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The Method of Indirect Assessment of the Quality of Energy Characteristics

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Abstract. *Based on research carried out by various enterprises and independent scientists, it has been established that the use of LED technologies in lighting systems – both inside residential and non-residential buildings, as well as in street lighting systems – significantly increases energy efficiency and provides economic benefits. The main purpose of the study is to develop a method for indirectly assessing the quality of energy characteristics during the operation of electric lighting systems to improve their technical and economic performance. In the course of the work, new theoretical and experimental data were obtained, mathematical dependencies were derived describing the ratio of electric and light power, taking into account the parameters of lighting devices and power sources. Graphs were also constructed demonstrating the theoretical dependence of illumination on the electrical characteristics of the power supply, and the relationship between thermal engineering indicators and the quality of the luminous flux was revealed. In the course of experimental studies conducted using laboratory samples of the system, radiation characteristics were obtained and numerical parameters of the optimal operating range of the LED device were determined. For this purpose, numerical computer modeling was used, which makes it possible to analyze changes in the physical processes occurring during the operation of LED lighting systems. The difference between the best and worst results was 9.91%. A unique method of indirect assessment of the quality of energy characteristics during the operation of electric lighting systems has been developed, aimed at improving their technical and economic efficiency.*

Keywords: *LED devices, external lighting systems, light flow, semiconductor materials, performance analysis, method of analysis.*

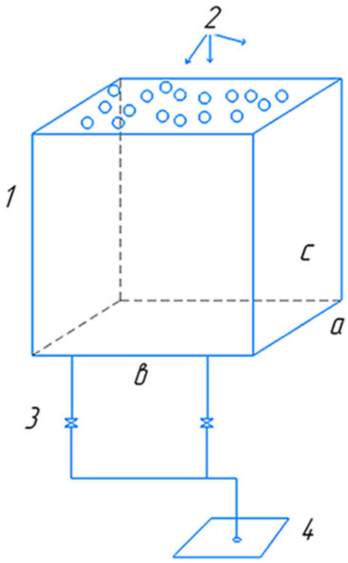
Introduction. The introduction of modern technological solutions is one of the most effective and rational approaches to reducing the consumption of natural resources, which helps to prevent electricity shortages [1-2]. According to research carried out by various enterprises and independent scientists, the use of LED technologies in lighting systems for residential, non-residential and street lighting can significantly increase energy efficiency and achieve significant economic benefits [3-4]. According to the financial statements of Philips Lighting, a leading developer and manufacturer of lighting equipment, 2 billion LED installations were sold in 2020.

The lack of a sufficient number of laboratory facilities and effective methods for assessing the quality of the luminous flux of luminaires makes it difficult for customers and operating organizations to verify that the installed equipment meets the requirements. The solution to this problem is possible through the development of a simplified methodology for evaluating the parameters of LED lamps, provided by the manufacturer and corresponding to the design requirements. [5].

Materials and research methods. During the testing and operation of the luminaires, the relationship between the power and the illumination level of the light spot was discovered, depending on the characteristics of the LEDs used. A hypothesis has emerged that this dependence may be useful for calculating the luminous flux of a light source. For the comparative analysis, luminaires with the same power and an identical luminous intensity curve (LCC) were used. To test the hypothesis, two luminaires were used, which were previously tested at the Physics and Technology Institute of Almaty in order to determine their basic lighting characteristics. The study also used analytical methods proposed by Kazakhstani and Russian experts [6-7].

A laboratory stand was designed and assembled for field testing. Its design allows devices to be placed in conditions similar to the actual operating conditions of lighting equipment [8]. A simplified diagram of the stand is shown in Figure 1.

Figure 2 shows a geometric model of a light spot.



1 – lighting device, 2 – side wall of the box, 3 – a window for placing light control devices, 4 – a unit of measuring equipment for monitoring electrical parameters, plug connector for network connections 220 V, 50 Hz

Figure 1 – Simplified layout of the stand

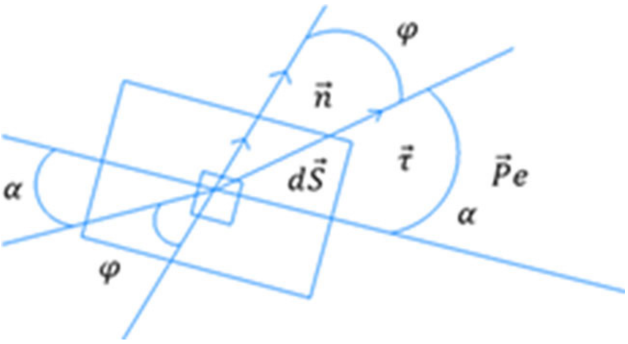


Figure 2 – Geometric model of luminous flux

The magnitude of the luminous power (total optical flux):

$$P_e = \int_s (\vec{p_e} \cdot d\vec{S}),$$

$$\frac{dW}{dt} = \frac{dW_e}{dt} + \frac{dW_s}{dt} = 0,$$

where W – total energy of the entire modeled system,

W_e, W_s – respectively, the total energies of the electrical and optical subsystems.

$$\frac{dW_s}{dt} = -P_s = -\int_s (\vec{p_s} \cdot d\vec{S}),$$

$$\frac{dW_e}{dt} = -P_e = -\int_s (\vec{p_e} \cdot d\vec{S}),$$

$$\frac{\partial W_{eV}(r;t)}{dt} + \vec{\nabla}(W_{eV}(r;t) c\vec{\tau}_e) = -q_{0V}(t).$$

For the volume distribution density function $\xi(r;t)$ for some characteristic non-stationary spatially inhomogeneous function of the process $\eta(r;t)$, when $\xi(r;t) = \frac{d\eta(r;t)}{dV}$,, for the parameter $\eta(t) = \int_V \xi(r;t)dV$, the condition is satisfied

$$\frac{d\eta(r;t)}{dt} = \frac{d}{dt}\left(\int_V \xi(r;t)dV\right) =$$

$$= \int_V \frac{\partial\xi(r;t)}{dt} + \vec{\nabla}(\xi(r;t) \cdot v)dV,$$

Where $v = \frac{dr}{dt}$.

From here,

$$\frac{\partial W_{eV}(r;t)}{dt} + \vec{\nabla}\ \vec{p}e(r;t) = -q_{SV}(r;t).$$

To develop a methodology for analyzing the stand design, LED street lamps, which are most in demand in the Karaganda region, were selected as the studied samples of lighting equipment. Three models are considered: Street-100, produced by Global Light LLP (Kazakhstan); Gemera-100 from Svetotekhnika Plus LLP; and SLP-96, produced by ProLed LLP.

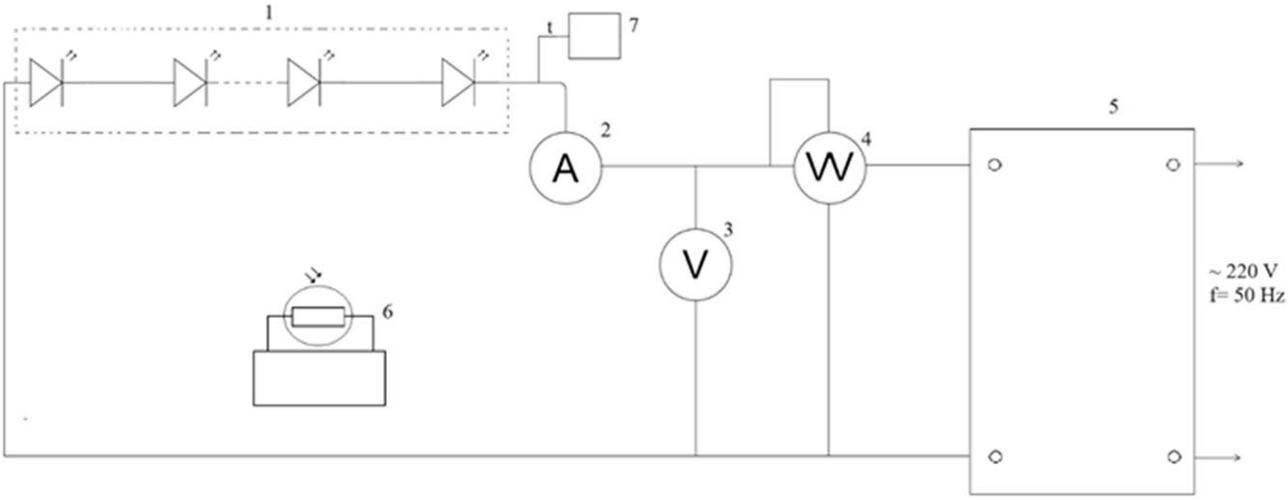
In the course of the study, a multiparametric evaluation method was used to verify the compliance of the luminaires with the passport data declared by the manufacturers. To improve the accuracy of experimental measurements, the luminaires were connected to a standard AC electrical network with a voltage of 220 V and a frequency of 50 Hz, with an acceptable deviation of no more than 5% from the standard values.

To measure the main characteristics of the electrical network, a wattmeter was used (factory verification certificate No. 316-7 dated 1.10.2019), designed to monitor power consumption, current and voltage. To improve the accuracy of the results, a statistical data processing method was used, including at least 10 consecutive measurements, which made it possible to identify and eliminate systematic errors or deviations from the standard values. The deviations in the sample were less than 1%.

The energy efficiency assessment of the luminaires included measurements of electrical, temperature parameters and luminous flux characteristics. The latter was measured using three analog and two digital instruments. All measurements were carried out in accordance with the requirements of GOST No. 16962.1 at room temperature of 25°C and humidity of 45%, corresponding to normal climatic conditions.

The schematic diagram of the laboratory stand is shown in Figure 3.

The following instruments were used to perform the measurements (figure 4): the Yu-



1 – LED lighting device, 2 – UT70B multimeter with thermocouple, operating in ammeter mode, 3 – UT70B multimeter with thermocouple in voltmeter mode, 4 – UT70B multimeter with thermocouple in wattmeter mode, 5 – a device for analyzing the quality of electrical energy, 6 – a tool for measuring the luminous flux, 7 – temperature measuring device

Figure 3 – Circuit diagram of the laboratory stand

Figure 4 – Conducting an experiment

116 analog luxmeter, the TKA-PKM-09 digital luxmeter, the Digital Lux Meter ZC51100 digital luxmeter, the UT70B digital multimeter with a thermocouple, the Fluke Ti25 thermal imager and the AKE-823 electrical energy quality analyzer.

Research results. Figure 5 shows the dependence of the lamp temperature on its operating time.

The experimental results showed that the use of calculations according to the proposed methodology provides a deviation from laboratory test data of no more than 2%. This level of accuracy is quite sufficient to evaluate the effectiveness of the luminous flux. When choosing LED lights, it is recommended to check each model for compliance with the technical parameters specified by the manufacturer using the suggested methodology.

The technique is easy to implement and suitable for use in industrial enterprises. It allows you to perform an express assessment of the quality of LED lamps by your own staff without the need to involve specialized laboratories, access to which may be limited. In the future, the methodology will be improved to increase the accuracy of the assessment and expand the list of estimated parameters.

Discussion and conclusions. The uniqueness of this technique lies in the use of electrical energy quality analysis, which has not been used before, but is key to improving the accuracy of evaluating the characteristics of luminaires. The results of the study confirmed that deviations in the parameters of the electrical network and problems with the quality of electricity can lead to inconsistencies in the characteristics of the luminaires, as well as a decrease in their efficiency and service life. Therefore, before commissioning LED lighting systems, it is recommended to analyze the electrical network for compliance with quality requirements.

Studies have also revealed dependencies in the operation of LED candles related to the heating of the semiconductor element, which leads to a decrease in their light output. At the same time, manufacturers do not indicate possible deviations in the accompanying product documentation.

Based on empirical data, a correction factor was determined that takes into account the light output and illumination level at a certain point at a fixed distance from the light source. This coefficient allows for a more accurate assessment of the effectiveness of LED lights.

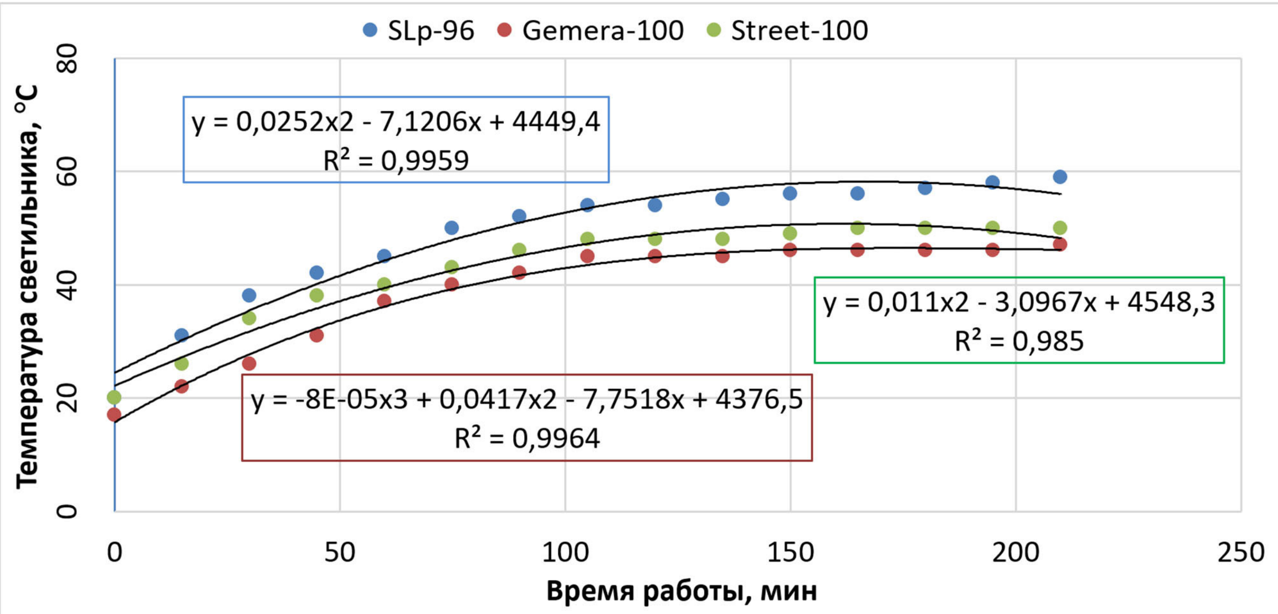


Figure 5 – Graph of the temperature rise versus the lamp's operating time

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Энергетикалық сипаттамалардың сапасын жанама бағалау әдісі

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Аңдатпа. *Әр түрлі кәсіпорындар мен тәуелсіз ғалымдар жүргізген зерттеулерге сүйене отырып, жарық диодты технологияларды жарықтандыру жүйелерінде – тұрғын және тұрғын емес ғимараттарда да, көше жарықтандыру жүйелерінде де қолдану энергия тиімділігін едәуір арттырып, экономикалық пайда әкелетіні анықталды. Зерттеудің негізгі мақсаты олардың техникалық-экономикалық көрсеткіштерін жақсарту үшін электр жарықтандыру жүйелерін пайдалану процесінде энергетикалық сипаттамалардың сапасын жанама бағалау әдісін әзірлеу болып табылады. Жұмыс барысында жаңа теориялық және эксперименттік мәліметтер алынды, жарықтандыру құрылғылары мен қуат көздерінің параметрлерін ескере отырып, электр және жарық қуатының арақатынасын сипаттайтын математикалық тәуелділіктер алынды. Сондай-ақ, жарықтандырудың электр қуатының сипаттамаларына теориялық тәуелділігін көрсететін графиктер салынды және жылу көрсеткіштерінің жарық ағынының сапасымен байланысы анықталды. Жүйенің зертханалық үлгілерін қолдана отырып жүргізілген эксперименттік зерттеулер сәулелену сипаттамаларын алды және жарықдиодты құрылғының оңтайлы жұмыс диапазонының сандық параметрлерін анықтады. Ол үшін жарықдиодты жарықтандыру қондырғыларының жұмысында болатын физикалық процестердің өзгеруін талдауға мүмкіндік беретін сандық компьютерлік модельдеу қолданылды. Ең жақсы және ең нашар нәтижелер арасындағы айырмашылық 9,91% құрады. Электр жарықтандыру жүйелерін пайдалану процесінде олардың техникалық-экономикалық тиімділігін арттыруға бағытталған энергетикалық сипаттамалардың сапасын жанама бағалаудың бірегей әдісі жасалды.*

Кілт сөздер: *LED құрылғылары, сыртқы жарықтандыру жүйелері, жарық ағыны, жартылай өткізгіш материалдар, өнімділікті талдау, талдау әдісі.*

Метод косвенной оценки качества энергетических характеристик

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Аннотация. _На основании исследований, выполненных различными предприятиями и независимыми учеными, установлено, что использование светодиодных технологий в системах освещения, как внутри жилых и нежилых зданий, так и в уличных осветительных системах, значительно повышает энергоэффективность и обеспечивает экономическую выгоду. Основной целью исследования является разработка метода косвенной оценки качества энергетических характеристик в процессе эксплуатации электрических систем освещения для улучшения их технико-экономических показателей. В ходе работы получены новые теоретические и экспериментальные данные, выведены математические зависимости, описывающие соотношение электрической и световой мощности с учетом параметров осветительных устройств и источников питания. Также были построены графики, демонстрирующие теоретическую зависимость освещенности от электрических характеристик питания, и выявлена связь теплотехнических показателей с качеством светового потока. В ходе экспериментальных исследований, проведенных с использованием лабораторных образцов системы, были получены характеристики излучения и определены числовые параметры оптимального рабочего диапазона светодиодного устройства. Для этого применялось численное компьютерное моделирование, позволяющее проанализировать изменения физических процессов, происходящих при работе светодиодных осветительных установок. Разница между наилучшими и наихудшими результатами составила 9,91%. Разработан уникальный метод косвенной оценки качества энергетических характеристик в процессе эксплуатации электрических систем освещения, направленный на повышение их технико-экономической эффективности._

Ключевые слова: _LED-устройства, внешние осветительные системы, поток света, полупроводниковые материалы, анализ характеристик, способ анализа._

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