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THE RESEARCH OF THE EXISTING METHODS OF ILLUMINATION DISTRIBUTION ON THE WORKSPACE SURFACE LEVEL OF THE ROOM TO ACHIEVE OPTIMUM VALUES

ОҢТАЙЛЫ МӘНДЕРГЕ ҚОЛ ЖЕТКІЗУ ҮШІН БӨЛМЕНІҢ ЖҰМЫС КЕҢІСТІГІ ДЕҢГЕЙІНДЕ ЖАРЫҚТАНДЫРУДЫ ТАРАТУДЫҢ ҚОЛДАНЫСТАҒЫ ӘДІСТЕРІН ЗЕРТТЕУ

ИССЛЕДОВАНИЕ СУЩЕСТВУЮЩИХ МЕТОДОВ РАСПРЕДЕЛЕНИЯ ОСВЕЩЕННОСТИ НА УРОВНЕ ПОВЕРХНОСТИ РАБОЧЕГО ПРОСТРАНСТВА ПОМЕЩЕНИЯ ДЛЯ ДОСТИЖЕНИЯ ОПТИМАЛЬНЫХ ЗНАЧЕНИЙ

Abstract. *This article analyzes the current state of functioning and development of LED lighting technology. The article explores the main methods: the luminous flux utilization factor method, the point calculation method, and also presents the method for controlling the modes of LED lighting devices through a microprocessor device as an opportunity for further research. The most efficient method for maintaining optimal illumination in the room has been chosen. As a result of the study, it was revealed that the chosen method allows additionally saving electricity and providing the required illumination with a uniform distribution pattern in accordance with the Building Codes and Rules of the Republic of Kazakhstan. On the basis of the studied methods, computer modeling of the lighting system was carried out, a 3D model of the distribution of illumination on the workspace surface level of the room was obtained. The state of illumination of the room was investigated. The article reveals the problem of the uniformity of the distribution of illumination on the workspace surface level of the room. As a result of the study, an idea was proposed to develop a system for correcting the illumination of an LED lighting system that would provide the required level of illumination at given points.*

Keywords: *Light-emitting diode (LED), light distribution curve, lighting, computer simulation, distribution uniformity, level of illumination, workspace surface level of the room, illumination correction.*

Аңдатпа. *Бұл мақалада жарықдиодты жарықтандыру технологиясының жұмыс істеуі мен дамуының қазіргі жағдайына талдау жасалды. Мақалада негізгі әдістер зерттелген: жарық ағынын пайдалану коэффициенті әдісі, нүктелік есептеу әдісі, сонымен қатар әрі қарай зерттеу мүмкіндігі ретінде микропроцессорлық құрылғы арқылы жарықдиодты жарықтандыру құрылғыларының режимдерін басқару әдісі ұсынылған. Зерттелетін әдістердің артықшылықтары мен кемшіліктері анықталды. Бөлмеде оңтайлы жарықтандыруды қамтамасыз етудің ең тиімді әдісі таңдалды. Зерттеу нәтижесінде таңдалған әдіс электр энергиясын қосымша үнемдеуге және қажетті жарықтандыруды Қазақстан Республикасының құрылыс нормалары мен ережелеріне сәйкес біркелкі тарату көрінісімен қамтамасыз етуге мүмкіндік беретіні анықталды. Зерттелген әдістердің негізінде жарықтандыру жүйесін компьютерлік модельдеу жүргізілді, жұмыс жазықтығы деңгейінде бөлме кеңістігінде жарықтың таралуының 3d моделі алынды. Бөлменің жарықтандыру жағдайы зерттелді. Мақалада бөлменің жұмыс кеңістігі деңгейінде жарықтың біркелкі таралу* *проблемасы анықталды. Зерттеу нәтижесінде жарық диодты жарықтандыру жүйесінің жарықтануын түзету жүйесін жасау идеясы ұсынылды, ол берілген нүктелердегі жарықтандырудың қажетті деңгейін қамтамасыз етеді.*

Түйін сөздер: *Жарық диоды, жарық күшінің қисығы, жарықтандыру, компьютерлік модельдеу, таратудың біркелкілігі, жарықтандыру деңгейі, бөлменің жұмыс кеңістігінің беті, жарықтандыруды түзету.*

Аннотация. *В данной статье проведен анализ современного состояния функционирования и развития светодиодной технологии освещения. В статье исследованы основные методы: метод коэффициента использования светового потока, точечный метод расчета, а также представлен метод управления режимами светодиодных осветительных приборов через микропроцессорное устройство как возможность дальнейшего исследования. Определены преимущества и недостатки исследуемых методов. Выбран наиболее эффективный метод обеспечения поддержания оптимальной освещенности в помещении. В результате исследования выявлено, что выбранный метод позволяет дополнительно сэкономить электроэнергию и обеспечить требуемую освещенность с равномерной картиной распределения в соответствии со строительными нормами и правилами Республики Казахстан. На основе исследованных методов проведено компьютерное моделирование системы освещения получена 3D-модель распределения освещенности в пространстве помещения на уровне рабочей плоскости. Исследовано состояние освещенности помещения. В статье выявлена проблема равномерности распределения освещенности на уровне поверхности рабочего пространства помещения. В результате исследования предложена идея разработки системы коррекции освещенности светодиодной системы освещения, которая будет обеспечивать требуемый уровень освещенности в заданных точках.*

Ключевые слова: *Светодиод, кривая силы света, освещение, компьютерное моделирование, равномерность распределения, уровень освещенности, поверхность рабочего пространства помещения, коррекция освещенности.*

Introduction. In modern society, there is a problem of providing uniform indoor lighting, especially for educational institutions.

The purpose of this article is to determine the most effective method of illuminance distribution on the workspace surface level of the room with optimal values.

To achieve this goal, it is necessary to solve the following main tasks:

1) Conduct an analysis of existing research methods

2) Conduct a computer simulation of the illumination of the room using LED lamps using the studied methods.

3) Determine the most optimal method of illuminance distribution.

4) Propose a development to solve the identified problems for research in the next stages.

Relevance. Energy saving is one of the most serious tasks of the 21st century. The position of our society in a number of economically developed countries and the standard of living of citizens depend on the results of solving this problem. The need for energy is constantly increasing with the growth of the population and the acceleration of technological progress. Therefore, the efficient use of energy and energy saving have become one of the most acute problems in recent years. Since the global energy crisis and the problem of natural resources are particularly acute today, a huge number of scientists have directed their efforts to the use of alternative energy sources and to the construction of energy-saving systems based on existing and newly developed technologies.

An analysis of the current state of energy-efficient LED lighting in office spaces reflects technological progress and the exponential growth in the number of ongoing research permits to increase the efficiency of lighting devices and, as a result, reduce energy consumption. Scientists are developing systems to improve the energy performance of lighting installations and increase their energy-saving capabilities. However, to date, a number of issues have not been resolved to achieve uniform illumination of the working plan [1-2].

Materials and methods of research. The computer simulation of an LED lighting system was performed on the example of a classroom in order to conduct the research in this article.

Several types of methods are used to model an LED lighting system.

The luminous flux utilization factor method is used when it is necessary to calculate the total uniform illumination of horizontal surfaces with luminaires of any type. It is the most applicable for calculating the general uniform illumination of premises in the operating conditions of office premises and industrial enterprises.

This method permits to take into account the reflected flows from the enclosing surfaces, which include: the ceiling, walls, floor and equipment installed in the room. Since in cases where these surfaces have high values of reflection coefficients, the reflected component of illumination can be comparable to the direct one, and its underestimation can lead to significant errors in the calculations.

In the process of carrying out calculations by this method, it is necessary to select a lighting system, a light source, a type of lamp for the room in question and perform directly the calculation of the general lighting of the room.

During the calculation according to this method, the number of necessary fixtures for the considered room is determined by the formula (1) [3]:

$$N = \frac{E_{\min\_} \cdot S \cdot k \cdot z}{F_l \cdot u_{oy}}, \quad (1)$$

where Emin – minimum illumination level, lm/m2; S – area of a room, m2; k – safety factor; z – factor taking into account the uneven illumination; Fl – luminous flux of the light source, lm; Иоу – luminous flux utilization factor.

Within the constraints of this article, the luminous flux utilization factor method is necessary to determine a sufficient number of luminaires.

The point method for calculating lighting is used to calculate general uniform and localized lighting, local lighting, regardless of the position of the illuminated surface with direct light fixtures. This method permits to determine the illumination at any point of the considered surface, relative to each lamp [4].

The sequence of calculations by the point method:

a) the minimum normalized illumination is determined;

b) the selection of types of lamps and the placement of lamps in the room;

c) control points are selected;

d) the illumination at each control point is calculated;

e) the total illumination at each control point is found by summing the illumination from all or the nearest lamps;

f) if necessary, the selected fixtures are adjusted.

The point method is based on equation (2), which relates illumination and light intensity:

$$E = \frac{I_\alpha \cdot \cos^3 \alpha \cdot \mu}{k \cdot h_p^{\,2}}, \quad (2)$$

where Iα – the luminous intensity in the direction from the source to a given point on the working surface (determined from the luminous intensity curves or from the tables of the selected type of luminaire), Cd;

α – angle between the normal to the working surface and the direction of the light intensity to the calculated point, degrees;

μ – factor taking into account the effect of luminaires remote from the design point and the reflected light flux from walls, ceiling, floor, equipment falling on the work surface at the design point (taken within μ = 1.05 ... 1.2);

k – safety factor;

hp – hanging height of the luminaire above the work surface, m.

In the course of performing the necessary calculations and computer simulation of the illumination of the room in this research, the main programs such as DIALux, MATLAB, MS Excel are used.

A distinctive feature of LED lighting technology is the angle of dispersion of the light flux emitted by the light fixture [5]. The task of designing the optimal arrangement of selected luminaires in order to reduce energy consumption with uniform illumination becomes relevant.

The article deals with the classroom of D. Serikbayev East Kazakhstan technical university (EKTU), long - 9 m, wide - 4 m and high - 2.8 m. There are light openings in the amount of 2 pieces. The normative illumination of the room is assumed to be 300 lux, which corresponds to the B1 category of visual work with a high-precision visual work characteristic in accordance with SP RK 2.04-02-2012 "Natural and artificiallighting". Illumination values are determined on the workspace surface - 0.8 m from the floor level [6].

For modeling, at first, LEDEL L-school 32 LED luminaire recommended for lighting office, residential, public, school, preschool and vocational institutions was selected. The body of this luminaire has a patented mounting system that significantly reduces installation time down to one minute. An integral LED driver is installed in the housing. Lighting prismatic plastic is used as a diffuser - a diffuser that gives soft diffused light. The light distribution diagram or luminous intensity curve (LCU) is shown in figure 1, and the main technical parameters are given in table 1 [7].

From how the light of the lamp is distributed in space, its purpose depends. Thus, along concentric circles, numerical values of the intensity of light in "Cd" are plotted (Candela is a unit of light intensity). By light distribution curve (LDC), it can be determined the intensity of light in any direction. To do this, it was drawn a radius at a given angle until it intersects with the luminous intensity curve [8]. Then a concentric circle was drawn from the found point on the luminous intensity curve to the axis 0-180°, which calculates the light intensity for the angle [9]. Thus, from figure 1 it can be seen that this luminaire emits a luminous intensity in the vertical downward direction, approximately equal to 420 cd.

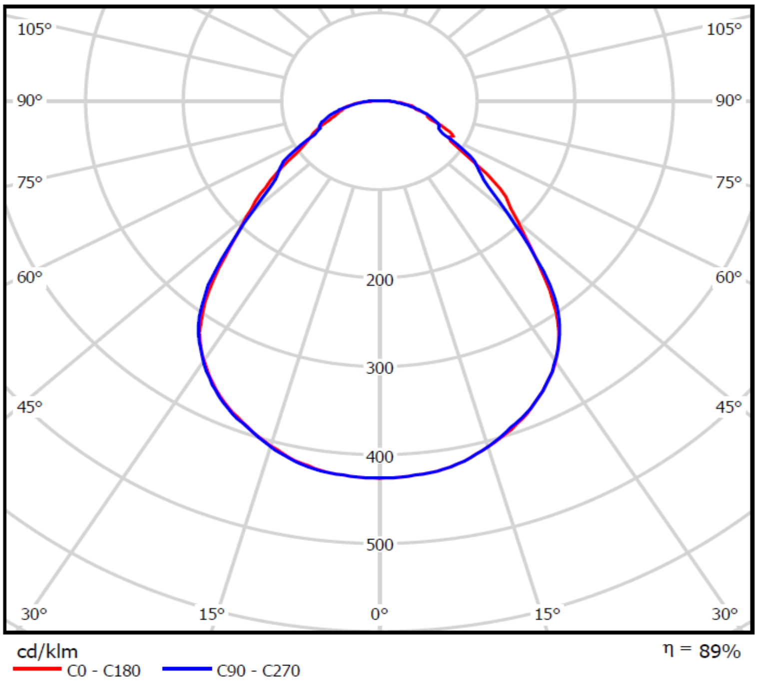


Figure 1. Diagram of the light distribution of the LEDEL L-school 32 luminaire

Table 1. LEDEL L-school 32 luminaire parameters

Parameter	Value
Supply voltage / frequency, V / Hz	140-265 / 50
Power consumption, W	32
Luminous flux of the lamp, lm	3000
Color temperature, K	5000
Color rendering index Ra	85
Lamp weight, kg	2
Overall dimensions of the luminaire, mm	56,5 x 1200 x 200
LED resource, h	> 50 000
Working temperature range, °C	from +1 to +35
Degree of protection	IP30
LDC type and optics angle, °	cosine, 120

To reduce the routine work and to ensure more accurate results in further calculations, the capabilities of the DIALux 4.12 Light program will be used. Based on lighting calculations using the luminous flux utilization factor and the point method, as well as this program, it permits to determine the optimal location of luminaires, estimated by the standard coefficient of uniformity of the distribution of illumination, subject to the restriction in the form of a minimum standard illumination [10]. Finding the optimal location is carried out by a gradientless search method for solving optimization problems - by scanning the region of change of independent variables with restrictions in the form of inequalities. The scanning method consists in sequentially viewing the values of the objective function (in this case, the value of the coefficient of uniformity of the distribution of illumination) at a number of points belonging to the area of change of independent variables (illuminance values at control points), and finding among them points with the minimum value of the objective function [10]. Since this method is laborious, especially when carrying out manual calculations, it is certainly advisable to use a ready-made software product - DIALux 4.12 Light.

The DIALux 4.12 program permits to calculate artificial lighting for a given type, number and location of various types of fixtures, taking into account the color and texture of the surface, as well as the interior and geometric parameters of the room [11]. As a result of data processing, we can get a full-fledged general 3D view of the illuminated room and a graphical representation of the distribution of light over a given surface. Using this program, a 3D model of the classroom was built (figure 2).

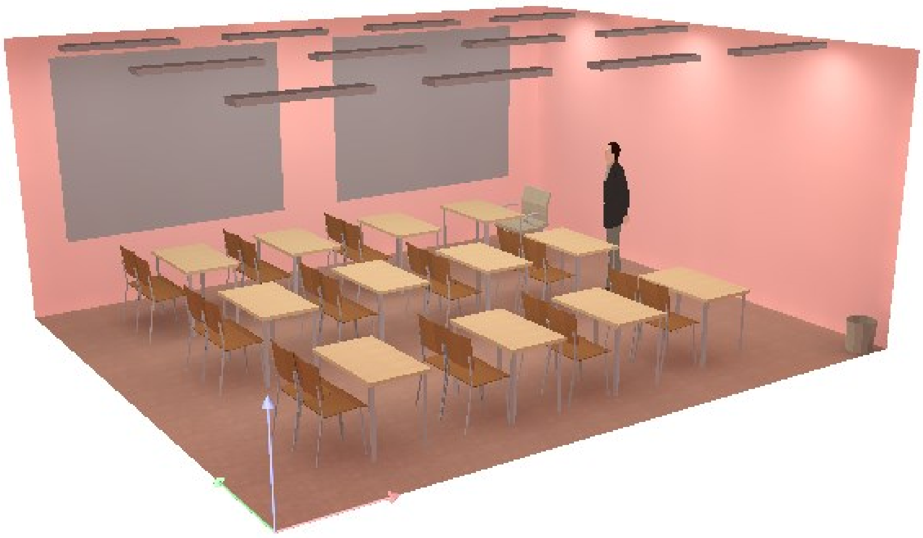


Figure 2. Model of LED lighting of the classroom using LEDEL L-school 32 luminaires

Thus, further calculations will be given in the work using the DIALux 4.12 Light program.

To perform calculations in the DIALux 4.12 Light program, the following parameters were entered: luminaire type; geometric parameters of the room: length, width, height; reflection coefficients: ceiling - 70%, walls - 50%, floor - 20%; workspace surface height; the required value of the illumination level. According to the standards of the International Commission on Lighting, the minimum illumination of an office space should be 500 lux, therefore, in the first research, the required illumination value of 500 lux was introduced in the first research using computer simulation [12].

The result of the calculation shows that with the selected LED lamp, the number of necessary lamps is 12 pieces, the optimal arrangement of lamps is as follows, as shown in figure 3.

The capabilities of the program permit to determine the values of illumination at different levels of the surface of the room. The indicators associated with are given for consideration (table 2).

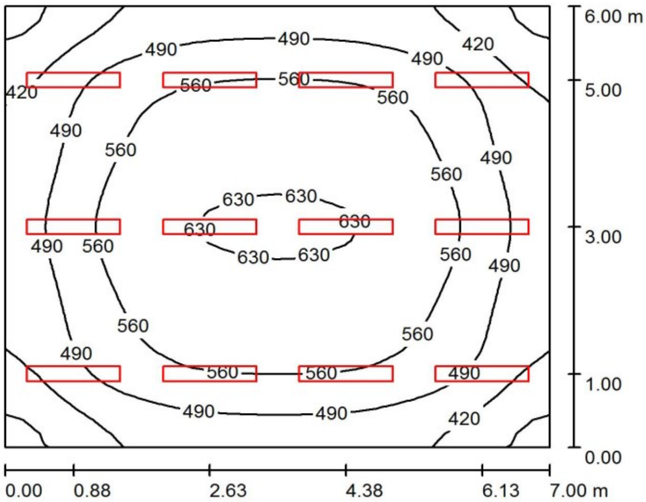


Figure 3. Optimal arrangement of LED lamps LEDEL L-school 32

Table 2. Illumination values on various surfaces in the room with LEDEL L-school 32 luminaires

Surface	Eav, lux	Emin, lux	Emax, lux	Emin/ Eav
Work plane	520	331	639	0,636
Floor	415	263	510	0,633
Ceiling	117	98	167	0,836
Walls (4)	279	110	584	-

The table shows that the uniformity coefficient of illumination distribution on the workspace surface level of the room is 0.636. This value satisfies the minimum threshold value equal to 0.500 [12].

To visualize the distribution of illumination on the workspace surface level of the room in order to show the nature of the illumination pattern, a 3D model was built (figure 4). The illumination values of the control points were processed in Microsoft Excel. There are 1056 control points in total, of which 33 points are along the length of the room, 32 points along the width.

As can be seen from figure 4, a hilly lighting pattern was obtained in the office space, according to which it is observed that in the center of the room there is a strong overexposure, the value of which reaches almost 700 lux, and in the area around the center, there is also a significant excess of illumination in size about 600 lux, and blackouts are observed in the corners of the room.

Thus, it can be concluded that the introduction of LEDEL L-school 32 LED lamps is inefficient within the research premises, since a significant excess of overexposure to the illumination of the room, a strong uneven illumination disturb the comfortable light environment. It will be very uncomfortable for students researching in this room and teachers to be and work in such conditions, the consequences of using this type of lamp will lead to eye fatigue, headaches, deterioration in mood and productivity, irritability, fatigue and, of course, deterioration of vision. In addition, the research shows that lamps consume a large amount of electricity, so the introduction of such devices is not only inefficient in terms of comfort, but also it is an inappropriate use of electricity, which leads to significant costs [13].

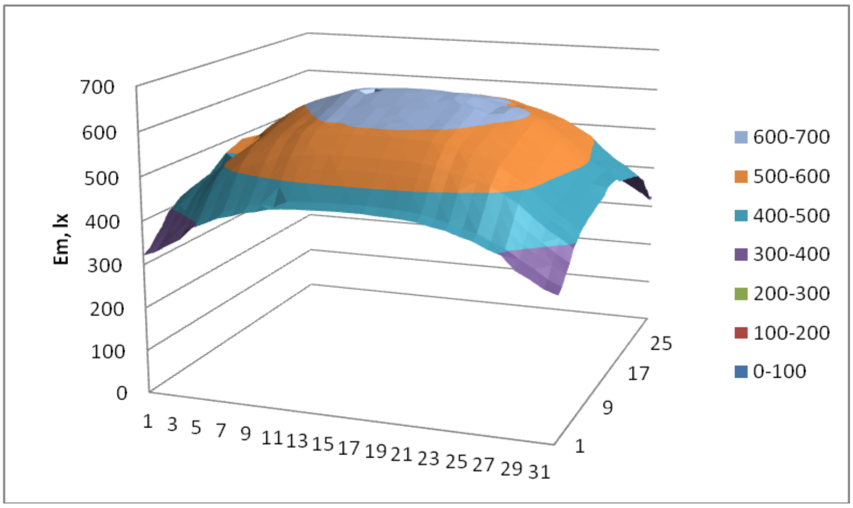


Figure 4. 3D model of the distribution of illumination of the workspace surface level of the room

At the next stage, the second research of the same room was carried out, but other LED lamps were selected: PLANT 02-25-3000-31 (120), manufactured by AtomSvet LLC, Moscow, the light distribution diagram of which is shown in figure 5, and the main technical parameters are given in table 3 [14].

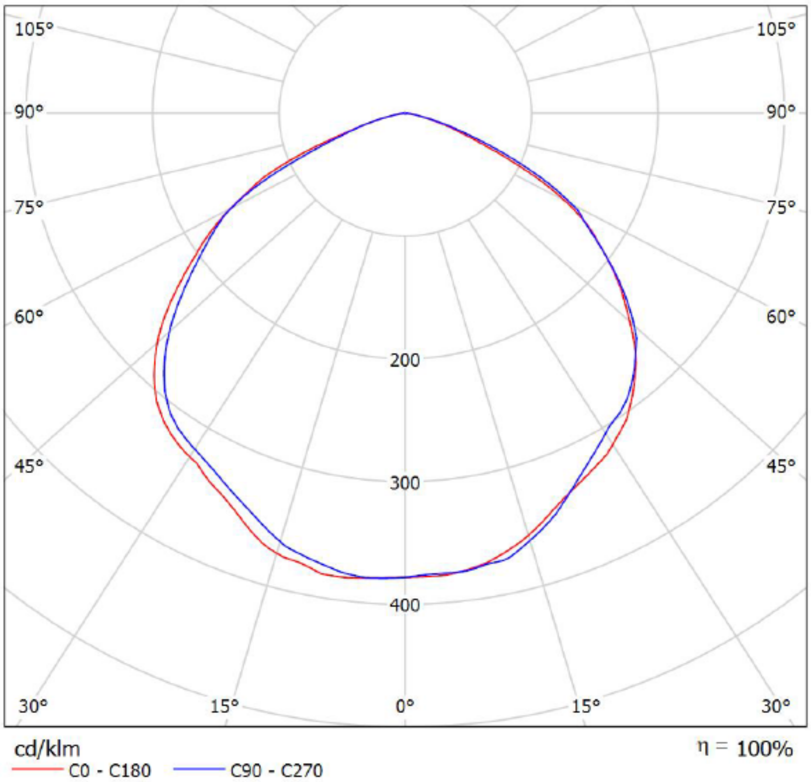


Figure 5. Diagram of light distribution

From figure 5 it can be seen that this lamp emits a luminous intensity in the vertical downward direction, approximately equal to 380 cd.

Table 3. Lamp parameters PLANT 02-25-3000-31 (120)

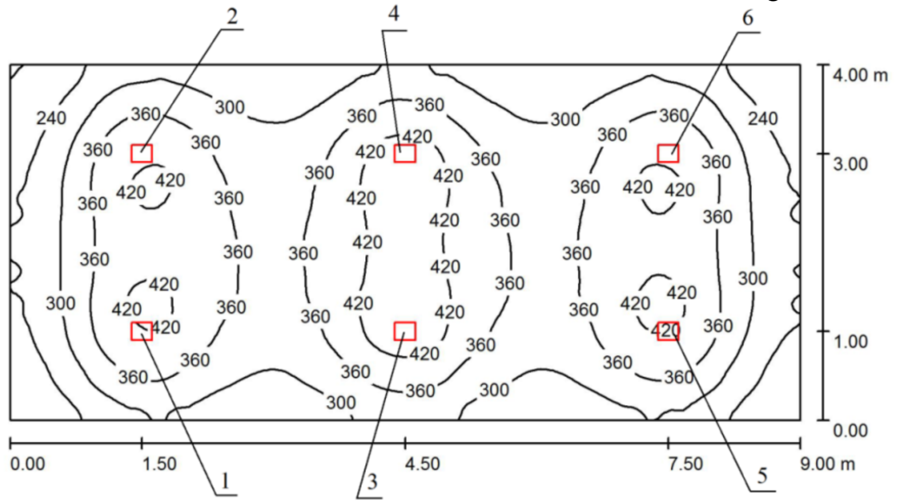
Parameter	Value
Supply voltage / frequency, V / Hz	150-265 / 50
Power consumption, W	31
Luminous flux of the lamp, lm	3120
Color temperature, K	5000
Color rendering index Ra	>80
Lamp weight, kg	2,2
Overall dimensions of the luminaire, mm	270 x 200 x 110
LED resource, h	> 50 000
Operating temperature range, °C	from -60 to +60
Degree of protection	IP67
LCU type and optics angle, °	cosine, 120

In the research, other fixtures were chosen because the former, as mentioned above, were inefficient in use. In addition, it was decided to introduce a normalized level of illumination according to the norms of the Republic of Kazakhstan. According to SP RK 2.04-02-2012, the minimum level in office premises is 300 lux, therefore, when performing this computer simulation, the normalized illumination level is set at 300 lux [15].

Further, using the DIALux 4.12 Light program, it was built a 3D model of the classroom on the base (figure 6).

Figure 6. Model of LED lighting of the classroom

The optimal location of the luminaires is shown in figure 7. The figure also shows isoluxes (lines with constant illumination values on the workspace surface level of the room) and the co-ordinates of the location of the luminaires in the room. The coordinates are given in table 4.



1-6 – lamp position

Figure 7. Optimal location of PLANT 02-25-3000-31 (120)

Table 4. Coordinates of the location of PLANT 02-25-3000-31 (120) in the space of the room

	Coordinates		
LED position	x – length, m	y – width, m	z – height, m
1	1,5	1,0	2,8
1	2	3	4
2	1,5	3,0	2,8
3	4,5	1,0	2,8
4	4,5	3,0	2,8
5	7,5	1,0	2,8
6	7,5	3,0	2,8

The capabilities of the program permit to determine the values of illumination at different levels of the surface of the room. The indicators associated with the workspace surface level of the room are used (table 5).

Table 5. Illumination values on various surfaces in the room

Surface	Eav, lux	Emin, lux	Emax, lux	Emin/ Eav
Work plane	340	177	463	0,519
Floor	285	171	353	0,601
Ceiling	69	49	81	0,709
Walls (4)	164	51	357	-

Table 5 shows that the coefficient of uniformity of illumination distribution on the workspace surface level of the room is 0.519. This value satisfies the minimum threshold value equal to

0.300, indicated in the SP RK 2.04-02-2012 State standards in the field of architecture, urban planning and construction "Natural and artificial lighting" [15].

The final stage of the simulation was the mapping of the illumination of the entire room by control points with a fixed step along the length of the room 9 cm, width - 4 cm based on the calculation data obtained in the DIALux 4.12 program. There are 8192 control points in total, of which 128 points are along the length of the room, 64 points along the width. A room illumination map is compiled to visualize the distribution of illumination on the workspace surface level of the room, which permits to show the nature of the illumination pattern, for example, peak, uniform, undulating, etc.

Thus, according to the illumination map in the MATLABR2012b program, a 3D model of the distribution of illumination in the space of the room on the workspace surface level of the room was built using the surf () function. The resulting 3D model is shown in figure 8.

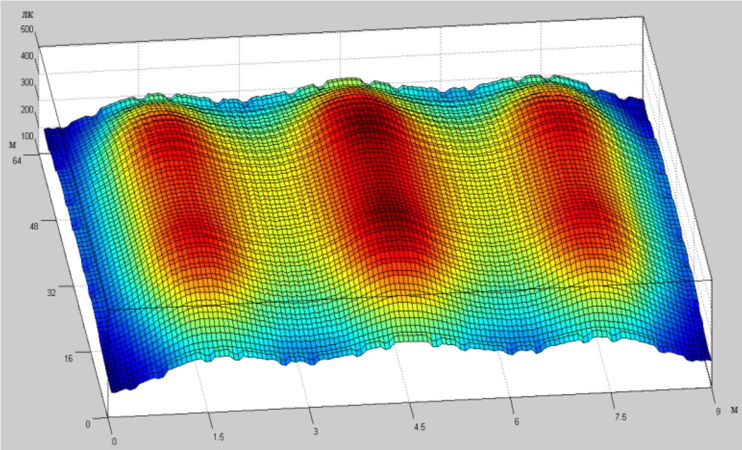


Figure 8. 3D model of the distribution of illumination in the space of the room on the workspace surface level of the room

As can be seen from figure 8, a wavy lighting pattern was obtained in the office space, which is the most improved result in comparison with the hilly pattern obtained in the previous research. It is also worth noting that it is impossible to obtain an ideal picture of illumination provided that lamps are used to one degree or another, as in the case of covering the entire ceiling with individual LEDs, which, of course, is not used in practice. In our case, the main central field of the room is sufficiently illuminated, however, with the presence of areas of overexposure, while there are "dips" along the edges, which is acceptable, but not entirely favorable for comfortable working conditions.

Results and discussion.

Achieving uniform illumination on the workspace surface level of the room is crucial for creating a comfortable environment for students. Among the lighting factors, the greatest attention is usually paid to the photoperiod (duration of daylight), the quantity (intensity) and quality (spectral composition) of light. The uniformity of the flux distribution over the illuminated surface is often ignored, despite the importance of this factor.

In the article [16], the authors also explore the methods of distribution of illumination, as a result, the need to ensure the uniformity of the distribution of illumination for growing crops in a controlled environment is determined. This reflects the need and relevance of this study in various spheres of life of modern society.

When providing lighting with the required value of illumination in accordance with the Building Codes and Rules of the Republic of Kazakhstan, the uniformity of light is no less important than other factors. The uniformity of lighting has a great impact on the health and psychological state of students, since human eyes perceive a light flux of varying intensity.

To sum up, there are two main methods to ensure the optimal distribution of illumination on the workspace surface level of the room. The first method is to self-place LED lamps. This requires an individual approach to each room: lamps will be placed depending on all existing parameters. This method is inappropriate at the architectural and construction level, since not all parameters are stable and, if one of the parameters changes, it will be necessary to recalculate the optimal location of the fixtures and place them in accordance with the new calculation.

The second and most effective method to ensure that optimal illumination is maintained in the classroom is to control the LED modes through a microcontroller. This will further save energy and provide the required illumination with a uniform distribution pattern.

Based on the results obtained, it is planned at the next stage to develop a system for correcting the illumination of the LED lighting system, which will provide the desired level of illumination at given points. The basis of the control system will be performed using the Arduino Uno R3 microcontroller. All software development for the microcontroller will be done in Visual Studio 2015 and Arduino IDE 1.8.3 in C #, and a webcam will be used as a light sensor.

As a result of the study of existing methods of distribution of illumination at the level of the surface of the working space of the room, this article defines the problem of distribution of illumination and presents a way to achieve optimal values. This is the subject of discussion and one of the directions of our further research.

Conclusions.

This article analyzes the existing methods for studying the distribution of illumination. The article defines the most effective method of distribution of illumination on the workspace surface level of the room with optimal values. The studied methods were applied in computer simulation of room illumination using LED lamps. The computer simulation carried out in the article allows to assess the degree of uniformity created in the classroom, as well as to compare it with the energy efficiency of the lighting installation. The article reveals the problem of the uniformity of the distribution of illumination at the level of the surface of the working space of the room. Based on the results of the work, a system for controlling the illumination of an LED lighting system by means of a microcontroller was proposed to ensure uniform lighting in educational institutions.

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