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RESEARCH AND DEVELOPMENT OF OUTDOOR LIGHTING SYSTEMS IN HOUSING AND COMMUNAL SERVICES

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Energy-saving technologies in shaping the lighting environment of residential neighborhoods are a priority area in the formation of measures and specialized subprograms for energy saving and increasing energy efficiency for the housing stock of the city of Vinnytsia.

Modernization of municipal lighting systems includes a set of measures and tasks related to the lighting improvement of buildings, as well as their adjacent territories, taking into account legislation in the field of energy conservation and rational use of consumed energy resources.

The goal is to create outdoor lighting for residential complexes and improve the quality of the lighting environment while using energy-saving technologies.

An analysis of housing and communal services facilities in the structure of a residential area was conducted for the current use of lighting equipment during daylight and darkness, and measurements of illumination were carried out on the territory of residential neighborhoods in Vinnytsia, a residential area with an approximate area of 50,000 m^2, located between Kosmonavtiv Avenue and 600-richchia Street were developed in the DIALux evo 13 program.

An analysis of the current lighting of the residential area was conducted, a number of problematic circumstances were identified that require consideration in terms of attracting energy-saving technologies, including ensuring high-quality and comfortable lighting. In the process, a general design project for the lighting of the object was presented in the lighting program DIALux evo 13 and lighting of individual parts of the object was created. LED lamps and spotlights were used as light sources.

The research conducted consists in considering the city's outdoor lighting as a complex of the main components of the human environment. The presented work is aimed at studying the issues of implementation and dissemination of energy-saving technologies in the sphere of housing and communal services.

Key words: *modernization of municipal lighting systems, energy-saving technologies, residential lighting, municipal infrastructure, DIALux evo, housing and communal services.*

Fig. 7. Table. 2. Ref. 10.

1. Problem formulation

The trend of transition to the creation of intelligent lighting systems (Lighting Smart Systems), which has emerged in recent years, is becoming mainstream. At the same time, it is becoming increasingly obvious that systems with intelligent control also require intelligent design (Smart Engineering), which, in turn, requires understanding the evolution of artificial lighting, analyzing the current state of systems and predicting directions for further development. This applies not only to the technical (and software) means of systems, but also, in fact, the required quality of lighting, dictated by the ever-growing needs, which are the driving forces for further development. It is also necessary to take into account that recently there has been a growing understanding of the limitations in the consumption of not only energy, but also other resources, and it is also necessary to take into account possible negative consequences for the environment.

There are a number of implemented projects of various kinds of intelligent energy-saving lighting systems that provide improved consumer characteristics. Of course, the developers of these projects are often carried away by the implementation of the next innovative concept and set themselves the task of comprehensive assessment and comparison with other promising projects. The generally accepted conceptual norm is to obtain an energy saving indicator of 25, 50 or even 80% compared to outdated lighting systems that are being replaced, and most often - physically worn out lighting networks.

Energy-saving technologies in the formation of the lighting environment of residential neighborhoods are a priority area in the formation of measures and specialized programs for energy saving and increasing energy efficiency for the housing stock of the city of Vinnytsia. Modernization of municipal lighting systems, which includes a set of measures and tasks related to the lighting improvement of buildings, as well as their adjacent territory, taking into account legislation in the field of energy saving and rational use of consumed energy resources.

2. Analysis of recent research and publications

Back in the middle of the 17th century, open spaces were lit mainly by torches, and on ceremonial occasions or during the visits of important people. The famous decree of the French king on the lighting of areas adjacent to houses with the help of lamps placed on the windowsills of private houses. Understanding the need to introduce evening street lighting to increase safety and increase the activity of the urban population of Paris led in 1667 to the issuance of a royal decree on the establishment of street lighting, for which (according to one version) Louis XIV received the nickname "the sun king". The first oil street lamps already provided a long burning time due to the large volume of the fuel tank. They were installed on poles and walls of houses in glazed cases, later called lanterns (from the Old Greek favos - "light and point"). These lamps gave little light, required daily maintenance and were not reliable and safe enough.

Maintaining oil-fired street lamps requires a large number of lamplighters who are responsible for lighting and extinguishing them, periodically cleaning and refueling them, and topping up with oil.

The introduction of alcohol-turpentine, and later kerosene street lighting somewhat improved its quality and reliability and reduced the laboriousness of maintenance, but there was still a long way to go before artificial street lighting could be compared to sunlight.

Further progress of combustion lamps is associated with an in-depth analysis of work. Understanding that in fact gas burns in all these lamps led to the conclusion that it is possible to separate the process of obtaining gas (which was called lighting) from the lamp itself. This concept led to the creation in the early 19th century of gas generation (pyrolysis) technologies from wood (Philippe Le Bon), coal (William Murdoch) and whale oil, as well as the technology of gas street lighting itself.

Street gas lighting first appeared in London in 1813, then in Paris in 1819, in Berlin in 1826, and a few years later in other European capitals. [1]

It is noteworthy that the world's largest wet gas tank with a capacity of over 400 thousand m^3 was built in New York, that is, exactly where T. Edison began implementing his electric lighting networks in the 1890s.

Very little time has passed by historical standards, and at the beginning of the 20th century. gas lighting began to be actively replaced by electric light from city streets. To this day, only in some cities in Europe have individual gas lighting networks been preserved as historical and cultural heritage. In Berlin, thanks to the activity of the public movement "Gaslight Culture" (Gaslicht-Kultur), more than 40 thousand gas lamps are in operation (Fig. 1 a) (mainly in parks and pedestrian zones), despite the fact that their operation costs the Berlin municipality almost four times more than electric ones. Of all the Berlin lamps, the first candidates for replacement and transfer to the museum are 4,500 gas lamps for street lighting with lines of four - six and nine-bulb caps (Fig. 1 b), which were installed back in the 1950. Such a replacement could reduce the municipality's gas and lighting maintenance costs by several million euros per year [2].


a


b

Fig. 1. Gas lamps: a) Berlin gas lantern b) Berlin gas street lamp [1]

In many countries, in areas without centralized electricity supply, both alcohol and kerosene lamps with incandescent grids have become widespread. And to this day, about 1 billion people use kerosene lamps in remote, unelectrified areas of Africa, Southeast Asia, and South America. Autonomous isobutane lamps with incandescent grids made of modern materials are used by tourists as camping lighting [3].

The first electric lighting networks to enter the fight against gas lighting systems were networks with P. N. Yablochkov's arc lamps. Having caused a sensation in 1876 at the London exhibition, they were able to be implemented in dozens of large projects in different cities, but they could not reach the level of mass application due to the fact that the short life of the lamps led to high operating costs. But electric lighting networks with incandescent lamps showed their advantage in operation, and this became obvious even before the appearance of long-lasting tungsten filaments and the creation of efficient three-phase power supply networks. Since then, the successes and failures of each innovative technology have been determined exclusively by integral economic criteria, as happened, for example, in the famous conflict associated with a breakthrough in the efficiency of power supply, which was called the "war of currents" [4].

In the early 19th century, experimental physicist Vasily Vladimirovich Petrov began researching artificial electric lighting. He was the first to obtain and study the glow of an electric arc between two carbon electrodes, feeding them from a unique electric battery he had created (the so-called voltaic pile) with a voltage of about 2 kV [5]. Later, the prominent English physicist Humphry Davy called this type of electric discharge a voltaic arc. [6].

However, since the main source of electricity for many decades was bulky primary and secondary chemical sources of direct current - electric batteries and accumulators, experiments with electric lighting practically did not go beyond the walls of laboratories.

Only the production of electromechanical current generators opened the way to the widespread use of electricity.

The first electric lighting system to replace the gas lighting that was dominant at the time was Thomas Edison's incandescent lamp system, a pilot project of which he was able to introduce in New York City in 1882. [7] . The distinctive features of Edison's project were:

- use of evacuated incandescent lamps with carbon filaments (carbonized bamboo);
- use of a patented bipolar constant voltage network;
- use of a number of patented components, including switches, screw lamp bases and holders, fuses, electricity meters, etc.;
- increasing the efficiency of DC generators [7].

The most important systemic innovation for electric lighting at the beginning of the 20th century was the transition to three-phase power supply networks, the main contribution to which belongs to M. O. Dolivo-Dobrovolsky [8]. The technology of three-phase networks made it possible, using transformer conversion, to transmit electricity over long distances with small losses, to abandon low-power and inefficient thermal power plants, to improve the environment and to reduce the cost of electricity due to its production at large hydro-thermal, and later at nuclear power plants.

Fluorescent lamps were widely used in street lighting in a number of countries. In our country, they did not go beyond a few pilot projects, since it is impossible to ensure their reliable ignition and high energy efficiency at negative temperatures. In addition, due to the large area of the luminous body and with supports located at great distances, they did not find application for uniform street lighting. In the language of lighting engineering, this means that obtaining a luminous intensity curve (LIC) of type W (wide) was quite difficult. In this regard, it would be possible not to dwell on them, if not for two circumstances. First, the luminescence effect was later widely used in even more efficient high-pressure mercury lamps, as well as in LEDs. Second, it was from fluorescent lamps that the widespread use of semiconductor electronics (electronic ballasts – EB) began in the early 1980s. The use of electronic ballasts can be considered the first successful example of the application of electronics in lighting, which became the harbinger of the era of semiconductor lighting.

EB, or so-called electronic ballasts, have replaced electromagnetic ballasts in fluorescent lamps, which contained a ballast choke, a starter (which provides preheating of the lamp electrodes and ignition) and a capacitor that reduces interference and improves the power factor. EB provide ignition of the discharge and stabilization of the current through the fluorescent lamp. The use of electronic ballasts improves a number of operational characteristics of fluorescent lamps, and, despite the increase in cost, the payback period is quite acceptable.

Modern thin (5/8 inch diameter) T5 fluorescent lamps with increased light output (more than 100 lm/W) are used only with electronic ballasts. The miniaturization of electronic ballasts has allowed them to be built into compact fluorescent lamps, which have received the title of "energy-saving".

Thus, by the end of the 20th century, gas-discharge lighting had reached the peak of its development, and almost all the latest innovations in this field did not lead to any qualitative changes in outdoor lighting systems. According to the law of the genre, the transition to the next technological stage of development was ripe. It was the stage of LED lighting.

3. The purpose of the article

The purpose of the study is to consider the city's outdoor lighting as a complex of the main components of the human environment. Research into existing lighting conditions in a certain neighborhood of Vinnytsia, and development of new lighting proposals using modern lighting programs DIALux evo 13. Study of issues of implementation and distribution of energy-saving technologies in the sphere of housing and communal services.

4. Results and discussion

The essence of the proposed concept consists of the following main provisions:

- the electrical lighting network is converted from a three-phase four-wire to a three-wire bipolar direct current network (Direct Current-DC);
- a power rectifier is installed at the electrical substation (or at the power point), which converts the alternating three-phase mains voltage into the direct voltage of the lighting network;
- The luminaires are controlled using the technology of transmitting a high-frequency signal over the power network (Power Line Communication — PLC), which has certain advantages in such a DC network.

This concept is called the Direct Current Lighting Smart Grid (DC LSG) technology platform. It should be noted that in recent years, DC networks have been developed in many industries, including large server centers, DC smart homes, power systems of commercial buildings and ships, solar power plants, electrical substations (self-consumption voltage), and finally, emergency lighting networks [9].

The transition to a DC network involves the use of a highly efficient three-phase power rectifier instead of one and a half hundred single-phase rectifiers and CCMs in luminaires. Typically, a single-phase rectifier contains a matrix of four semiconductor diodes, and a CCM consists of one diode and one transistor. To simplify a little, we can say that 900 (150x6) low-power semiconductor devices in luminaires can be replaced by one three-phase rectifier at the power point, consisting of six power diodes (for example, according to the scheme of A. N. Larionov). This reduces the cost and increases the reliability of luminaires and the lighting line as a whole. The number of wires in the line is reduced from four to three.

When powered by direct current, more efficient transmission of the PLC power network is ensured due to the absence of power factor compensating capacitors (mandatory for lamps with LVT and EB), and interference from pulsed KKM (in lamps with electronic ballasts and drivers). The not very successful experience of the first domestic pilot projects with controlled electronic ballasts showed that the difficulties of implementing PLC in an alternating voltage network were not fully overcome.

It is also very important that DC networks provide increased electrical safety for service personnel, since DC voltage is safer than AC [10]. The possibility of damage to pets (dogs) from step voltage leakage currents is also significantly reduced.

The object of the study is a residential area with an approximate area of 50,000 m^2 , located between Kosmonavtiv Avenue and 600-rychya Street. There are a number of buildings - residential and administrative buildings. The territory of the object is crossed by roads for the movement of people and transport both inside the residential area and from its external sides. The infrastructure of the object has an adjacent territory with a playground, retail premises, places for collecting garbage, areas for the movement of people, areas for planting plants. The object of the study belongs to buildings of a certain historical antiquity, but with current and continuing functioning as municipal facilities.

Figure 1 shows photographs of residential building № 78 during the day and at night. The residential building has six entrances, five of which are equipped with compact fluorescent lamps and one incandescent lamp. The height of the lamps was 2.5 meters near the first entrance, and 4 meters near entrances 2-6. Measurements were carried out in the dark at 23.00. The highest value of the average illumination was recorded near entrance №. 4, equipped with a compact fluorescent lamp, and it was 3.95 lux, which does not meet the standards for lighting the adjacent territory, which should be 10 lux.

Accordingly, in the course of this work, a 3D model of a residential area was developed in the DIALux evo 13 program. Illumination/brightness measurements were carried out in the territory of residential neighborhoods. A design project of the current outdoor lighting of this area was presented in the DIALux evo 13 program.

The residential neighborhood chosen as the object of the study belongs to the priority projects for the formation of the housing stock of the city of Vinnytsia. The neighborhood is located in the city center, with convenient access roads.

The residential neighborhood consists of four 9-story buildings, one 5-story building with different layouts, and 2 administrative buildings. The proposed photographs (Fig. 2. a, b) demonstrate fragments of streets and buildings located on a given territory of the residential area.

a ***b***

Fig. 2. 600th Anniversary Street, house 105
a) time: 15.30, date 12.05.2024 b) time 24.00, date 12.05.2024

When analyzing the current lighting situation and the availability of lighting equipment in a given residential area, the following points should be considered when creating a new lighting design:

1. In the evening, the city experiences uneven outdoor lighting, as buildings located in the center have more or less good architectural lighting, while many residential areas in the city are illuminated only by street lighting.
2. To create a general harmonious lighting environment in Vinnytsia, it is necessary to create a visual expressiveness of residential neighborhoods using structured outdoor and utilitarian lighting.
3. In the city's microdistricts, it is necessary to create structured lighting of their internal spaces. At the same time, it is necessary to divide the areas into a park zone, a roadway, and parking lots, because their lighting should be intended for different types of activities.

The DIALux evo 13 software package allows you to make a lighting calculation taking into account the entire luminous flux, materials of reflecting and absorbing surfaces, etc. However, the initial stage of work is the construction of a three-dimensional model of the object, the result of the implementation is shown in Fig. 3.

Fig. 3. Three-dimensional model of a residential area

As can be seen from Fig. 3, when creating an external scene in the DIALux evo 13 program, three-dimensional building models are built using standard elements by specifying the required dimensions and geometric shape.

To calculate outdoor and street lighting, as shown in Fig. 4-7, it is necessary to enter the type and number of luminaires into the project, as well as specify their location.

This paper proposes a variety of design solutions for a given facility in order to show the possibilities and approaches to implementing an optimal design solution.

Fig. 4 shows the first option for outdoor lighting of a residential area, replacing existing lighting fixtures with STAR NBT LED light sources. The advantage of this lighting model is that it illuminates only the front part of the entrance, while lighting the area where people move and pedestrian crossings is complicated due to the small luminous flux, which is the main disadvantage of this lighting model.

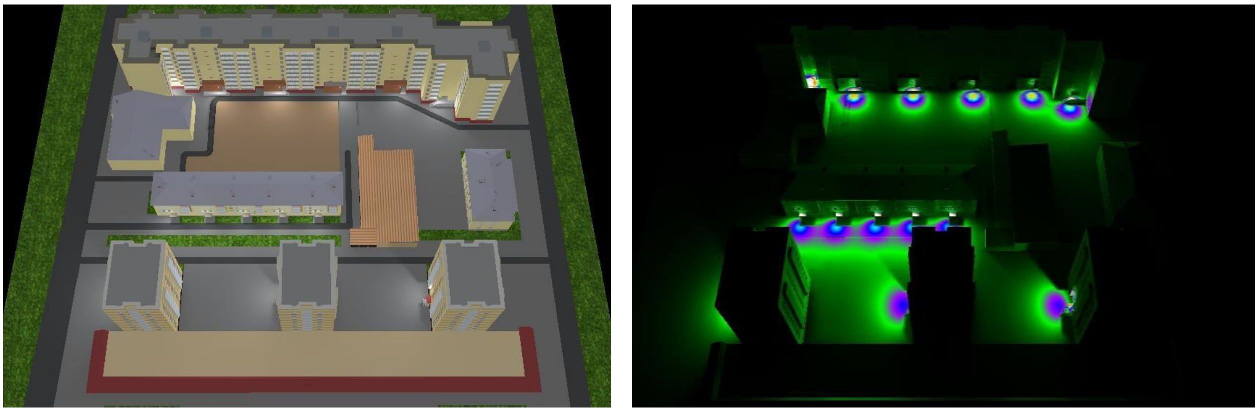

Fig. 4. The first model of outdoor lighting. Outdoor lighting of a residential area

Fig. 5 shows a second model of outdoor lighting of a residential area using LED light sources. LIGHTING TECHNOLOGIES ATHINA LED and MARK LED. The advantage of this model is the simultaneous lighting of the entire part of the residential area (entrance to the entrance, area for people to move, playground, pedestrian crossings, etc.). The disadvantages include:

- when the flow of people decreases, the lamps that illuminate the areas where people move are not turned off, which increases the need for electricity and reduces energy efficiency.

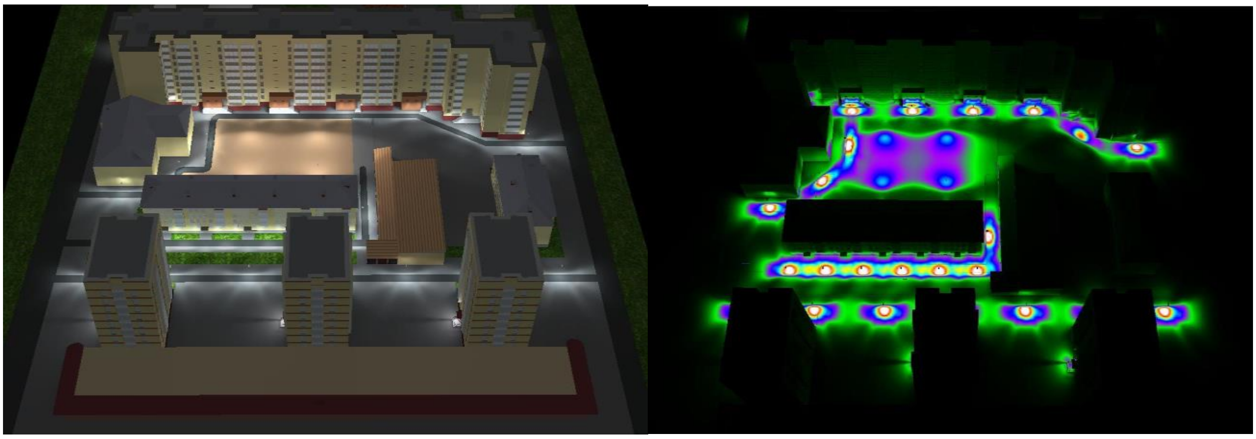

Fig. 5. Second option. Outdoor lighting of a residential area

Fig. 6 shows the third option for outdoor lighting of a residential area with an automated outdoor lighting control system (AOCS) DC LSG. The advantage of this model is the simultaneous lighting of all parts of the residential area (entrance to the entrance, people movement area, playground, pedestrian crossings, etc.). When the flow of people decreases from one o'clock in the morning to six in the morning, the luminous flux of the lighting devices of the people movement area decreases and the lamps that illuminate the playground are turned off . The disadvantage is the high cost of implementing this project.

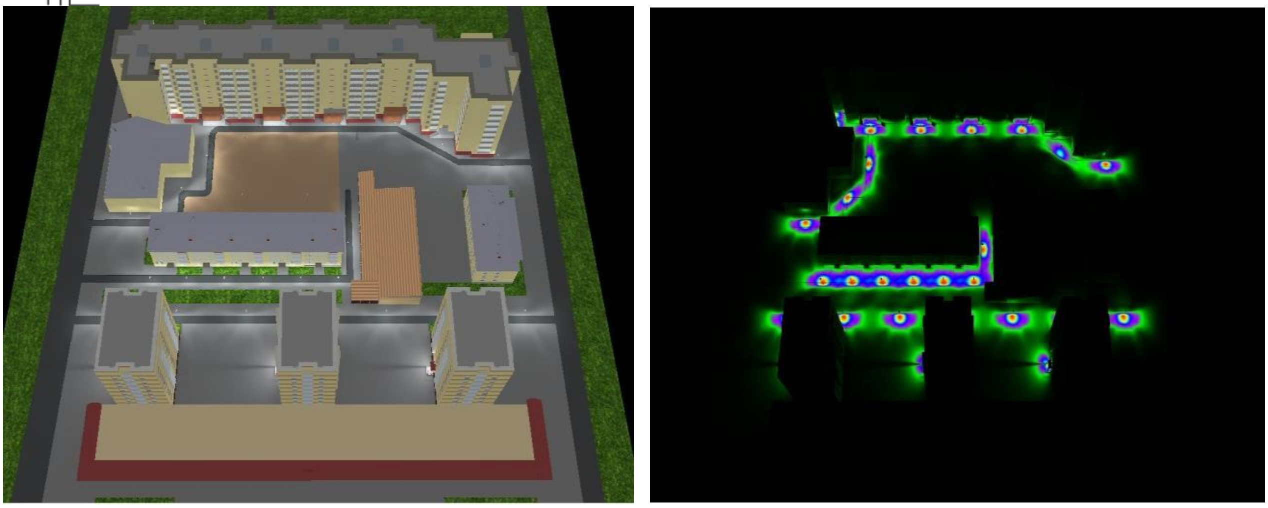

Fig. 6. Third option. Outdoor lighting with ACS

At the same time, the objects of the urban environment with the greatest energy consumption are housing and communal facilities, where the needs for electric lighting are quite high, but not sufficiently formed. The use of incandescent lamps, gas-discharge light sources that do not provide the required color rendering or continue to "work" in the non-switching mode during the daytime is not excluded. One or another approach does not provide either comfortable lighting or savings in consumed energy resources.

It is obvious that the announced DC LSG technology platform largely regulates the issues of power supply, control and communication, assuming the use of all existing and future energy-efficient light sources.

Currently, it can be considered that the only real factor hindering the implementation of DC LSG is the presence of third-party consumers that are powered directly from lighting lines with traditional single- or three-phase alternating voltage.

Thus, it is clear that when considering the transition to DC LSG, the presence of third-party consumers is not an absolute priority. Moreover, this transition can contribute to streamlining connections to lighting networks.

To create outdoor lighting for the residential area under consideration, the luminaires listed in Table 1 were used.

Table 1.

Types of luminaires

IP type	Name	Luminous flux, lm.	Power, W.	Quantity, pcs.
LED	Lighting Technologies Athina Led	3868	62	23
LED	Lighting Technologies Star Nbt Led	1540	18	4
LED	Lighting Technologies Mark Led	6461	56	9

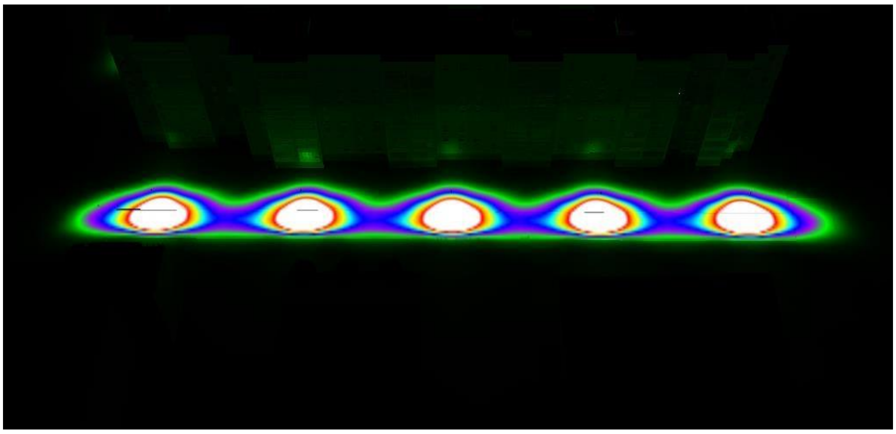

Fig.7. Lighting of the 600th Anniversary Street

When designing the lighting of the 600th anniversary street, a comparison was made of several types of lamps from different companies, which were chosen arbitrarily. According to SP 52.13330.2011, the road under consideration belongs to category B1, where the average illumination should be at least 20 lux. The results of the comparison are given in Table 2.

Table 2.

Results of luminaire comparison

Type	Name of lamps	Ecp, lk	Emin, lk	Emax, lux	Emin/Ecp	Emin/Emax
LED	Ledel l-street 72xpg/12636/135/sh4/cr	13	9.68	16	0.762	0.615
DRI	Galad gku12-150-001	11	6.03	17	0.551	0.363
DNAT	Lighting technologies Corvus NTK 10 150s	15	8.54	24	0.56	0.363
LED	Lighting technologies mark led 60 w 4000k	22	15.4	27	0.7	0.57

A comparison of lighting indicators for lighting a selected road section showed that the optimal luminaire for installation on this section is Lighting Technologies MARK LED 60 W 4000K.

On the DC LSG technological platform, outdoor lighting looks quite good. Additional connection of a diesel or gas generator will allow creating an effective long-term uninterrupted lighting system with the possibility of operational control on this technological platform.

Thus, it should be stated that the development of control and power electronics has led to a change in the assessment of the efficiency of three-phase power supply of lighting networks, which was considered "natural" and the only possible for over 100 years. The DC LSG concept envisages a return to more energy-efficient and convenient intelligent bipolar DC networks, invented at the end of the 19th century.

It is also very important that DC networks provide increased electrical safety for service personnel, since DC voltage is safer than AC.

It is obvious that the announced DC LSG technology platform largely regulates the issues of power supply, control and communication, assuming the use of all existing and future energy-efficient light sources.

The lighting system of the facility includes all lighting installations, as well as their power supply and control network (including control panels). The electrical network diagram for the selected lighting method is developed after the final approval of the device specifications, their placement and operating modes. The entire system is divided into groups according to their placement, energy consumption and operating modes. For each group, the power supply network, cable routing, and automatic or manual control methods are calculated.

Based on the values of electrical loads, the calculation of lighting networks and the selection of electrical equipment are carried out. The cross-section of the conductor in the network up to 1000 V mainly depends on the value of the rated current. This parameter is also influenced by the need for overload protection, ambient temperature conditions, type of conductor insulation, etc.

Based on this data, it is possible to select the cross-sections of power cables and switching devices. For groups of lighting devices powered by:

- from transformer station № 1, a cable of the VVB 4x2.5 brand and circuit breakers of the VA 47- 63 10A brand were selected;
- and circuit breakers VA 47-63 2A were selected .

To visually demonstrate the lighting installation power supply scheme, a single-line diagram was constructed and the cable routing was also drawn.

5. Conclusion

The concept of forming an artificial light environment of the city consists not only of ensuring the necessary illumination on highways and individual "artificial" architectural lighting of buildings. A comprehensive approach to designing the evening urban light space is necessary in order to create visual expressiveness.

1. The use of the concepts of "lighting master plan" and "lighting ensemble" allows us to take into account the entire range of tasks facing the designer.

2. The correct solution for the lighting design of a city consists not only in the rational arrangement of individual lighting installations, but, most importantly, in their successful coordination with each other, which necessitates a comprehensive solution for the lighting design of the city.

3. The main task of the lighting design of the city as a whole is to correctly distribute light and color accents, highlighting the most important historical and highly artistic buildings with light, creating a picturesque play of light and shadow on fountains and trees that decorate the city, and highlighting shopping centers and individual stores, and entertainment enterprises.

4. Individual tasks consist in a rational and modern solution for each of the lighting installations in the city's lighting design system.

5. This article presents design solutions for the modernization of lighting installations in the current residential area.

6. The optimal option has been selected, for which a schematic diagram has been calculated and presented.

7. Any of the proposed options can be considered final, provided that the connection diagrams are finalized.

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ДОСЛІДЖЕННЯ ТА РОЗВИТОК СИСТЕМ ОСВІТЛЕННЯ ЗОВНІШНЬОГО СЕРЕДОВИЩА У ЖИТЛОВО-КОМУНАЛЬНОМУ ГОСПОДАРСТВІ

Енергозберігаючі технології у формуванні світлового середовища житлових мікрорайонів є пріоритетним напрямом у формуванні заходів та спеціалізованих підпрограм з енергозбереження та підвищення енергетичної ефективності для житлового фонду міста Вінниці.

Модернізація систем комунального освітлення включає комплекс заходів та завдань, пов'язаних із світловим благоустроєм будинків, а також їхньої прибудинкової території, з урахуванням законодавства у сфері енергозбереження та раціонального використання споживаних енергоресурсів.

Метою є створення зовнішнього освітлення житлових комплексів та підвищення якості світлового середовища під час використання енергозберігаючих технологій.

Проведено аналіз об'єктів ЖКГ у структурі житлового масиву на предмет поточного користування світловим обладнанням у світлий та темний час доби, проведенно вимірювання освітленості на території житлових мікрорайонів м. Вінниці, житловий масив приблизною площею

50000 м^2, розташований між проспектом Космонавтів та вулицею 600-річчя

Розроблено 3D моделі об'єкта житлового масиву та прилеглих територій у програмі у DIALux evo 13.

Проведено аналіз поточного освітлення житлового масиву, виявлено низку проблемних обставин, які потребують розгляду щодо залучення енергозберігаючих технологій, у тому числі із забезпеченням якісного та комфортного освітлення. У процесі роботи було представлено загальний дизайн-проект освітлення об'єкта у світлотехнічній програмі DIALux evo 13 та створено освітлення окремих частин об'єкта. Як джерела світла використовувалися світлодіодні світильники та прожектори.

Проведене дослідження полягає у розгляді зовнішнього освітлення міста як комплексу основних складових оточення людини. Представлена робота спрямована на вивчення питань впровадження та розповсюдження енергозберігаючих технологій у сферу житлово-комунального господарства.

Ключові слова: *модернізація систем комунального освітлення, енергозберігаючі технології, освітлення житлових районів, муніципальна інфраструктура, DIALux evo, житлово-комунальне господарство.*

Рис. 7. Табл. 2. Літ. 10.

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