specifies channels with frequency different from that of competitors, which allows us to arrange a network even in close proximity to powerful sources of radiation.

The RCU has the form of a unit plugged in the power supply socket with a coloured *TFT* indicator (diagonal size of 3.5 inches) and a six-button keyboard. The RCU sets the specified T_{cc} and brightness of lighting as well as the mode or time of their change. RCU controls LS at a distance of up to 35 m.

The network software includes a set of programmes and allows us to control a branched network via a radio channel using a RCU or a PC throughout the day and in energy-saving mode.

4. EXPERIMENTS OF ILLUMINATION OF PAINTINGS BY CONTROLLED LED LIGHT SOURCES

The developed controllable LSs were tested for lighting of paintings with different colour palette in exhibitions [22] and museums [23]. The experiments showed that the optimal selection of lighting reached as a result of varying T_{cc} of LSs allows obtainment of the best reproduction of colours of a painting close to that in daylight. T_{cc} of the controllable LS selection is determined by the subject of a painting and by what is painted in it, and, of course is partly subjective, basing on opinion of the expert group evaluating varying lighting conditions. For example, Fig. 8 shows the painting by B. Karafyolov with cold blue hues prevailing at two lighting variants. In Fig. 8a, the painting is lighted with light from a controllable LS after selection of T_{cc} = 5,000 K as optimal, whereas Fig. 8b shows the same painting lighted with an incandescent lamp with T_{cc} = 2,800 K. Comparison of the figures clearly shows distortion of colour rendering caused by standard lamp lighting since the blue part of spectrum is reproduced insufficiently.

It is worth noting that in some cases adjustment of the controllable LS may differ from the standard requirement of high CRI. Deviation from good white light may be used for the so-called accent lighting. For example, lighting without green and yellow component (low values of R_3, R_{10}, R_{11}) may be applied for increasing of image contrast. It means to increase brightness of blue and red objects against the background of the others. The same approach, i.e. selection of particular spectrum components of lighting, may be used for art conservation allowing particular layers of paint to distinguish from others.

5. CONCLUSION

The article reviews the operational principle, design and major characteristics of controllable LED based lighting systems with application of multicrystal polychrome matrices. It shows the capability of adjustment of spectral and colour characteristics

Fig. 8. Comparison of a painting with optimal lighting by means of a controllable LS with T_{cc} = 5000 K (a) and of an incandescent lamp with T_c = 2800 K (b)

including creation of high-quality white light with T_{cc} in range (2800–6500) K, with general and special CRIs ~ 90, in other words, the capability to return artificial light to natural light with its variations depending on the time period and weather conditions. At the same time, it is possible to set special accent lighting for contrast reproduction of particular colours.

In our opinion, application of such controllable LED LSs opens new interesting prospects for museum lighting. It can be transformed from general to individual, complying with the subject of a painting. Roughly speaking, it means that if a painting shows a marine landscape at noon, the controllable LS should illuminate it at T_{cc} ~ 6,000 K so that the spectator sees it with the same lighting that the artist saw while creating the painting.

Although the production volumes and product lines of controllable polychrome LED LSs are less than those of phosphor white LEDs, they are already ready to be applied in the following fields:

– General lighting of single objects,

– Special lighting for treatment of psychological and physical state of human,

– Lighting of operating rooms for contrast visualisation of tissues, etc.

In this row, the controllable museum lighting seems to be an important and interesting field, development of which requires cooperation of developers and museum workers.

Measurements of luminous parameters were performed in Common Use Centre "Hardware Components for Radio-photonics and Nano-electronics: Technology, Diagnostics, and Metrology".

The work is issued with partial support of the State Contract with Ministry of Education and Science of the Russian Federation, No. 14.604.21.0187 dated on 26.09.2018, Unique ID No.RFMEFI60417X0187.

REFERENCES

1. Whitaker, T. LED lights illuminate paintings in London's National Gallery // LEDs magazine, 2011, June, p. 9. URL: http://ledsmagazine.com/news/8/4/13.

2. Philips Sheds New Light on Night Watchat the Rijksmuseum // LED professional, 2011, # 28, p.5.

3. Hurni, Ch.A., David, A., Krames, M.R. et al. Bulk GaN flip-chip violet light-emitting diodes with optimized efficiency for high-power operation //Appl. Phys. Lett. 2015, Vol. 106, # 3, p. 031101.

4. Cree: First to Break 300 Lumens-Per-Watt Barrier. URL http://cree.com/News-and-Events/Cree-News/Press-Releases/2014/March/300LPW-LED-barrier.

5. Cree's MK-R LED Offers up to 200 Lumen-Per-Watt // LED professional Review. 2013, V. 35, p. 6.

6. Specifications for the Chromaticity of Solid State Lighting Products. ANSI/NEMA C78.377–2008.

7. Mirhosseini1, R., Schubert, M.F., Chhajed, S., Cho, J., Kim, J.K., Schubert, E.F. Improved color rendering and luminous efficacy in phosphor-converted white light-emitting diodes by use of dual-blue emitting active regions // OPTICS EXPRESS, 2009, Vol. 17, # 13, p. 10806.

8. Schubert, E.F., Kim, J.R. Solid-State Light Sources Getting Smart // Science, 2005, Vol. 308, # 5726, pp. 1274–1278.

9. Zakgeim Alexander L. Light-emitting Diode Illumination Systems: Energy Efficiency, Visual Perception, and Safety for Health (Review)// Light & Engineering Journal, 2013, Vol.21, #2, pp.25–40.

10. Shur M.S. Zukauskas A. Solid-State Lighting: Toward Superior Illumination // Proc. of the IEEE, 2005, Vol. 93, # 10, pp. 1691–1703.

11. Eduard M. Gootzait, Alexander L. Zakgeim, Lev M. Kogan, Vladimir E. Maslov, and Soschin Naum P. Concerning Simulation of Standard Light Sources Using Light-emitting Diode Modules// Light & Engineerig Journal, 2013, Vol.21, #4, pp.75–80.

12. URL http://seoulsemicon.com/en/technology/SunLike/.

13. Nina Carli, Armin Sperling, and Grega Bizjak "Optimization Methods for Spectral Synthesizing of a Tuneable Colour Light Source"// Light & Engineering Journal, 2018, Vol. 26, #3, pp.99–108.

14. Zukauskas, A., Vaicekauskas, R., Ivanauskas, F., Gaska, R., Shur, M.S. Optimization of white polychro-

matic semiconductor lamps // Appl. Phys. Letters, 2002, Vol. 80, # 2, pp. 234–236.

15. Zukauskas, A. et al. Quadrichromatic white solid-state lamp with digital feedback // Proc. of SPIE2004, Vol. 5187, pp. 185–198.

16. Ohno, Y. Spectral design considerations for white LED colour rendering // Optical Engineering, 2005, Vol. 44, # 11, pp. 11302–1 – 11302–9.

17. Bulashevich K.A., Kulik A.V., Karpov S. Yu., Chernyakov A.E., Aladov A.V., Talnishnikh N.A., Sackheim A.L. Optimisation of Colour Mixture for Adjustable Solid Light Sources // Abstracts of the Reports of the 10th All-Russian Conference "Nitrides of Gallium, Indium and Aluminium – Structures and Devices", Saint Petersburg, 2015, pp. 12.

17. Bulashevich K.A., Kulik A.V., Karpov S. Yu., Chernyakov A.E., Aladov A.V., Talnishnikh N.A., Zakgeym A.L. Optimizatciia semshcheniia tsvetov dlia perestraivaiemykh tverdotel'nykh istochnikov sveta //Tezisy dokladov desiatoi Vserossiyskoi konferencii "Nitridy gallia, indiia i alumiia – struktury i pribory. S-Pb, 2015, pp. 12.

18. URL http://www.osram-os.com/osram_os/en/company/index.jsp.

19. Aladov A.V., Valyukhov V.P., Zakgeim A.L., Chernyakov A.E., Tsatsulnikov A.F. Dynamically Controlled LED Lights Sources for New Lighting Techologies // Scientific and Technical Bulletin of SPbPU. Physics and Mathematics. 2014, Issue 4 (204), pp. 38–47.

19. Aladov A.V., Valyukhov V.P., Zakgeim A.L., Chernyakov A.E., Tsatsulnikov A.F. Dinamicheski upravliaemyie svetodiodnyie istochniki sveta dlia novykh tekhnologiy osveshcheniia // Nauchno-tekhnicheskiie vedomosti SPbPU. Fiziko-matematicheskiie nauki. 2014, Issue 4 (204), pp. 38–47.

20. ZigBee and IEEE802.15.4. Wireless Networks. Yu. Semenov (ITEP-MIPT): http://book.itep.ru/4/41/zigbee.htm.

20. ZigBee i IEEE802.15.4. Bespovodnyie seti. Yu. Semenov (ITEP-MIPT).: http://book.itep.ru/4/41/zigbee.htm.

21. Aladov A.V., Valyukhov V.P., Dyomin S.V., Zakgeim A.L., Chernyakov A.E., Tsatsulnikov A.F. Wireless Networks of Controllable Energy-Efficient LED Light Sources // Scientific and Technical Bulletin of SPbPU. Physics and Mathematics, 2015, Issue 1 (213), pp. 50–60.

21. Aladov A.V., Valyukhov V.P., Dyomin S.V., Sackheim A.L., Chernyakov A.E., Tsatsulnikov A.F. Besprovodnyie seti upravliaemykh energoeffektivnykh svetodiodnykh istochnikov osveshcheniia // Nauchno-tekhnicheskiie vedomosti SPbPU. Fiziko-matematicheskiie nauki. 2015, Issue 1 (213), pp. 50–60.

22. URL http://artholtn.ru/exhibitions/2016/dina-rubina-okna.

23. Aladov A.V., Sackheim A.L., Mizerov M.N. On Capabilities of Application of Smart LED Light Sources for Museum Lighting // Architecture and Construction. 2012, Issue 2–3 (13–14), pp. 2–6.

23. Aladov A.V., Zakgeim A.L., Mizerov M.N. O vozmozhnosti primeneniia intellektual'nylh svetodiodnykh istochnikov sveta dlia nuseinogo osveshcheniia // Arkhitektura i stroitel'nyie nauki. 2012 Issue 2–3 (13–14), pp. 2–6.

Andrei V. Aladov graduated from the Department of Physics of the Belorussian State University (1981). At present, he is a Senior Scientific Researcher with Russian Academy of Science Microelectronics and Submicron Hetero-structures Research Centre

Alexander L. Zakgeim, Ph.D. in Technical Science, graduated from the Leningrad Electrotechnical Institute named after V.I. Ulyanov (Lenin) in 1972. At present, he is an Academic Secretary, head of a laboratory in Russian Academy of Science Microelectronics and Submicron Hetero-structures Research Centre

Anton E. Chernyakov, Ph.D. in Physical and Mathematical Sciences, graduated from Saint Petersburg State Electrotechnical University named after V.I. Ulyanov (Lenin) (2006). At present, he is a Senior Scientific Researcher in Russian Academy of Science Microelectronics and Submicron Hetero-structures Research Centre

Light & Engineering
Vol. 27, No. 4, pp. 89–92, 2019 *https://doi.org/10.33383/2018-155*

UPGRADE OF LIGHTING IN HALL 277 OF THE STATE HERMITAGE

Margarita P. Belyakova

International Lighting Engineering Corporation BL GROUP, Svetoproekt, LLC, Moscow
E-mail: bela@svsrv.ru

ABSTRACT

This article outlines the experience associated with the reconstruction of lighting of Museum Hall No. 277 located in the historical interiors of the Winter Palace of the State Hermitage. This work is aimed to create a harmonious light environment in the Museum Hall, favourable for the general perception of the architecture and interior of the hall, and to provide conditions for the full perception of the exhibited items. Identified difficulties are:

– Non-classical dimensions of the Hall, which is part of the French enfilade;

– Polychrome painting and stucco on walls and ceiling;

– Venerable age (darkening of the paint layer) and uniqueness of the paintings, as well as large dimensions of the frames.

The general parameters of the lighting system consisting of two parts – the general lighting of the Hall and the lighting of exhibited items – are determined. The system shall provide a joint combined operation of two independently flux-controlled diffused (reflected from the ceiling) and directional (direct) light components. The system should be adjustable (to an extent) to possible exhibition changes. The system should not have a negative impact on the exhibited items and the interior. The system influencing technical parameters, such as types of light sources, their correlated colour temperatures, levels of general and special colour rendering indexes, the types of lighting devices and their location, approximate illumination levels in paintings and walls, the approximate ratio between illumination, and direct and scattered light in paintings, are selected.

The performed construction and installation works, as well as the adjustment, have shown that the updated lighting installation meets the set tasks and complies with the requirements of quality perception and safety of exhibited items and interior of the hall.

Keywords: museum lighting, exhibition lighting, lighting of museums in historical buildings

In preparation for the 1st International Scientific and Practical Conference “Light in the Museum” our company, which is a part of BOOS LIGHTING GROUP International Lighting Corporation, performed the works on the illumination modernization of Hall No. 277 of the State Hermitage Museum in St. Petersburg, dedicated to the 17th century French fine arts. The Hall exhibition presents five paintings of medium size and one large-sized painting. 300–400-year-old paintings of different artists due to the very dark background and under the existing lighting were hard to perceive by the viewers. Before the modernization, the lighting installation of the hall consisted exclusively of cornice lighting devices – the light fixtures with 3,000 K fluorescent lamps are installed on the cornice in the vault impost and focused on the ceiling; the light reflected from the vault illuminate both the walls and the paintings on the walls. The illumination on paintings (and walls) in the evening was no more than (25–38) lx. The luminous flux falling on the paintings was only scattered. The second component for a good perception of paintings – the direct light – at night time was absent at all. Thus, with almost the

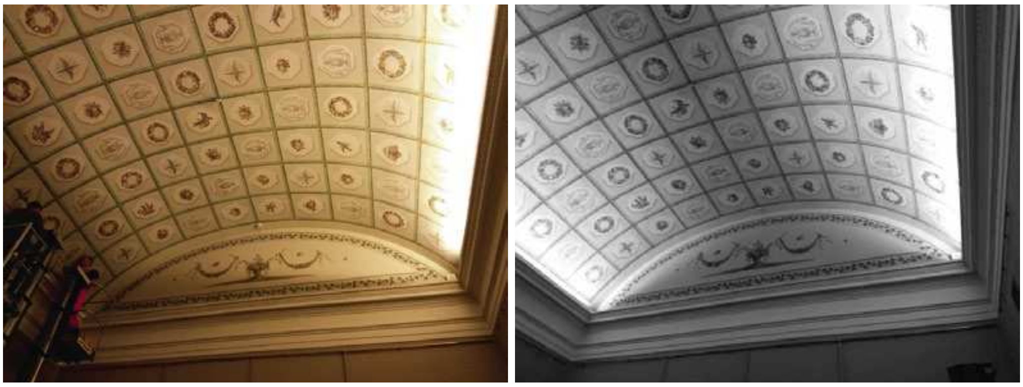


Fig. 1. The vault illuminated by fluorescent lamps (old lighting installation) (left) and LEDs (new lighting installation) (right); in the right photo, the ceiling shape is better read

Fig. 2. Photo of Valentin Lefebvre's painting "Esther before Ahasuerus", taken during lighting with high R_a and R_9 LEDs (new lighting installation). The amazing palette of the artist revealed, and the plot became not threatening, but positive – the pointing hand of Ahasuerus with the rod saving Esther is clearly visible

same illuminance from scattered light on mostly dark paintings and quite bright walls, the paintings could not attract the attention of visitors.

Relatively small Hall No.277 (slightly more than 40 m^2) has the same height as the adjacent halls of the French enfilade: the cornice top is more than 5 m from the floor and the top of the cylindrical vault is in about 7 m away. That is, the ratio of the height of the possible mounting point of the bus bar (the cornice top) and the linear dimensions of the hall is not quite convenient for lighting fixtures installed on the bus bar. In order to ensure the proposed angles of light falling on the paintings (within (45–75) ° to horizontal) at high level of bus bar suspension, it is necessary to sufficiently distance the bus bar from the wall with paintings. At the same time, the enfilade arrangement of the halls imposed the restrictions on the installation of the bus bar with light fixtures. In order to minimize the possible blinding of the visitors when looking along the axis of the enfilade, it was necessary to exclude the appearance of the blind lamp in the enfilade, that is, to bring the bus bar closer to the wall with paintings. With such counter directed geometric requirements, the large frames of paintings proved to be an additional complicating factor. However, it was necessary to help visitors to see the paint-

Table. Technical Data of Aphrodite and Vega Lighting Devices by *GALAD*

Device Name	Power, W	Correlated colour temperature, K	Full angle of radiation at 0.5 degrees	Place of device installation
Aphrodite	6, 13	2,860–3,040	12, 24, 52	On the bus bar
Vega	20	4,000	22 x 90	On the cornice

Fig. 3. Photographs of Valentin de Boulogne's picture "Expulsion of the Money-Changes from the Temple" (central painting of the hall), taken during lighting with fluorescent lamps (old installation) (left) and LEDs (new installation) (right); in the right photo the leading characters look more expressive

ings of hall No. 277 better, because there was actually no special lighting of the paintings in the hall.

Moreover, it was necessary to show the shape of the ceiling and its beautiful paintings, to preserve the usual image of the hall, and therefore, the cornice lighting. Therefore, the updated lighting installation of the hall was to consist of general lighting (reflected light) and lighting of paintings (directional light). It was also necessary to bring the lighting system to one type of light source, and precisely to the one with better spectral characteristics for lighting the canvases – the modern LEDs with high general colour rendering R_a index and high special colour rendering $R_9 – R_{14}$ indexes (for saturated colours).

Therefore, it was necessary to replace the cornice lighting devices with LED devices, capable to reduce the brightness in the base of the vault and stretch the illuminated part of the vault in height, and having a group control (Fig. 1). To illuminate the paintings, LED devices of several types by luminous intensity distribution, independently flux-controlled, were required. The Vega (cornice lighting) and Aphrodite (painting lighting) devices by *GALAD* were chosen.

The light fixtures for installation on Aphrodite's bus bar are designed for 48V, which not only visually minimizes the installation by dimensions, but also allows manually controlling the flux (in situ, for each lamp), without using the automated control system, which cannot be installed without damaging the interior in such a miniature hall.

Installation works and targeting of luminaires were performed in a short time.

The work results are presented in the photographs taken during the installation (Fig. 2, 3). Even with low quality of photos, the accents appeared which were not noticeable earlier. Since the general colour rendering R_a index of Aphrodite LEDs is 98 % and the red R_9 index is also 98 %, the colours of paintings look more saturated than in lighting by fluorescent lamps. The paintings have become more expressive.

Correlated colour temperature of Aphrodite LEDs is about (2,900–3,000) K, Vega LEDs is about 4,000 K. Thus, the joint action of the two types of lighting provides a correlated colour temperature about 3,200 K to the light falling on the paintings, which also positively influenced the artistic expression; the important areas of paintings, inconspicuous under the previous lighting, were displayed (Fig. 3).

In our opinion, at the adjustment the best ratio of the general lighting for evening perception from the cornice (25–30) lx and the lighting from the bus bar (40–120) lx was set (Fig. 4). And, the light fixtures on the cornice operate in 20 % of their maxi-

Fig. 4. View of Hall No. 277 with updated lighting

mum luminous flux. The bus bar luminaires are set at (40–60)% of their maximum luminous flux. If, over time, there is a need to shift the semantic accents or to hang the paintings somewhere else, by changing the luminous flux of Vega's lamps, controlled in a group manner, and Aphrodite's lamps, controlled individually, it is possible to set not only new values of illumination, but also, in small limits, the ratio of cold-white and warm-white light in the paintings.

Earlier, the evening illumination in the paintings was no more than (25–38) lx, whereas in the new installation the illumination in the paintings from two types of lighting was no more than 150 lx, of which about 25 lx is from the general lighting.

Technical data of the lighting devices used to modernize the lighting of the Hall No. 277 are presented in the Table.

International Lighting Engineering Corporation BL GROUP appreciates the cooperation and assistance of the State Hermitage Museum staff, who contributed to the installation works on lighting the hall No. 277 in a short time.

Margarita P. Belyakova,
engineer, graduated from the Moscow Power Engineering Institute with a degree in Lighting and Light Sources in the1976. At present, she is a Chief specialist in lighting solutions of SvetoProekt, LLC and member of the Russian Designers Association. Her professional interests are design of architectural and landscape illumination, internal electric lighting of public facilities, lighting of museums and exposition lighting

Light & Engineering
Vol. 27, No. 4, pp. 93–100, 2019
https://doi.org/10.33383/2018-156

MUSEUM LIGHTING: APPROACH, EXAMPLE AND DIRECTION

Sergei V. Koynov and Dmitry M. Hodyrev[1]

International Light and Engineering Corporation "BL GROUP", Moscow
[1]E-mail: hodyrev@bl-trade.ru; hodyrev@bl-g.ru

ABSTRACT

The article reviews the lighting engineering problems in general to be resolved by lighting installations required for exhibition and museum lighting, as well as the ways to achieve the task while designing the lighting equipment (illustrated by an example of one of manufacturers). Also, as part of the analysis of approaches to resolving of these problems, the major ideas presented in "The Light in the Museum" conference held in St. Petersburg in April, 2018, are described.

Keywords: lighting, lantern, museum lighting, lighting fixture

1. INTRODUCTION

A museum is a place where pieces of culture, history and art are being stored and exhibited. A place where people come to see, to learn something new, something they cannot see every day. It's storage of human memory. People come to museums to understand the cultural and historical periods presented inside of it.

Exhibitions may stay in the visitors' recollection or they may go unnoticed. And it is caused not only by the quality of exhibited works but by the way they are being presented to the visitors. And the light is not the least critical factor here. In fact, it determines everything you see in the museum. Incorrect lighting may distort the colour balance of a piece of fine art. Each exhibit should be lighted individually immersing a visitor into a particular historical and cultural era, influencing a person's emotional perception. For estimation of the quality of museum lighting, it is necessary to take luminous exposure, luminous distribution in the spectator's field of vision into account [1].

Today, there are 3,062 museums in Russia. The total area of Russian museums is 485 thousand hectares. 4 million m^2 of them is the area of museum spaces [2]. Despite the number and significance of these institutions, there are a number of problems in lighting of museums.

Currently, the Government of the Russian Federation pays a great attention to modernisation of museums [3]. It resolves several problems at once. From the one hand, preservation of cultural heritage enriches the nation, promotes patriotic education and love towards homeland and its outstanding people and their art; from the other hand, it promotes development of tourism and redistribution of tourist traffic. It is an important task for the government since the tourism is a powerful driver of economic development and also promotes improvement of the country's prestige. The key for implementation of this task is elaboration of a statutory framework and correct approaches to solving of the existing problems.

The applicable Russian regulations in the field of museum lighting were worked out in the end of the previous century and are to a great extent experimental because the impact of light on materials had not been studied enough by the moment of their elaboration. The recommended light sources (LS) for lighting of exhibits are fluorescent lamps (FL) and incandescent lamps (IL) [4, 5]. For exhibits with medium and low light-resistance, limitations of ultraviolet (UV) and infrared (IR) radiation are to be provided. Therefore, application of

Fig. 1. Example of picture lighting at different values of T_{cc}

Fig. 2. Example of impact of R_a on the quality of picture lighting

FL's becomes limited since light-resistance of exhibits is determined by preservation of colour and physical properties of a material under exposure to LS radiation in the visible part of the spectrum, especially in UV and IR regions. The more intensity of these types of exposure is, the longer duration of exposure to them is, and the less the light-resistance of an exhibit is, the more destructive impact they cause. There are GOSTs [6, 7] regulating determination of resistance of various fabrics/materials against radiation of artificial LSs but all these methods are relevant only for gas discharge types of LSs. Introduction of new semiconductor LSs cause necessity of re-evaluation of these standards to make it possible to elaborate new state-of-the-art standards in the field of museum lighting. Application of ILs has already become inefficient nowadays. Moreover, in 2009, the Law "On Energy Saving and Improvement of Energy Efficiency and on Introduction of Amendments to Particular Legal Acts of the Russian Federation" was adopted. Its major provisions specify prohibition of manufacturing of ILs with capacity of 100W and more. Since the end of the previous century, there has been a great breakthrough in the lighting industry. New efficient LSs, which can resolve a number of problems of museum lighting, has appeared. That's why we have been evidencing a clear trend aiming at reviewing of standards of exhibition lighting in the world today [8]. Primarily, it's definitely the legalisation of application of light emitting diode (LED) LSs. Also, there is necessity of studies relating to positive impact of LED LSs on perception of exhibits and their preservation, which have been being made nowadays. Moreover, there are studies of the limits of possible increase of illumination level using LED LSs which do not impact preservation of materials of exhibits. The results of such studies should become a basis of the updated regulatory documents.

The museum lighting should be designed in accordance with requirements to preservation of exhibits, to comfortable perception, energy efficiency, appearance and usability of a lighting installation (LI).

The glares caused by natural and artificial LSs prevent examination of a picture or of an item inside a case and are one of the most frequent causes of the visitors' dissatisfaction [9]. As a matter of fact, to estimate which type of lighting is suitable for an exhibit, it's necessary to define its exposure limit which depends on chemical composition of paints and materials. There is a general belief that great pieces of art should be perceived in the same way as the author saw them, i.e. with the same lighting conditions as those existing at the moment of creation of the piece of art and available when the first spectators saw it. These conditions could include candles, a kerosene lamp, a campfire light, sunset light or an ordinary incandescent lamp. Of course, in a museum environment, we cannot use the same light source but, with help of modern technologies, we can select a similar one to the most possible extent. Resolving of this problem nowadays requires design of a new LI with chromaticity of radiation selected so that it is similar to the environment in which a painter was creating his work.

Application of LED LSs allows creating and using almost any spectrum of radiation, which allows us to increase aesthetic perception of pieces of art and to improve environment for this perception, which attracts additional visitors to the museum.

Possibility to adjust correlated colour temperature (T_{cc}) of a lighting device (LD) or a group of de-

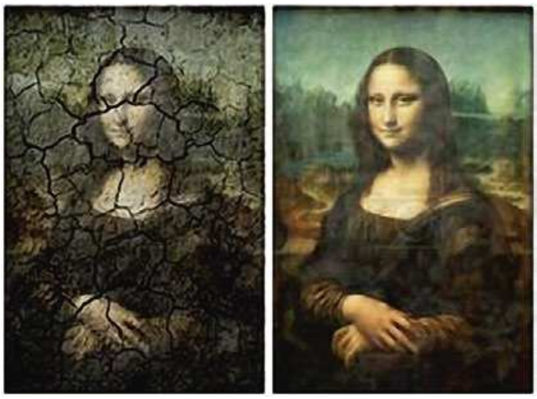


Fig. 3. Example of picture deterioration under impact of UV and IR radiation: left – impact of IR radiation (cracking), right – impact of UV radiation (discolouration)

Fig. 4. *GALAD Aphrodite LED*

vices allows selecting a correct type of tint for each exhibit: warm, neutral or cold (Fig. 1).

And a high value of the colour rendering index (R_a) of at least 95 will allow a visitor to see real colours of a piece of art (Fig. 2).

Wrong selection of the LS may case increase of the speed of degradation of a number of museum exhibits [10]. In particular, UV and IR radiation cause degrading impact on many polymers, fabrics, paper and paintings (Fig. 3). LED LS, with its unique features, is a great option for museum lighting [11]. LED luminaires allow more flexible and delicate management of chromaticity and value of UV radiation, the quantity and direction of heat dissipation from LSs.

One of advantages of LED LSs is high degree of energy saving and low power consumption (PC). Long service life of LED allows us to reduce the scope of electrical installation works for replacing of LSs after their breakdown. If we calculate annual PC of one light source using a gas discharge LS with capacity of 75W and a LED LS with capacity of 20W, both with equal values of luminous flux

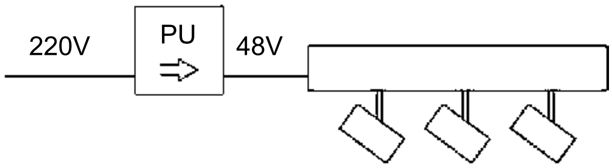


Fig. 5. Example of connection of a group of *Aphrodite LED* luminaires to one power unit

(Φ_v), we'll see that after switching to LED, it will decrease by about 4 times. If we speak about museums where great numbers of LDs are used, such energy saving will turn out to be very sufficient. Therefore, application of LED LSs in LIs under design is preferred rather than traditional LSs [10].

Modern LDs and devices for museum lighting should also comply with architecture and design of premises. In the course of modernisation of LDs, it's necessary to take their own design and usability in account among others. Portability, appearance, economic feasibility, simplicity and usability are important criteria when selecting a LD.

The International Lighting Engineering Corporation BL GROUP has a long-term experience in design of LI for museums. As the specialists of the corporation designed lighting for a number of museums (including the Pushkin State Museum of Fine Arts) using own ideas but foreign equipment in 90's, now we have made the next step forward and have developed a product line of luminaires for museum lighting. In the case of one of them described below, it's clear how many nuances should be considered by a developer when selecting suitable equipment.

2. GALAD APHRODITE LED LUMINAIRE FOR MUSEUMS

Special design, additional modules and options, adjustable parameters allow using of these luminaires for lighting of any exhibitions and to maintain a unified design and management of LI in all halls (Fig. 4).

The museum may have both temporary and permanent exhibitions, and the space of halls may be rearranged. That's why it is necessary to use track luminaires installed on bus ducts. This makes it possible to move the luminaires along the exhibition to form accent lighting correctly. The luminaires may be also fixed to ceilings.

Operating voltage of a bus duct is 48V. It is safe and allows us to install a separate power unit for

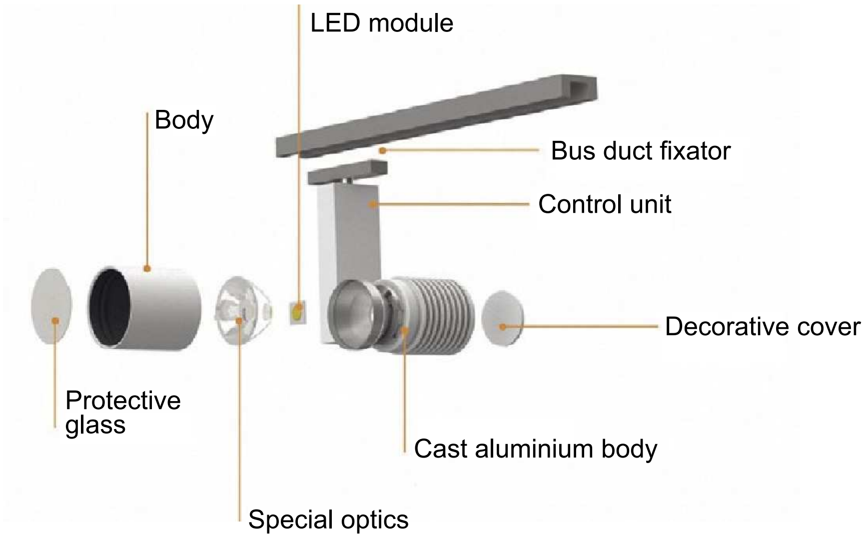


Fig. 6. Structural diagram of the *Aphrodite LED* luminaire

a group of luminaires and avoid application of an *AC/DC*220V power unit for each device, which significantly reduces the size and dimensions of a LI. The weight of one luminaire itself does not exceed 1.6 kg. The power unit of *Aphrodite LED* provides minimal flicker index of less than 1 % and power factor of at least 0.9. There is a capability to connect a group of LDs (Fig. 5).

In Fig. 6, the structure of the *GALAD Aphrodite LED* luminaire is presented:

- The cast aluminium body acts as a radiator for maintenance of an optimal heat mode of the LED operation, and it can rotate 355°×90°, which allows us to direct the LS at different angles and to the opposite side;
- The body of the luminaire may be painted by any colour, which allows us to integrate it into an interior of any exhibition space to make it barely noticeable;
- The LED module by *CREE* with special spectral specifications and high light quality, because there are 5 adjustable LEDs of various colours, which provide to adjust T_{cc} within the range of (3,000–4,000) K, and adjustment of T_{cc} causes no impact to R_a, which remains high, at least 95;
- Special optics (14°, 42° and 52°) does not lead to the colouring of the edges of the illuminated objects (dispersion), and different optics allow us to resolve various tasks of exhibits lighting, floodlight or accent light;
- The protective glass allows us to install filters, which is necessary for protection of exhibits from destructive IR and UV radiation;
- The luminaire has *IP20* protection degree, which maintains protection from hard particles with size more than 12 mm;
- The control unit provides management of the luminaires via the *DMX512* protocol (with support of *RDM* protocol and capability of feedback link), which allows us to assign an original number to each luminaire and control it from the beginning, i.e to monitor its service period, temperature of LED, current, voltage, degrading of a crystal and the most important parameter – the dose in lx hours. All data is saved in a computer and is visible for the maintenance services of a museum.

The special options available for each *GALAD Aphrodite LED* luminaire are presented in Fig. 7.

All options allow us to adjust the size and the shape of a light beam, which provides ability to select the most optimal arrangement of the luminaires so, that they will be almost unnoticeable for visitors and wherein:

- **The lens shade** provides the required angle of shade preventing glare effect;
- **The case** concentrates the light beam, prevents direct lights to the visitors' eyes and improves visual perception;
- **The lens** forms the light beam with required size and clarity;
- **The picture frame** forms the trapezoidal shape of a light spot in order to light the pictures in strict accordance with their contours.

It is significant that all *GALAD* luminaires for museum lighting (Fig. 8) are manufactured in Russia of Russian parts.

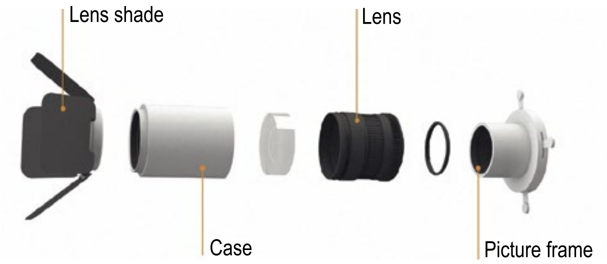


Fig. 7. Additional accessories of the *Aphrodite LED* luminaire

3. PROJECTS ON BASIS OF *GALAD* LUMINAIRES

Nowadays, there have been a number of significant projects implemented using the Russian *GALAD* luminaires, and one of them is rearrangement of lighting in the hall No. 277 of the State Hermitage in the beginning of 2018 [1].

Paintings are being exhibited in the hall No. 277. Each painting is unique there, and to select correct lighting, each specific case should be considered individually. But there are some, always to be adhered to, rules:

- At first, the optimal place of examination is being selected, i.e. the point where the visitors will be standing more frequently while examining a painting, because it's much important that the light from a lighting the painting luminaire does not fall on surrounding paintings and does not interfere in examination of them, so for this purpose, the lens shades or special optics are often used (Fig. 9);
- The materials the painting is made of (wood/canvas/paper) and the paints used for it (oil/water-colour/pastel) are significant factors influencing lighting of a picture, for instance, the oil paintings have increased volume due to brush strokes, and if the lighting is arranged incorrectly, the brush strokes form shades interfering in the author's vision;
- Glazed surface of a picture may create overtones and reflections, that's why the light often falls on a picture at acute angle, which allows the overtones to move under a spectator's feet; the angle of incidence of direct light at flat exhibits placed on walls or stands are selected in the range between 45° and 75° to horizon, but in case of angles exceeding 75°, there are shadows of frames on exhibits, textures distorting them; at angles less than 45°, the overtones on exhibits with glazing surface may cause dazzling effect;
- For each painting a specific standard exhibition duration is specified, which is the time period during which the light can fall on it, excess light may cause quick deterioration;
- An annual dose is specified for each picture, which provides relatively acceptable degree of its deterioration;
- In case of permanent exhibitions, the uniform illumination is usually applied in order not to form large contrast with the background and not to interfere in art perception; too dark background decreases light comfort and too light background makes exhibits to be 'lost'; wherein exhibition space gives an opportunity to make experiments and to create bright and contrast accents;
- Maximum allowed illumination level is specified as well, for instance, for water-colours, paper and fabrics, it is 50 lx and for oil paintings, it does not exceed 150 lx [4].

Among distinctions of Hall No. 277, it is important to note the whitened arched ceiling used for formation of the overall illumination by means of reflected light. The previous LI was equipped with fluorescent lamps luminaires (FL). A study conducted by specialists of ILEC "BL GROUP" showed insufficient illumination level of both exhibition and paintings and the space itself, provided that sufficient illumination levels are still not standardised and are specified only in recommendation documents.

It was decided to implement the overall illumination by means of strip luminaires hidden behind the ceiling cornice. The number of luminaires was determined by lighting calculation so that, with consideration of the ceiling reflection, the overall illumination of the hall became compliant with regulatory requirements.

The *Aphrodite LED* luminaires were applied for lighting of the exhibits (Fig. 10). The task included minimal construction interference. In 4 areas approved by the management of the museum, the unique mount fittings designed with consideration of wall materials and the load weight were installed, then a cable was pulled and a bus duct was attached to it. The calculations of the mount fitting, cable material and tension had been made with consideration of allowed slackening and so that it could not affect the luminaires aiming system.

[1] The rearrangement of lighting in the hall No. 277 of the State Hermitage is comprehensively described in [12].

Fig. 8. Product line of *GALAD* luminaires for museum lighting

The type of optics was selected and aiming of the luminaires was performed by the specialists of BL GROUP with consideration of the dimensions of the exhibits, evenness of illumination distribution on the paintings (with gradient taken into account as well). The LED type was determined with consideration of paintings properties and necessity to provide high level of colour rendering.

The specialists of ILEC "BL GROUP" conducted estimation of the object, design, approval and mounting as soon as possible. Now the visitors of the State Hermitage can rate the renewed Hall No. 277.

4. RESULTS OF THE FIRST CONFERENCE OF LIGHT IN THE MUSEUM

The project described above and other similar projects are first stages of the serious modernisation of museum facilities to be performed in the coming years. Given the scale of the targets of the lighting industry, the community of specialists requires coordination of their actions and elaboration of new principles of work in this sphere which has nationwide scale.

That's why the first Light in the Museum conference took place in the State Hermitage in Saint Petersburg between the 18th and the 21st April, 2018. The conference was organised by the State Hermitage, the Scientific and technical Council of the Lighting Industry (NTS SVETOTEKHNIKA) and the Russian Lighting Research Institute named after S.I. Vavilov (VNISI) with support of the Russian Committee of the International Council of Museums (ICM of Russia) and the Union of Museums of Russia.

Representatives of the museum and light industry communities, Russian and foreign specialists in museum lighting presented their reports.

Fig. 9 Lighting options of painting lighting with *GALAD* luminaires

Fig. 10. Location and aiming of track luminaires for painting lighting

The agenda of the conference Light in the Museum was very busy, and the active discussions regarding current challenges in the museum lighting took place during all conference days.

The first and the most significant challenge is necessity of development of a standard specifying requirements to the museum lighting and methods of supervision of compliance with these requirements; it is also required to organise monitoring of parameters of the existing museum lighting LDs applied for lighting of museum entities and to conduct research of the state of museum lighting.

Much has been said that the museum lighting should not only be aesthetically acceptable but also energy saving. Some of the speakers shared their own experience in museum exhibits lighting speaking about challenges they had faced and methods used for their resolving.

After the end of the conference (April 20, 2018), the head of the Association of the Scientific and technical Council of the Lighting Industry (NTS SVETOTEKHNIKA) G.V. Boos and the director of the State Hermitage M.B. Piotrovsky signed the Memorandum of Scientific and Technical Cooperation in the Field of the Museum Lighting in the Council Hall of the State Hermitage.

As part of the conference, the Illumination Equipment for Museum Lighting roundtable of the Light Industry Trading Association (STA) chaired by the Vice-President of STA S.V. Koynov and the president of Lighting Business Consulting V.G. Gabrielyan took place. The question of museum lighting was examined from several practical points of view during the roundtable. A.V. Isaev, the Chief Energy Engineer of the State Hermitage, described the principles and approaches the museum adheres to when creating its own lighting systems. Some reports by representatives of equipment manufacturing companies, e.g. *Philips*, *iGuzzini*, were devoted to specific devices and their advantages. The president of the *Tochka Opory Company* S.N. Kolomiytsev, from the other hand, accentuated individual approaches to design of exhibition lighting and non-standard solutions. The representative of *Erco* company M.A. Berzin spoke not about luminaires but about the types of track systems for their installation. And the marketing director of Trion LED, LLC, T.M. Trishina reported about criteria and tools for illumination evaluation in museums. The representative of ILEC "BL GROUP" examined the question of museum lighting as a whole: not just the exhibition but the surrounding territory, offices, storage rooms… This subject was even more detailed in relation to linked sectors by the Director General of Lighting Business Consulting S.V. Borovkov. His report was called "The Modern Museum as a Factor of Urbanistic, Economic and Social Development".

The main objectives of cooperation are involvement of professionals in lighting of museum resources and preservation of cultural objects as well as carrying out of studies of impact of artificial light on museum exhibits, elaboration of legal framework, quality and safety control of museum lighting equipment and introduction of high-performance light sources for lighting of exhibitions.

All participants of the conference perceive cooperation for achievement of the goals and resolving of existing problems as the main target.

G.V. Boos and M.B. Piotrovsky came to a conclusion the Light in the Museum conference will become traditional and will be conducted biyearly. There is an exhibition of lighting equipment for museum lighting planned alongside with the conference, during which the manufacturers may present their devices and tell about distinctions of their designs and demonstrate their application for different tasks of exhibit lighting. The next Light in the Museum conference is planned to be held in 2020.

REFERENCES

1. Shakhparunyantz, A.G., Rozovsky, E.I., Chernyak, A. Sh., Fedorishchev, P.A. LED in Museums: New Capabilities and Challenges // Svetotekhnika, 2018., Special issue Light in the Museum, pp. 36–39.

1. Shakhparunyantz, A.G., Rozovsky, E.I., Chernyak, A. Sh., Fedorishchev, P.A. Svetodiody v museyakh: novye vozmozhnosti i problemy / Svetotekhnika, 2018, Spetsvypusk Svet v museye pp. 36–39.

2. Data by LightBusinessConsulting, LLC (private message).

3. The State Programme of the Russian Federation 'Development of Culture and Tourism in 2013–2020' [Electronic Source] URL: https://www.russiatourism.ru/content/2/section/27/detail/27/.

4. Recommendations for Design of Artificial Lighting in Museums, Galleries and Exhibition Halls. Moscow: F.B. Yakubosvsky VNIPI Tyazhpromelectroproekt, 1992, 91 pages.

4. Rekomendatcii po proektirovaniiu iskusstvennogo osveshcheniia museev, kartinnykh galerei i vystavochnykh zalov. M: F.B. Iakubosvskii VNIPI Tiazhpromelektroproekt, 1992, 91 pages.

5. Museum Design Recommendations. B.S. Mezentsev TsNIIEP. Moscow: Stroyizdat, 1988, 48 pages.

5. Rekomendatcii po proektirovaniiu museev. B.S. Mezentsev TsNIIEP. M: Stroyizdat, 1988, 48 pages.

6. GOST 9780–78 Bookbinding Material. Light-Resistance Determination Methodology.

6. GOST 9780–78 Material pereplotnyy. Metod opredeleniya svetostoykosti.

7. GOST 21903–76 Paints-and-Lacquers. Methods of Nominal Light-Resistance Determination.

7. GOST 21903–76 Materialy lako-krasochnyie. Metody opredeleniya uslovnoi svetostoikosti.

8. Lobatskaya E. About Luminaires for Museum // Light Design, 2005, No. 2 [Electronic Source] URL: http://www.artlight.ru/index.php/actionsvetilniknews/newsidsvetilnik49/.

8. Lobatskaia E. O svetilinikakh dlya museev // Light Design, 2005, No. 2 [Electronic Source] URL: http://www.artlight.ru/index.php/actionsvetilniknews/newsidsvetilnik49/.

9. Surikova, K. Light Design in a Museum: Major Mistakes [Electronic Source] // Berlogos online journal about design and architecture. URL: http://www.berlogos.ru/article/svetovoe-proektirovanie-v-muzee-osnovnye-oshibki/ (reference date: 21.06.2016).

9. Surikova, K. Svetovoie proektirovaniie v musee: osnovnyie oshibki [Electronic Source] // Internet zhurnal o disaine i arkhitekture Berlogos. URL: http://www.berlogos.ru/article/svetovoe-proektirovanie-v-muzee-osnovnye-oshibki/ (reference date: 21.06.2016).

10. Amrita Bhattcharjee and Saswati Mazumdar "A Study of the Suitability of LED Light Sources over Conventional Light Sources in a Museum Environment"// Light & Engineering, 2016, Vol.24, #1, pp.36–44.

11. Ya. Shanda, What is Colour Fidelity in Museum Lighting? // Light & Engineering, 2014, V.22, #4, pp.51–58.

12. Belyakova M.P. Modernisation of Lighting in the Hall No. 277 of the State Hermitage // Svetotekhnika, 2018, Special issue Light in the Museum, pp. 62–64.

12. Beliakova M.P. Raboty po modernizatcii osveshcheniia v zale # 277 Gosudarstvennogo Ermitazha // Svetotekhnika, 2018, Spetsvypusk Svet v muse, pp. 62–64.

Sergei V. Koynov, graduated from Novosibirsk State University of economic and management, manager by speciality. At present, he is the general director of trade policy of ILEC BL Group

Dmitry M. Hodyrev graduated from MPEI. A present, he is a Head of the Technical Support Department of ILEC BL Group

Light & Engineering
Vol. 27, No. 4, pp. 101–107, 2019 *https://doi.org/10.33383/2018-157*

ORGANIC LIGHT EMITTING DIODES – INNOVATIVE LIGHT SOURCES

Sergei A. Stakharny

Joint-Stock Company "TsNII "Tsiklon", Moscow
E-mail: stakharnys@ya.ru

ABSTRACT

This article is a review of the new light source – organic LEDs having prospects of application in general and special lighting systems. The article describes physical principles of operation of organic LEDs, their advantages and principal differences from conventional non-organic LEDs and other light sources. Also the article devoted to contemporary achievements and prospects of development of this field in the spheres of both general and museum lighting as well as other spheres where properties of organic LEDs as high-quality light sources may be extremely useful.

Keywords: organic light emitting diodes, OLED, light sources, colour rendering index, lighting

1. INTRODUCTION

Light emitting diodes (LED) have been being applied currently in lighting as a new light source gradually out-competing conventional light sources – different types of lamps. The organic LEDs (OLED) are a separate class of devices and the newest direction of development of solid state lighting (*SSL*). Though there are a limited number of commercial OLED panels in the market, lots of concepts and implemented projects illustrating capabilities of OLED are presented in open sources (Fig. 1).

They include lighting windows and ceilings including transparent ones, luminaires with different forms and configurations, luminaires based on flexible OLED panels. Currently, some qualitative characteristics of organic LEDs lag behind those of non-organic LEDs, for instance, luminous efficacy and service life, but the main constraining factor of their spread is their high cost. Nevertheless, gradual improvement of characteristics of OLED structures and start of their mass production, hence reduction of unit cost (*$*/lm) of these light sources alongside with their unique properties will lead to their wide spread.

2. PHYSICAL PRINCIPLES OF OPERATION AND DISTINCTIONS OF OLED

Both non-organic and organic LEDs belong to electroluminescent light sources which generate light inside the structure as a result of radiation recombination of carriers (electrons and holes) injected from anode and cathode respectively. But there are principal differences between physical principles of operations of white-light organic and non-organic LEDs. In non-organic LEDs, white light is generated as a result of mixture of original radiation of a crystal in the blue region of spectrum (electroluminescence) and fluorescence of phosphor mixture covering the crystal in the wide green-yellow-red region of spectrum (Fig. 2a).

The dimensions of the LED crystal rarely exceed 1×1 mm, and the power of LED is about 2 W or more. An example of a LED in a body with dimensions of 3.5×3.5 mm is shown in Fig. 2b. Low dimensions and such high specific capacity categorises non-organic LEDs as point light sources with high luminance and application of secondary optics (Fig. 2c) allows us to obtain almost any curve

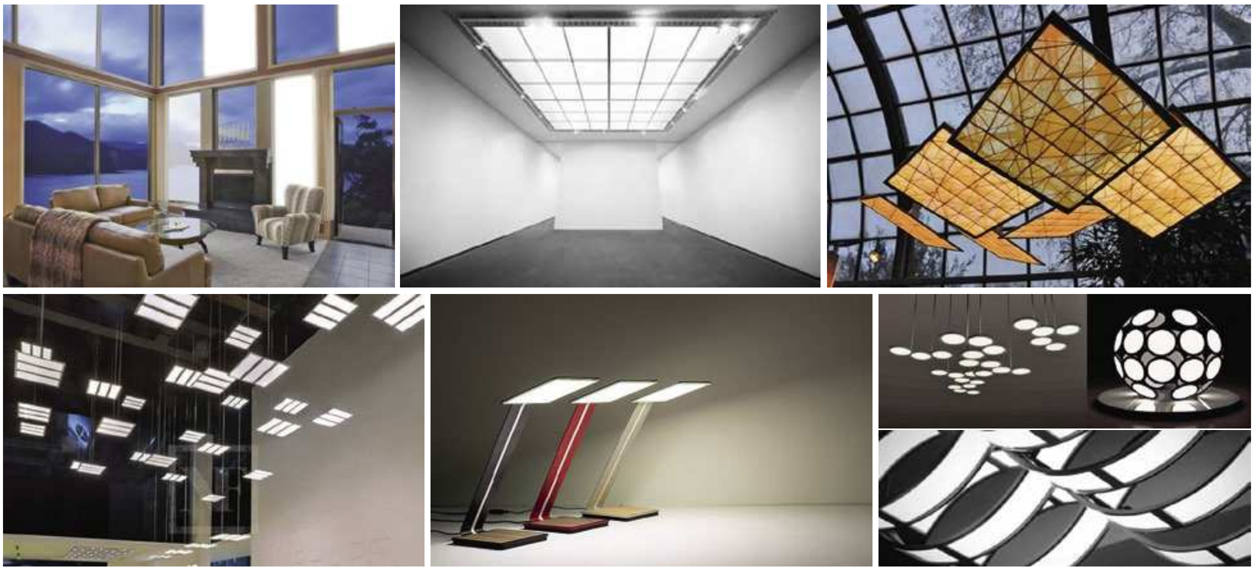


Fig. 1. Concepts and implemented projects based on OLED panels

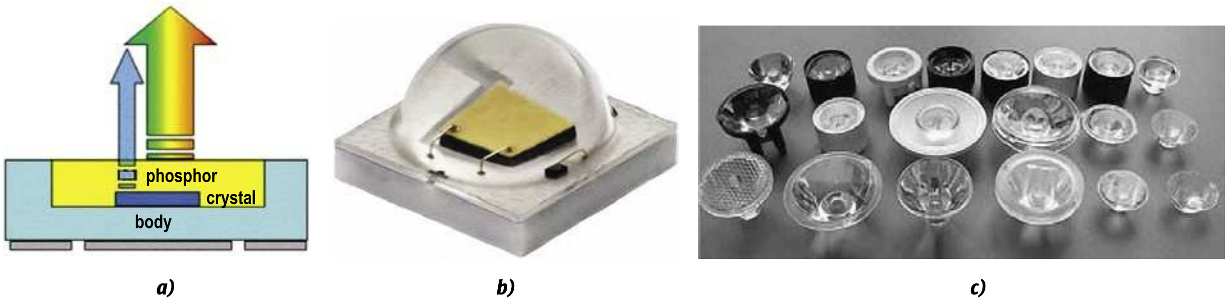


Fig. 2. Principal diagram of a white LED (a), example of a LED in a 3.5×3.5 mm body (b), secondary optics (c)

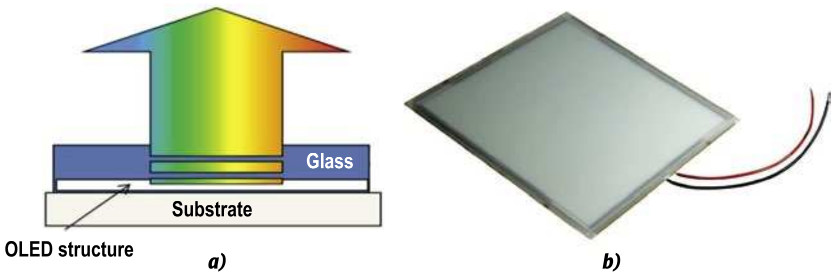


Fig. 3. Principal diagram of OLED (a), OLED panel by *LG Chemical* (b)

of luminous intensity. In order to obtain diffused light by luminaires based on non-organic LEDs, it is necessary to apply diffusers of different design and the body of the luminaire should provide efficient heat removing.

OLED is a thin-film multi-layer hetero-structure of organic semi-conductors mounted on a glass or non-transparent base (Fig. 3a). Radiation is uniformly distributed over the whole surface of the device and has almost ideal cosine curve of luminous intensity. For example, Fig. 3b shows an OLED panel by *LG Chemical* (Korea) with dimensions of 300×300 mm which is the distributed diffuse light source with thickness of just about 1 mm, which does not cause any glare effect. Heat is also distributed over the whole surface of the device and it does not require any additional constructive elements acting as a radiator. The most popular and technologically developed method of manufacturing of OLED is ultra-high vacuum thermal spraying method.

The structure of OLED contains up to 10 and more functional layers with thickness varying between 1 and 10 nm with total thickness of about

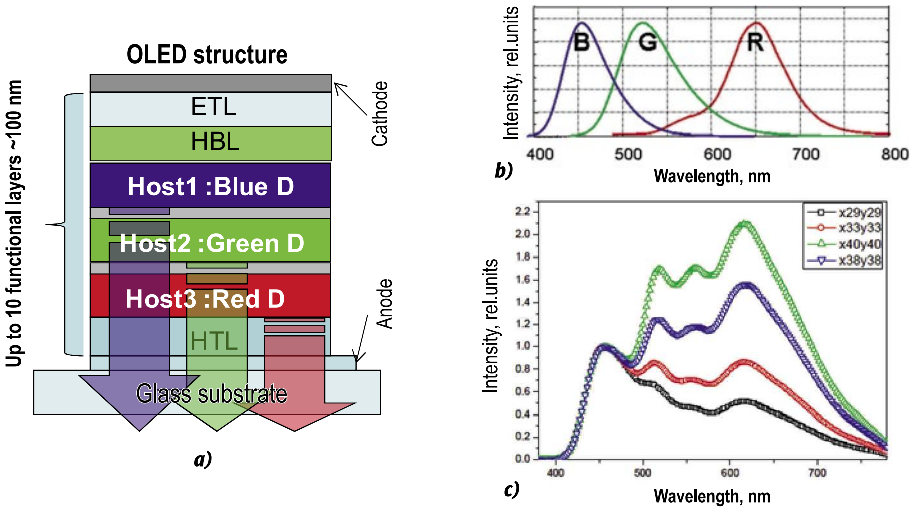


Fig. 4. Schematics of OLED structure (a), electroluminescence spectra of red, green and blue glow layers (b), electroluminescence spectra of white light OLED structure (c)

100 nm (Fig. 4a). The simplified structure of OLED contains a cathode and anode and an electronic transporting layer (*ETL*), a hole blocking layer (*HBL*), electroluminescent layers of matrix material and luminescent dopants with red, green and blue light (*Host* 1/2/3: *Red*/*Green*/*Blue D* respectively) and a hole transporting layer (*HTL*) located between them. Examples of electroluminescence spectra of red, green and blue light layers are shown in Fig. 4b. The half-breadth of spectral components is about 100 nm which is due to amorphous nature of organic semi-conductors, and the resulting spectrum of the white light structure with various colour coordinates, depending on the balance of components in the structure, is shown in Fig. 4c.

Therefore, OLED panels may have almost any colour or white light with different hues and corre-

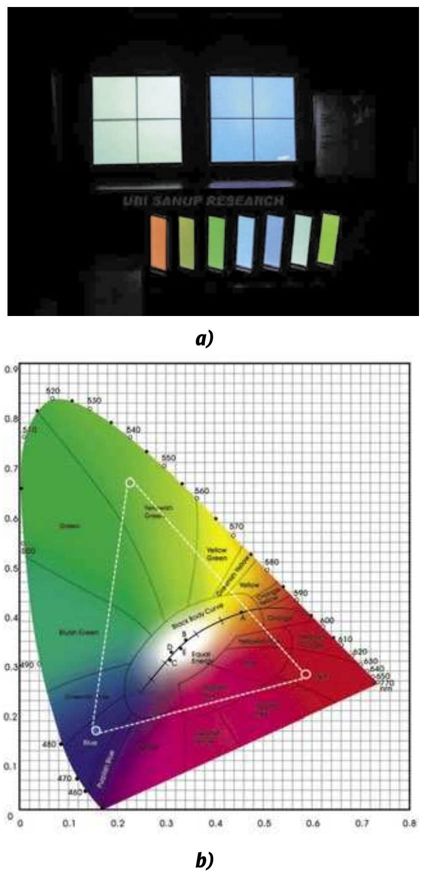


Fig. 5. Example of OLED panels with different hues of glow and shades of white (a) and colour space of CIE chromaticity coordinates *x*, *y*

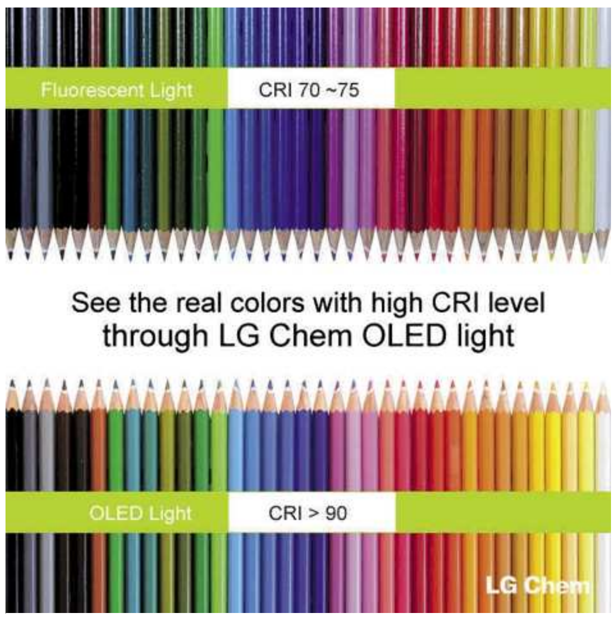


Fig. 6. Image from informational materials by *LG Chemical* as an example of colour rendering quality of OLED panels (above: lighting by means of a fluorescent lamp with colour rendering index of 70–75; below: OLED lighting with colour rendering index exceeding 90)

a) b) c)

Fig. 7. Application of diffused light sources: objective photo studio (a), art studio of Olga Gordon (b), *Ever BoutiqueMake-up* studio (New York) (c)

lated colour temperatures (Fig. 5a) with their chromaticity coordinates located within a triangle placed on the CIE colour space *x*, *y* chromaticity coordinates with its corners determined by spectra of red, green and blue colour of radiation.

3. QUANTITATIVE CHARACTERISTICS OF OLED AND THEIR CONTEMPORARY LEVEL

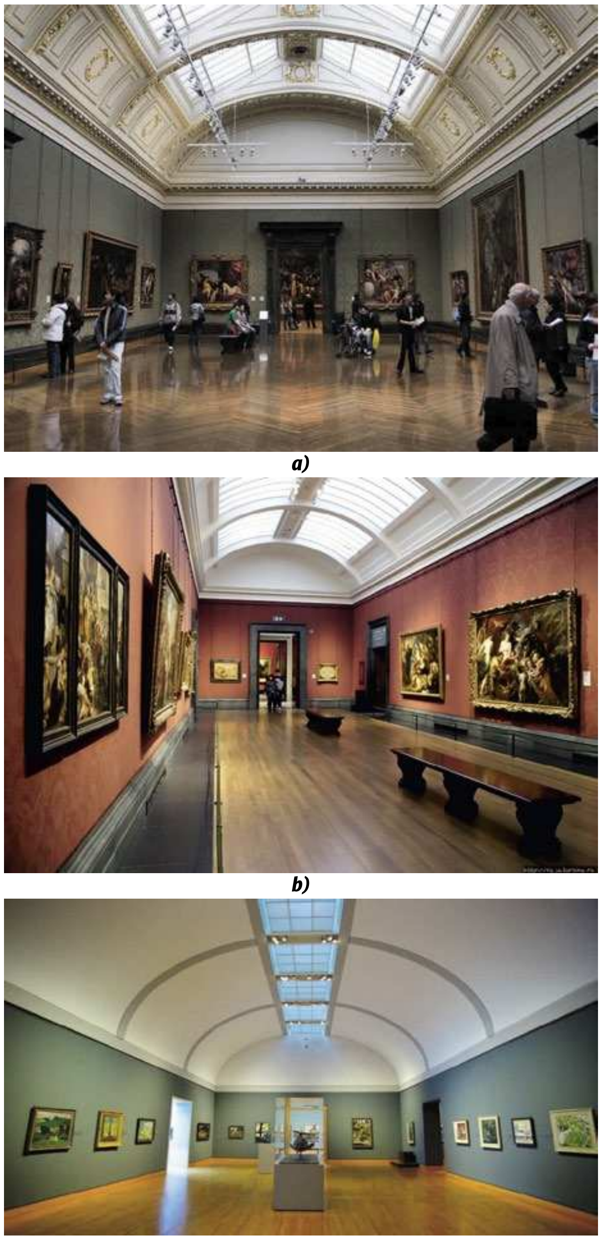
Displacement of points of major colours from the border of monochromatic colours inside the surface of spectral colours is determined by a rather large spectrum breadth of these components. In case of display applications, this feature may reduce colour gamut of a fully-coloured image and is compensated by application of *RGB* filters or more narrow-band irradiating materials and modes of their spraying.

In relation to lighting, the resulting spectra of white-light OLED structures have continuous spectral distribution without sharp peaks and crevasses and include almost the whole visible spectrum. Such spectral characteristic of OLED determines an extremely high quality of colour rendering of lighted objects irrespective of correlated colour temperature (Fig. 6).

As mentioned above, another important feature of OLEDs is their distributed nature with uniform diffuse glow all over the surface. This feature eliminates dazzling effect and lowers possibility of bright glares on smooth or reflective surfaces.

Such properties of OLED panels may be used in special systems of lighting, for instance, museum lighting and studio lighting where quality of colour rendering and lack of glares are extremely important (Fig. 7).

In museum lighting, the best result may be obtained in case of combination of point directed



a) b) c)

Fig. 8. Examples of combined museum lighting systems: National Gallery of Art in Washington, DC (a), The National Gallery of Great Britain (b), National Gallery of Canada (c)

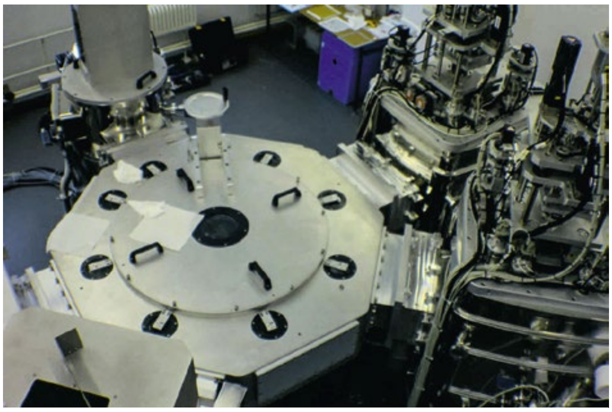


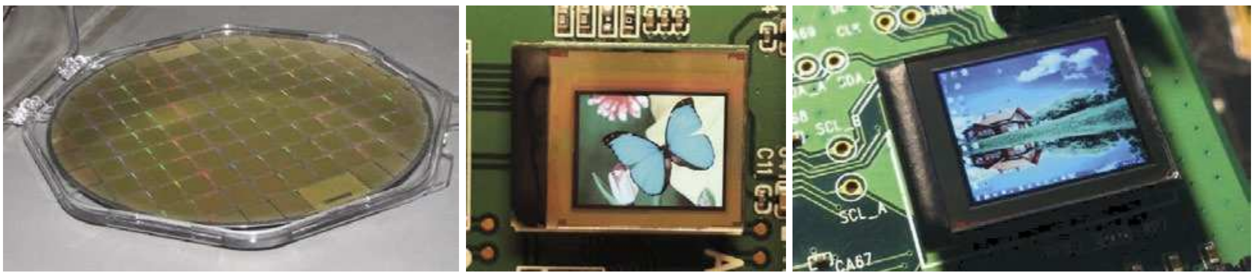
Fig.9. Vacuum cluster equipment for manufacturing of OLED devices (TsNIITsiklon, JSC/ TOPE, LLC)

lighting devices and distributed light sources. Natural lighting through glass roofs of buildings or its imitation with sources of artificial light hidden behind several layers of diffusing panels (Fig. 8) are traditionally used as a source of distributed light.

Luminous efficacy of organic LEDs is a little less than that of non-organic LEDs as it is illustrated in the Table.

The luminous efficacy of the best examples of commercial OLED panels is 65 lm/W which is significantly less than that of non-organic LEDs, for which luminous efficacy is about 180 lm/W and more. But luminous efficacy of multi-phosphor LEDs with high colour rendering indexes (~ 95) and correlated colour temperature of about 3000 K can be equal to just (80–100) lm/W. If it is necessary to create a light installation with uniform diffused glow, the losses on the diffuser system may be equal to more than 30 %, which makes the resulting luminous efficacy equal to that of OLED panels or even less. The luminous efficacy of laboratory samples of non-organic LEDs is already proximate to the theoretical maximum value and may exceed 250lm/W but with correlated colour temperature about 5000 K. According to information from reliable sources, the luminous efficacy of laboratory samples of OLED already exceeds 180 lm/W, which is equal to that of commercial non-organic LEDs. There is still a problem of relatively limited service life equal to 10,000 hours but it is being gradually solved by application of high-stability materials and enhancement of technology of encapculation of OLEDs which are extremely sensitive to atmospheric vapours of water and oxygen.

The main constraining factor of application of OLED panels is high cost of these devices, which is explained by non-availability of mass production of OLED panels in the world nowadays. At present, the world leading companies, such as *LG Chemical*, *Konica-Minolta*, *GE*, *Osram* and *Philips,* have been maintaining only small-batch production and their products are applied mainly in image-building pilot projects. Such situation is caused by necessity to develop a new type of expensive vacuum equipment adjusted for special aspects of production of OLED panels and allowing them to operate with bigger dimensions of substrates. Relatively rapid development of LED technology is caused by the fact that the technology of manufacturing of crystals is close to the technology of manufacturing of silicon microchips, where all technological equipment and processes have been worked out well. Nevertheless, the OLED technology has become widely applied for displays, gradually out-competing LCD screens. Nowadays, all flagship models of smartphones by leading manufacturers such as *Samsung* and *Apple* are equipped with OLED screens and full transition of the product line to this type of screens had been announced. There had been a similar situation with non-organic LEDs in the end of the 2000s when sharp increase of demand, increase of production volumes, and reduction of costs were connected with application of LEDs for backlighting of LCD screens. Therefore, if we suppose that the



a) b) c)

Fig. 10. Silicon plate with diameter of 200 mm with OLED micro panels (a), OLED micro display 02 PTs, 600×800 pixels, screen size 15 mm (b), mock-up specimen of an OLED micro display, 1,280×1,024 pixels, screen size 20 mm (c)

Table. Comparison of Development Levels of LED and OLED Technologies (2016)

Parameter	LED	OLED
Luminous efficacy, commercial products	180 lm/W (T_{cc} = 5,000 K, CRI = 70)	65 lm/W (T_{cc} = 4,000 K)
	100 lm/W (T_{cc} = 3,000 K, CRI = 95)	60 lm/W (T_{cc} = 3,000 K)
Luminous efficacy, laboratory samples	>250 lm/W (T_{cc} = 5,000 K)	>180 lm/W (T_{cc} – no data)
Service life	> 50,000 hours	10,000 hours
Cost	Low (mass production)	High (no mass production)
Process	Similar to *Si* technology	Special equipment

Note: T_{cc} is correlated colour temperature, CRI is CIE general colour rendering index

technology will be transferred to the lighting from display applications in a similar way OLED panels will be able to keep stable positions in the lighting equipment market in 10 years. U.S. Department of Energy and leading analysts forecast that the market of light sources and lighting devices, which takes a significant part of the global lighting engineering products with its estimated cost of €100 billion (by 2020), will be shared by LED and OLED devices in relation 60/40 by 2025. These suggestions are confirmed by increase of investments in OLED technology. For instance, *Konica-Minolta* (Japan) will invest ¥10 billion (*$*83 million) in an OLED panel plant with production capacity of 1 million 30×50 mm panels per year and forecasted revenue ¥50 billion already in 2020. *Merk* (Germany) invests €30 million in a plant for synthesis of organic materials for OLED with area of 2000 m^2, which will make it a very large facility in the field of high-purity materials production.

The only facility in the Russian Federation possessing a commercial-level OLED technology is JSC "TsNII "Tsiklon" (part of the Roselektronika Holding) and its subsidiary company OOO TOPE, which possess a high-vacuum cluster equipment for production of OLED devices as part of a closed automatic cycle (Fig. 9).

The facility started serial production of active matrix OLED micro-displays on 200 mm silicon bases with resolution of 800×600 pixels and screen size of 15 mm in monochrome white and full-coloured designs. The size of a pixel cell of this device containing three sub-pixels with major colours (blue, green and red) is 15×15 µm.

It is planned to finish development of OLED micro-displays with resolution of 1280×1024 pixels and screen size of 20 mm (Fig. 10) by 2019.

These products are used for ocular and binocular individual display devices, for instance, for virtual and augmented reality helmets (*VR/AR systems*) which have been gaining popularity recently. JSC "TsNII "Tsiklon" started developing OLED-based devices in the middle of 2000s and first laboratory samples of OLED panels on 40×60 mm bases were produced in 2007 (Fig. 11).

The luminous efficacy of white light laboratory samples was equal to about 30 lm/W at that time which is close to the global achievements of that period. Maximum luminance of OLED micro-displays of ocular devices is (50–100) cd/m^2 control

Fig. 11. Laboratory samples of OLED panels manufactured by TsNII Tsiklon, JSC

currents, moreover, the control current of the sub--pixels of the microdisplay matrix are only a few nanoamperes for an OLED structures with a similar level of luminous efficacy.

The lesser sub-pixel control currents are poorly controlled, especially in dark regions of gray gradations, so sufficiently larger values of luminous efficacy are not required for these devices. For projection-type information reproduction systems with OLED screen of a micro-display projected on a sufficiently larger area, a higher illuminance value may be required, therefore, a higher luminous efficacy will be needed for the purpose of energy saving. TsNII Tsiklon, JSC, keeps working for enhancement of parameters of OLED structures for micro-displays including luminous efficacy.

This experience may be used for development of OLED panels for general and special lighting including exhibition and museum lighting. The advantages of OLED panels may be critical for a number of other premises where more qualitative (from physiological point of view) light is required, for example, for premises intended for long presence of human without natural light (polar night in Arctic and Antarctic regions) and for pre-school institutions and prenatal centres where child's sight is not formed completely yet. For mass application in the field of household lighting where "quality" of light is also important, reduction of costs is necessary too what is possible only with mass production of OLED panels.

Design and development works in JSC TsNII Tsiklon, are performed with financial support of the Ministry of Industry and Trade of the Russian Federation.

The article uses materials from the research and development reports of TsNII Tsiklon, JSC, informational materials and messages by *LG Chemical*, *Konica-Minolta*, *GE*, *Osram*, *Philips*, *Merk*, *UBI*, *Digitimes*, *OLEDInfo* as well as other analytical materials and images from opens sources in the *Internet*.

Sergei A. Stakharny
graduated from Lomonosov Moscow State University, Department of Physics in 2002. At present, he is a Deputy Head of a Department, Deputy Chief Engineer for visualisation means of JSC "TsNII "Tsiklon". S.A. Stakhany is an author of a number of articles in the field of organic electronics including those in leading foreign journals, participant of Russian and foreign scientific conferences including the role of a guest speaker, member of the Svetotekhnika Scientific and Research Council. His Research Interests are OLED-based devices (indicators, active-matrix micro-displays, sensors, and field transistors), measurement of characteristics of OLED devices

Light & Engineering
Vol. 27, No. 4, pp. 108–00, 2019
https://doi.org/10.33383/2018-158

LIGHT DRAMATURGY AS AN ELEMENT OF AN INTEGRATED APPROACH TO THE CREATION OF MUSEUM EXPOSITIONS AND EXHIBITION PROJECTS

Nicolay R. Vorobyov

Neo EXPO-Art, LLC, Moscow
E-mail: nicholasvorobyov@gmail.com

ABSTRACT

Architectural and artistic construction of museum is one of the most complex genres in environment development and design, with its inherent qualities, means of expressiveness, principles of environment and image development, scientific concepts, in the context of historical development, artistic styles and trends. The author of the article considers the artistic lighting design in isolation from the integral dramaturgy of the project to be deeply flawed, and the setting of accent lighting at the final stage – to be simple, but not outstanding. Based on extensive hands-on experience in the construction of museum expositions, the author of the article reveals some peculiarities, especially significant to the participants of the lighting system setting for museums and other cultural facilities.

Keywords: integrated approach, design, dramaturgy, light setting

The sun changes its colour and position infinitely, but we can't control it. The painting technique of depicting items in natural light and conditions, familiar to all artists as "plein air", literally "open air", always gives a breath of inspiration, a freedom of thought, a sense of harmony. This term is also used to refer to the true reflection of the colourful richness of nature, all colour changes in natural conditions, with the active role of light and air. And the "open air" is nothing but the LIGHT with its endless transformations. Each artistic project becomes for us a kind of "plein air", which feeding the imagination gives some clues, helps to develop the future composition. Each lighting solution has its own style, "material", shape. Architectural lighting, landscape lighting are similar to monumental art, light "sculpture"; artistic accent lighting is like the painting; the light of lanterns on the city streets is much like a clear expression of graphics. Setting accent lighting at the exhibition requires special knowledge, skills and experience, as there are many specific features that lighting designers should bear in mind.

Each accent lighting project should not consist only of a "mandatory technical part" for us. The main thing is immersion in creative thinking, leading to a special vision of IDEA.

Technical and creative approaches are the components of complexity, ensuring the fusion of artificial light with art, integrating them.

And if for the artist, an artistic means is a tool of creation, then for the lighting designer these tools are a variety of lamps, light sources, as well as a great desire to find and emphasize the invisible, on the first glance, nuances and enhance the perception, achieving the admiration of the viewers. The immense possibilities of LIGHT, the subduing of its inexhaustible power and the directing of its fluxes to the purposes of the art make the transformation of any space viable.

We are well aware that no artificial light source can be compared to the Sun. But it can teach us a lot. The lighting is one of the most difficult tasks for designers. Remember, the light is not to be seen, the light is colossally theatrical and dramatic! Artistic construction of the light balance with all light sources, all multimedia elements, all reflections from the items present in the field of view, deliberate creation of bright and dimmed dominants – this everything, in my opinion, is the light dramaturgy, and it is the key aspect influencing the integrity, the emotionality, and the relevance of the project.

It is obvious that by the time of this article publication, the number of questions will grow and the answers to them will be different, but the situations presented below will allow us to look at the habitual in a slightly different way.

I draw attention to the fact that I am not a theorist, but a practitioner. I have worked for 18 years in the State Tretyakov Gallery, 7 years – in TRINOVA, 2 years – in TOCHKA OPORY. Taken altogether, 20 years of development, not without emotional explosions in standing the own ground, led to recognition by the best exhibition designers, the directors of museums, galleries, exhibition centres, private cultural institutions and top officials of ministries and departments.

The understanding of the museum environment, the ability to communicate in the language of art and literature, and the experience of discoveries led to the inclusion in the project as co-author and the team movement to achieve the goal.

A person who claims to be a performer of museum conceptions needs to be an art critic, a curator, an architect, a designer, and an economist (it should be born in mind how difficult to gain funding when "There is no money for anything!"). One should be an expert in the exhibited items, and also participate in the exhibition arrangement, in the discussion of colour layouts, in the choice of architectural forms and textures, and much more.

To create the light dramaturgy, as well as any other one, you need money. As an artist needs canvas, easel, stretcher, paints, brushes, so the lighting designer needs brushes, but light brushes, and they are not always cheap. You could limit yourself to theoretical reasoning, write about how good it would be if…, but that is not our way.

I will try to reveal a number of relationships in order to explain where it is necessary to begin. If you have already decided on the goal, made the necessary choice, there is a slight problem – where to take the money?! This is a topical question in all spheres of life.

To save is pointless, because the "pipe" will necessarily break somewhere, and the accumulated money will flow into it. So what? So – That! And the head of the cultural institution addresses for additional funding to the Department/Ministry, writes applications for sponsorship programs, forms targeted programs, etc.

So, here we go.

— What do they want in the Ministry of Culture? The Ministry of Culture strives to increase the role of the museum in our society. But due to lack of budget, it also calls the museums for being more self-reliant, which should lead to an increase in extra-budgetary revenues. Since entrance fees are one of the most significant ways in receiving the extra-budgetary revenues, an increase in the number of visitors is required. Attract, lure, smearing the front door with honey!

– What do museums want? The museums strive to promote the art, educate the target audience. To have enough funds for the implementation of the first three – five points specified at the beginning of the average Charter of the budgetary institution, it is necessary to properly expend the funds. At the same time, there is no other way but to minimize the cost of the purchase of this or that equipment, as a rule, technical one, including, the exhibition lighting equipment. Indeed, why buying some lamps, when "we have any already bought ten years ago".

– What do the visitors want? Some of them want nothing but to take a photo of yourself (selfie) in the museum space. How should we treat them? You can send them out or reprove a little, but you can preset the labels, landmarks on the floor with the arrow of the direction, and make special lighting zones for "photo selfie".

If the exhibition is thought out, attracts and fascinates, believe me, any visitor will come again and bring his friends. Starting with traditional photos on the background, those who have already visited will pull the newcomers to watch the most memorable moments. And yes, there is a giant world audience eager for new cultural discoveries. This audience is educated and picky. And chic exhibitions by the content will not remain without criticism, if made catch-as-catch-can.

Involving a huge audience in museums, galleries, exhibitions are our common way to increase the profitability of a budget institution. The lighting in this case is crucial. After all, it is guiding.

How do the light designers work now? What will the "lighting technician" is interested in? He will ask a customer for technical task on the lighting, which as usual is absent and not mentioned. Then he will be interested only in the budget, the distance to the exhibition surfaces, the height of the ceiling and a little more.

What will happen next? The bus bars, the luminaries are installed, everything is connected, checked. We're waiting. Oh, thanks the Gods, finally the paintings are hung, and, my God…

The tapered glass wall with graphic works appeared to us in all its glory and all the luminaries illuminating it are reflected on it, playfully blinding! Familiar situation, isn't it?

The only solution in this situation would be the remote installation of the lighting fixtures with narrow beams, and there was appropriate place, but who knew that it would happen…

After all, in the design project the area was clearly and laconically defined as "**paintings**" and that's all. Well, yes, there was an intermediate version with three paintings, but it was rejected for "somehow empty looking".

Thunder, lightning, ashes and excuses in this case could be any, but still resembled by famous Russian satirist Arkady Raikin: "Well, it really does not matter that the suit doesn't fit! Do you like the buttons? Yes! They're fine".

So, what is the museum lighting? As an expert, I can say: The museum lighting is the most sophisticated of all existing artificial ones. It can only be compared in emotionality with a theatrical light in static, climax scenes.

The museum lighting psycho-emotionally affects the public. It can cause delight, and create unconscious dislike. The dramaturgy of light can transmit the musical sounds.

Narrow oblique rays will convey Rachmaninov's spirit in the moments of writing the "2nd concert", and the weak light with small flashes of brightness will reflect Chopin's nocturnes.

At the location of the graphic works the flute and the piano will hardly be heard, and the location of the picturesque battle scenes is consonant with the light oboe and horn.

Technical education only is not enough to achieve this understanding.

The museum lighting should be of a certain intensity, desired shape and chromaticity or colour. Various light filters, lenses, gobo filters, screens, lens shades, masks can be used.

The museum lighting is to reveal the advantages and conceal the losses.

There is multifunctional lighting equipment ensuring the universality of application, but is far from being low-budget. Alas.

Ask if you can get decent visual results using conventional equipment?

I will answer unequivocally: Yes! But in achieving the goal one should have 100 % psychological training, self-efficacy and the ability to defend your decision at the highest level of reviewers.

Most of the works were created on the plein air, in natural light, but then no one thought about their preservation.

Time passed, and the creations of the great masters of the "first brush" level, turned into masterpieces, into works of art.

Today, all museums, both public and private, as well as the collectors, ask questions not only of exhibiting, but also of ensuring best conditions for the preservation.

There are two main compromise concepts that are beauty and preservation, the solution of which is in the spatial matrix of perception and appreciation.

Ah, these Standards, GOSTs, lux, after all… With the new generation of lighting equipment – the LED one, with parameters worthy of the Museum, the research has been resumed to amend the existing standards.

What illuminance level in lx is permitted?

As a lighting designer, I'd say: "Forget about the lx! Let it be as many as necessary for the beauty!", but as a person of the museum community, who is to protect objectively, I will answer that the standards of illumination are essential.

Standard lighting techniques and the regulations in force specify only the right direction, but do not provide ready-made answers to engineers or designers. Their task is to find the only unique way to transmit information about the exhibited item, whether it is a unique painting or a piece of modern technical thought. The situation is complicated by the fact that, in each case, many other factors have to be taken into account alongside the rules. For example, the architectural features of the room, its colour, texture of walls, height of ceilings, windows arrangement, are of great importance in creating optimal conditions for the perception of exhibited items, and if the room lets in the natural light, then – the daily and meteorological changes in the illumination of the exhibition space. The size of a work of art and its location relative to the windows and other exhibited items play a significant role, not to mention that it is impossible to adequately represent any work of art without deep insight into the author's conception. The ideal environment for each exhibited item inside the exhibition is always created by the efforts of a group of professionals, which includes lighting technicians, installation specialists, art critics and designers.

In the artistic lighting of the halls of museums, galleries, it is necessary to:

— Select the optimal colour rendering, which will emphasize the colour composition of exhibited works of art and mitigate the losses caused by the time;

— Create high-tech lighting for exhibitions of contemporary art or for exhibiting any other items (jewellery art, technology, etc.); arrange the accent lighting fixtures in such a way that, if possible, avoid shadows, glare, looms what is particularly difficult to achieve when the part of the exhibited items is behind the glass and the other is in deep massive frames;

— Another key aspect to consider in the museum lighting concerns the preservation of exhibited items, because Museum values, sometimes dating back to more than a hundred years, are extremely sensitive to ultraviolet radiation, which has a direct destructive effect, disintegrating the molecular bonds; the adverse impact has a so-called cumulative effect – the ability to accumulate, and this also applies to infrared radiation, which indirectly contributes to the aging of materials by accelerating chemical reactions through increasing temperature.

Therefore, one of the requirements for accent lighting fixtures located inside the hall to illuminate the works of art and other exhibited items is that their radiation should, if possible, be free of ultraviolet and infrared components.

The ideal conditions for exhibiting the works of fine art under the regulations still in force mean the room fully closed for natural light. In the buildings constructed specifically for museums, they adhere to this rule. However, the vast majority of depositories of world art masterpieces are historical buildings: Palace buildings, mansions and even railway stations, where this principle cannot be consistently maintained. Here it should be advised to close or curtain the light openings – to use the reflective film absorbing ultraviolet rays, although it will not give a full protection.

In determining the illuminance level, many museums use the devices, in the museum language called "luxmeters". What and how do we measure? Distance is up to the glass, if there is one. After all, you can't put a sensor under it. And non-reflective glass may be of 6 degrees, to add ordinary and "ultra view", that is, ultra transparent. And their thickness may be different. The light, passing through the glass, is partially reflected. And in oblique incidence, the light passes through a greater thickness and is even more quenched. It is important to know both the time of daily exhibiting and the time of rest (when the light is off). And the duration of the exhibition project should be kept in mind (permanent or temporary exhibition). It is the cumulative impact, not instantaneous, that should be taken into account. The light pulsations in the adjustable equipment should not exceed 5 % in the entire adjustable range, as they cause the fatigue of visitors and "curses" of correspondents trying to capture the movie-photo moments. When developing modern lighting standards, such aspects should be considered.

I want to share the joy because having gained the knowledge and experience, I had the opportunity to present, like Prometheus, an exquisite artistic light to everyone who needs it.

Great hands-on experience in all genres of exhibition concepts allowed to fully satisfy the ambitions, but I always wanted to achieve something more, comprehensive, integral.

And finally, I found it. And, in fact, returned to the museum world. In the team of the best architects, designers and exhibition constructors, who solve exhibition problems only in a complex manner, I learn to create something unprecedented, I teach and advise.

For a specialist free of fear or clichés, able to explain, inspire by an idea and bring it to realization, to make a thunderstorm cloud, which fills the exhibition with the artificial Sun rays, is no longer a problem.

I emphasize that only complex design, necessarily including lighting solutions, can meet the multitasking of the museum environment and its dramaturgy.

I will give a few hands-on examples, the emotional description of which will show everything exactly as it was, or shouldn't be, but it became.

• I recall that once, in one of the halls of the world-famous museum, I saw dirty thick black cables under the vaulted ceilings, and all in the dust of centuries. And under that wire bundle there was a nice little door of the Middle Ages, forged, with a cast iron hand-ring – exactly the subject of the project about the knights and their valour. And behind the door there were all sorts of utility and museum boxes from modern era. After five-minute persistent requests to remove this out of sight – they did so. Focusing a soft diffused light, I achieved an architectural fill of the corner, light shine of metal on the bindings. Then, yes, the director came and asked:

— Why did you, dear man, make an exhibited item of a non-exhibited one?

– Do you like it? – answered I in a poor manner.

– Very much! But why, tell me?

– Psychologically shifting the bright accents, I urged your brain to pay attention to what I need. And I need to keep all this stuff out of sight.

And I pointed upwards. Everyone looked upwards. A soft-voiced whoopee raised in the air: "Oh, Gosh…"

• Once at the exhibition, a part of the works provided by the museums of Great Britain, the upper threshold of luminance on the paintings was defined as 180 lx. I have two portraits of the 16th century – the king and his wife. The Queen i so slim, in a light dress, and the King – in the black caftan. There was no problem with the queen – shining, and as for the king, these 180 lx showed only the face and hands, and nothing else could be seen. I asked how and with whom it is possible to agree the illuminance level increase? They replied: You have to get it approved in the following order: Chief Custodian – Deputy Supervisor – Supervisor – Ministry of Culture – Embassy – Consulate of Great Britain – British Museum, and back. At least, two weeks. And the opening is tomorrow! In short, your humble servant preferred a different solution. I began to increase the brightness until the details of the king's clothing became visible. The tails appeared and even a red scarf became visible! I came nearer, measured the illuminance – 215 lx. I leave two luminaires – one adjusted to 180 lx, the other one to 215 lx and called the English custodians. Closing with the palm one luminaire, then another one, I show the difference. Naturally, they made a choice in favour of a brighter scenario! We come nearer to the painting, show the custodians the figures on the device. On the King – 215lx, on the Queen – 45lx! Why 45 and no more, you ask? Because it is at such proportions of visual light balance, they became a real married couple!

The British quickly have dialled some mobile number. One minute of conversation. And the approval was received. And in contractual documents in five minutes there were all necessary signatures of the two parties.

• From the Il'ya Glazunov's collection, the curator took two works of Roerich – painting and graphic. According to the composite decision, they were placed side by side, close to each other. The visual contrast is such that the light on the graphic work is not visible at all, and the maximum level has already been reached, and even slightly exceeded 75 lx (relative to 50 lx). All experiments led to the same – it's dark there, it's light here. But the solution was found: The high-power luminaire was focused on the painting with a slightly higher angle of light distribution than originally. In the centre of the light spot there was a painting, and the edge of the beam illuminated the graphic work. The mistake, in this case, was in a non-comprehensive approach to the exhibition design. As for the arrangement of museum pieces with low light resistance you can always make a kind of snug, some architectural form, to protect them from the bright space with a kind of "umbrella".

• Light marble floor or white ballet floor can be used as a mirror to illuminate the lower exhibition area.

• Stop criticizing the shadows of the frames! The audience is not interested in them. But ridding the item of glare through the oblique light would be necessary.

• Glass ceiling-high showcases will always reflect artificial light and space elements. Does the designer or the light engineer think about that? The answer is very rarely, and in reality only a few. The distance of built-in luminaires in such showcases cannot illuminate the lower exhibited items. It is necessary to provide additional external light at the design stage and explain why it is needed where it is already available. Besides, the exhibition should be made so that no exhibited item blocks the light to another.

• Is it possible to illuminate numismatics with spotlights? If you want to convey the delight of the treasures found during the excavations, then yes. The heap is shining, no details to see, and no need. If we talk about the detail, the historical value, it is possible to achieve visual details only through a matt floodlight. The distance from the light source to the exhibited item and the illumination are better to determine not in a calculated way, but by means of an experiment and necessarily with specific works of art or their analogues.

Precious stones and diamonds are in the counterbalance to metal exhibited items that do not stand the spot light. If you do not want to turn them into nondescript glass, you should set micro-spot lights, or focus external spotlights on them. Keep in mind such decisions are not made at the stage when the architect/designer thought about the lighting at the last moment, but at the very early stage when the content of the exhibition is being elaborated.

• And how to place a cameo next to a 17th century engraving? The Curator: "We will hang it in the showcase, on the wall." You can, but! The showcase is installed in the centre of the hall, the power supply is not connected, the beam from the external luminary is blocked by the upper opaque cap, and the allowable levels of illumination differ multi-fold. Again, a mistake in a non-comprehensive approach! Solution: it is possible to correct the situation using a framing (contour) luminary, which from the outside, with all its power will penetrate the body of the cameo without damaging the graphic artefact.

• Lighting of interior exhibitions. Very often, not wishing to come up with the new, the lighting designer uses traditional ways, using track lights, busbars, etc. Would we highlight the painting: this one, there that and the next one. But what about the rest? Gentlemen, remember: The interior exhibition does not imply the public access to the "Sancta Sanctorum". And if we cannot come nearer and scrutinize everything, then there is no need to increase the cost of the project, creating a fair over-lighting. Imagine, once the sunbeams, passing through the windows, illuminated the part of the interior, and the rest was illuminated by the backlight. Therefore, when designing, speaking about its complexity, focus a narrow beam on the table, under the table lamp, and highlight the largest exhibition items with other light brushes. And remember that illumination of giant paintings, from floor to ceiling, is very difficult, but the glare exclusion techniques in such cases is a particular challenge.

• Intelligence task: How to expose a huge, up to one and a half meters in length and 75 cm in diameter, polished to full gloss Easter egg lying on a red podium of 70 cm high? The issue of lighting mirrors and similar items is too exciting to reveal all the "military" secrets of the staged genre in this article. Calling for imagination, always ready for open meetings to exchange experiences.

• Almost every modern exhibition project has multimedia equipment. Even at the design stage, it is necessary to determine the zoning of the exhibition, semantic and title accents. The experience shows that at the stage of implementation the media equipment does not provide the saturation and brightness originally presented in references and visualizations. Since it is unacceptable to divide the project into "mine – not mine", all lighting equipment for exhibition a priori should have sufficient power with mandatory light regulation function. The border areas of exhibited items/multimedia should be thoroughly elaborated, as ambient light can destroy the plans of the curator and the media artist.

• I do not know why, but many people make mistakes, probably again by reason of the lack of a comprehensive approach to the construction of a uniform project dramaturgy. Once I took part in the anniversary project of *CHANEL* Trading House. The French project, as to the design is great, but the lighting, there were serious problems with the light. If analyzing, it will be a separate article. Let me give you just one example. Imagine, on a half-meter podium there is a two-and-a-half-meter cage, as for parrots, but the rods are encrusted with large pearls. Inside the cage there are mannequins in silk and diamonds. The French installed the illumination of the cage rods from the inside… Did you imagine?

"Sorry," I say, "but the pearls will never be transparent! In the backlight they will lose the sophistication, turning into cast iron balls!" "Oh, yes", they said bewildered, "and what should we do?"

Since the central accent was still the contents of that cage, I suggested building a light circle of low-power spotlights with a half-meter shift, from the outside. And, voila (!), here is a laconic solution! In addition, for full practical persuasion, always carry a flashlight with a variable beam angle! It is a light pointer and a universal luminaire without an electrical outlet, and your companion in a dark alley. When by the movement of the flashlight you show how the angles of the item change, how the shadows change the architectural images, how the beam of light, slipping on the eyes, changes the mood, immediately there is a complete mutual understanding. I call my flashlight "a light drama in my pocket."

• The task is the architectural illumination of a large pavilion, the walls of which are made of a wavy mirror, requires a giant piece of frozen blue jelly. Did you imagine it? One specialist without hesitation (not an artist – a craftsman of our light affairs), immediately offered subsurface lighting. Persuasion, appeals to common sense and threats did not yield the desired result. And all the experimental techniques were sent by plane to another city, by far away. They built a fragment of the wall, dug in the luminaires and turned them on… Please, doesn't laugh, but the replica of the responsible specialist struck down everyone: "It seems that something went wrong… Maybe improperly dug in?!… Don't worry, we will bring other luminaries, these are, probably, defective, the light in them is somewhat wrong!" The silent scene from "Auditor" play by Gogol was like that pause…

And it would be possible to surround the building with blue flags on flagpoles (territory and dramaturgy allowed) and illuminate them in the direction from the building. The surface would appear, reflecting the fluttering flag cloths, but wouldn't get a blue tint.

Therefore, your humble servant proposed to install along the perimeter of the building with an indentation of 4 meters and a step of 4 meters 6-meter poles (building height of about 20 meters) with slit vertical illumination of blue glow. Whether a man is walking, whether he is driving a car, whether he is sailing on a ship past the building – wave-shaped mirrors break the linear form of reflection of LEDs, and he can see exactly the iridescence that the architect has planned. And since the level of the man's view in any of the positions does not exceed the height of the position of the LED luminary on the support, the illumination of the proposed height and stylistics would become quite sufficient for achievement of a given drama.

Since the idea was mine and the head of the project was another person, everything ended with a "zealous" result – "nobody will get it"! The customer liked the idea very much, but… the builders installed on the four corners of the building 25-meter poles with industrial lamps. We wanted to do the best, but it turned out, as always.

• The designer with the curator, the art director and the producer of the project chose the colour of the floor covering. They chose purple, according to *RAL*, cursing each other for any shift on the scale, sitting in a cosy atmosphere, with a cup of coffee and cookies in the afternoon and by the window while the museum spaces are closed to natural light, and the museum luminaires are all, though chic, but with a correlated colour temperature 3,000K.

I'm not going to continue. The colour of the floor turned out chic, but different, sea-green, from the fairy tale of the Little Mermaid. I just suggested not to make such mistakes in the future, that is, I called the colleagues for using the complex approach.

• In one of the international exhibition projects, the director asked me: "Don't you think that Stradivari violins are lighted somewhat weakly?" – I say: "They are highlighted exactly as it should be. The line between "dark-light" is determined not by luxmeter, but by the eyes, through the mind and in the heart. When your skin crawls, then "stop" – it is the same." – Director, insisting: "Oh, let's set the brightness of the luminary at 100 %, and then we'll start to reduce it smoothly, and I'll tell you "stop"!" I answer: "All right, and I'll tell you stop. We agreed, right?"

The assistant regulating the light, with trembling hands, in pursuance of smoothness, began to reduce the illumination. Two opponents fastened their gaze upon the lacquer surface, longitudinally crossed out with four strings, silently, almost breathless, prepared for the classical director's "Stop! Cut!".

What was next? We said the word synchronously, and then we looked at each other with surprise. Then I added: "Here it is. It was the level set."

Let me add a few words about objectivity. What do you mean by that? May be it is an attempt to examine the same subject, fact, or phenomenon at different angles, preferably with a 360-degree rotation. The view from the outer space will not improve the situation, because in this scenario at least 180 degrees remain "behind". Installation of mirrors will only worsen the situation, because distortion is inevitable contrary to all the laws of physics, and not "in accordance", but just contrary. For the simple reason, that laws change over time. By the way, who can determine the time and prove its existence? Everything remains at the level of hypotheses, which with all the will in the world are impossible to be treated objectively.

Objectivity is just a concept that is used to reconcile multiple points of view and establish common rules.

These examples, without claiming exclusivity, are only part of the vast hands-on experience of the author of the article. I will be glad if for you they become fertile ground for nurturing individuality in approaches, boundless fantasies based on the foundation of knowledge, and aspirations to make our world beautiful and bright.

Nicolay R. Vorobyov, graduated from the Moscow Aviation Institute in 1984. At present, he is the Deputy Director General of Neo EXPO-Art Company, dramatic art lighting designer, leading expert in exhibition lighting of cultural facilities, and consultant of the Department of Culture of Moscow

CONTENTS

VOLUME 27 NUMBER 5 2019

LIGHT & ENGINEERING

(SVETOTEKHNIKA)

PARTNERS OF LIGHT & ENGINEERING JOURNAL

Editorial Board with big gratitude would like to inform international lighting community about the Journal Partners Institute establishment. The list with our partners and their Logo see below. The description of partner's collaboration you can found at journal site *www.sveto-tekhnika.ru*

BL Group
International Lighting Engineering Corporation
BOOS LIGHTING GROUP

ВНИСИ

REFLUX
HID Lighting systems

interlight RUSSIA | intelligent building RUSSIA