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Increasing the reliability of calculation methods for determining illuminance

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Abstract

The use of modern computer programs is essential for the rapid creation of high-quality lighting, flexible transformation of systems at the design stage to obtain the best engineering solution in every case — reliable, safe, comfortable for performing visual work and acceptable for real installation and subsequent maintenance. The key criterion for choosing light engineering programs is the reliability of the design values, which is expressed by the coincidence of illuminance at control points as a result of measurements and computer calculations. In this case, it is important with what degree of reliability the program calculates the distribution of illuminance in the scene. However, setting of the calculated parameters depending on the complexity of the scene and the tasks performed by the user can significantly affect the accuracy of the results of computer calculations.

The objective to increase the reliability of the results of computer simulation of the lighting installations was achieved by solving the following tasks: identifying the reason for the unreliability of the results of existing calculation methods in comparison with the measured and set values of the errors of determining the parameters of lighting systems on the basis of analysis of existing calculation methods; introduction of the generalized coefficient of maximum error, which takes into account the coincidence of the simulation results with the experimental values obtained when measuring the illuminance at the control points of the room with a digital luxmeter; the proposed expansion of the error of determining the quantitative parameters of the light environment ensures an increase in the reliability of the results obtained using light engineering computer programs, which, in turn, determines their effective application and reduction of the period of reconstruction of obsolete lighting systems.

Keywords: reliability of the calculated values, illuminance, methods of determining the illuminance.

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Introduction

Effectiveness of visual perception is evaluated by how fast and reliable is the recognition of the shapes, details and colors in the existing lighting conditions. From numerous scientific research it is known to what extent the efficiency of the visual apparatus depends on the lighting parameters. The so-called basic visual functions characterize the effectiveness of visual activity, depending on the illuminance in the area of the visual activity, the uniformity of the illuminance in place and time, as well as the distribution of luminance at the workplace and luminance of light within the field of view. In most cases, the increase in illuminance rises the effectiveness of visual activity. Extremely high luminance in the field of view and the effects of gloss due to their dazzling effects can reduce the effectiveness of the visual system.

Therefore, in order to provide a comfortable indoor environment, it is necessary that the lighting system meets the following demands that specify the requirements [1]:

- Sufficient level of illuminance on the working surface and its high uniformity on this surface (if necessary for recognizing specific shapes of objects of recognition) for the rapid correct recognition of all necessary parameters of the object (shape, color, texture);
- Limiting the dazzling effect of light elements of the installation (structural features of the luminaires), preventing the creation of glares with high luminance on the working surface and objects within this surface [2];
- Sufficient saturation of the room with light to avoid significant negative effect of light-modeling effect on the ratio of horizontal and cylindrical illuminance in different lighting schemes [3].

Taking into account the above-mentioned factors with a large number of light-emitting diodes and their switching circuits in order to create a certain lighting scene by the light engineering system made more complicated the multivariate calculations of lighting systems by conventional engineering methods and significantly lengthened the design and determination of the parameters of lighting installations (LIs) [4, 5]. Indeed, the application of modern computer software is essential in these conditions for the rapid creation of high-quality lighting, flexible transformation of systems at the design stage to obtain the best in each case engineering solutions — reliable, safe, comfortable for performing visual work and acceptable for the real installing and subsequent maintenance [6, 7].

Computer light engineering design has significant differences [8] from the standard design methodology based on engineering methods for calculating light engineering parameters. The main tool in this case is the light engineering program (the calculation environment used in the Radiosity method), rather than a set of simplified calculation methods. The calculation of light engineering indicators of illuminance by the Radiosity method is performed on the basis of finite element methods, which forms the main difference between the calculation methods.

The use of light sources in electronic databases significantly shortens the time to search for optimum lighting equipment.

Lighting software allows to calculate the LIs based on real geometric sizes of the illuminated object, have means for detailed simulation of interior and surrounding space [9—13]. They also provide tools for simulation the photometric properties of materials used in a three-dimensional scene, which in general allows the program to use a ray tracing method to create photorealistic images of a future LI.

In the application of light engineering programmers, the following approach to light engineering design, which consists of three stages, is used. At the first stage, a geometric simulation of the lighting scene object is performed. This implies a set of solid state three-dimensional simulation techniques based on existing drawings, photographs and other information. At the second stage, the light engineering calculation is performed with the choice of lighting equipment. At this stage, depending on the calculation program, the optimal calculation parameters are selected: the step of the calculation grid, the method of calculation, accuracy, etc. The third stage is the generation of photorealistic images and the printing of design documentation of the project.

An effective method for physically correct simulation of light propagation is the procedure [14], which is designed on the basis of two-way ray tracing using the Monte Carlo methods. It allows using a single mechanism and algorithmic base to solve a wide class of computer graphics and optics tasks: to synthesize images of photorealistic quality, to calculate and analyze illuminance, to simulate and design complex optical systems and devices.

In most cases, when performing design work there is a need to move from stage to stage and in reverse order to achieve the optimal quantitative, qualitative and aesthetic criteria of LIs. In [2], the influence of input parameters on the final result of the calculation of the Unified Glare Rating (UGR) was analyzed and one of the main input parameters for its calculation was considered, which takes into account the placement against the observer's line of sight.

The criterion for choosing light engineering programs is the reliability of the calculated values, which is expressed by the coincidence of illuminance at control points as a result of measurements and computer calculations.

We will be interested in the degree of reliability with which the program calculates the distribution of illuminance in the scene. Since all programs work with diffuse surfaces, we can talk about the reliability of the calculation of the distribution of luminance.

In order to provide a high-quality and comfortable environment for a room when implementing a lighting model on the basis of computer simulation, it is necessary that the parameters of a LI, determined as a result of computer simulation, would not differ from the reference ones by more than it is established for lighting systems [1]. When checking the characteristics of the light environment and the parameters of LI by instruments of the appropriate accuracy class, it has been shown that the results of computer simulation and the measured values of illuminance do not coincide [9—13].

The purpose of the paper is to increase the reliability of the results of computer simulation of lighting installations, the criterion of which is the coincidence of the results of measurements of illuminance in control points with the results obtained by computer calculation. To achieve this purpose, it is necessary to solve the following tasks: based on the analysis of existing calculation methods to identify the reasons for unreliability of their results compared with the measured; on the basis of analysis of the reasons to propose a method for eliminating the unreliability of the results of simulation.

Analysis of light engineering software

In general, the methods of calculation existing and applied in computer programs can be divided into two groups. The first method is based on a usage rate, which allows to quickly perform a checking calculation (programs Light – in – Night, WinELSO-Light). The second method, the Global Illuminating method, is based on the solution of the global illumination equation and is implemented in all other light engineering programs. Depending on the solution method of this equation, the Radiosity method and the Ray Tracing method can be used to create a realistic image with the accurate simulation of surface luminance in three-dimensional scenes, taking into account multiple diffuse and mirror reflections of light.

It is obvious that the main scatter of values will prevail in the case of multiple reflections, that is, when using a scene with at least two surfaces with nonzero reflection coefficients. On the other hand, some part of the error in the result will be due to the approximation step of the luminous intensity distribution curve (LIDC), which is usually set to 5–10°. This raises the question of what LIDC values will determine the program in the intermediate nodes (points).

Thus, with the application of computer methods of calculation there are a number of problems that need to be addressed [15]:

• Criteria for choosing one or another program depending on the light engineering task;

• Determination of the error of calculation of light engineering parameters in programs in comparison with precise analytical solutions;

• Formulation of the principles of the correlation of light engineering programs with computer-aided design systems (CADs), design and architectural applications;

• Need for development of methods of computer analysis and calculation of illuminance on the basis of the Radiosity method;

• Calculations and estimation of the light field created by LI in space.

Evo version of DIALux program has the option of design and simulation of the whole constructions, switching between internal and external plans is possible, and integrated calculation of the whole construction as a single object. Due to the indicated above, the time spent for calculation does not exceed the previously included in version 4.x for calculating the construction as the amount of successive calculations of its individual premises.

Previously, the Radiosity method was used in DIALux and other light engineering applications. In this method, the exchange of energy between surfaces in the lighting scene, which are conditionally divided into sectors, was calculated. When using an adaptive interconnection, computer simulation provides non-static separation of surfaces within specified grids, and separation with large differences in the growth of illuminance values.

Thus, the high resolution of the visualization is achieved in the shortest possible time. However, this method is the opposite of the usual standard methods in which the grids of calculation points is given as described in EN12464–1 [16]. To fulfill these requirements, the calculation points must be determined before the beginning of the process of calculating the surfaces, or the values of the calculation points should be interpolated according to the results on the surfaces.

This procedure is well tested and provides in many cases with a sufficiently accurate calculation. However, Radiosity has two disadvantages:

1) Calculation of large scenes can take a long time. Separate and simple premises can be calculated very quickly using Radiosity but for a complex geometry of individual premises or the whole buildings the calculation takes a very long period of time.

2) The calculation method takes into account only materials with diffuse scattering. Only a simplified calculation of light-transmitting and mirror-reflecting surfaces is possible with the introduction of some tolerances.

After experiments with several alternative methods of calculation, a photonic method was introduced. According to the light distribution, the radiation is distributed only on visible surfaces. From these surfaces, the photons are redirected — are scattered diffusely or depending on the properties of the material are transmitted or absorbed. The luminance or illuminance of the surface is determined by the number of photons on the surface and their energy. The advantage of this method is the maximum approximation of the distribution of light to the real one.

The photon method has the following disadvantages [17]:

Firstly, simple geometric forms take more time in comparison with using Radiosity method, because the maximum number of photons is used. Secondly, when using a large number of photons on small surfaces, they either collide with the surface or insufficient number of them encounter with each other. For further optimization of the photonic method, a dynamic adaptation of the number of photons to a given situation is required.

On the basis of the analysis of the calculations performed for illuminance with different reflection coefficients and different models according to the models described in CIE171:2006, DIALux evo provides calculated results of high accuracy that can bear comparison with reference test procedures [18]. However, in some cases, the possibility of significant deviations from the reality exists, due to the fact that [18]:

• The effect of photometric distance in the nearest areas is not taken into account;

• The model of the calculation material is very simplified, although the direct reflection, refraction and transmission coefficients was included in the previous model;

• The number of photons used is limited by the permissible capacity and the expected calculation time;

• Scenes with large surfaces, which require high precision results on small surfaces, are problematic for the photonic method used by the system. When limiting the number of photons there is a risk of insufficient number of photons to reach a certain small surface.

Thus, despite all the advantages and attractiveness of the use of computer programs for designing and determining the quantitative parameters of the lighting system, due to the average accuracy laid down in their algorithm of work, all programs in one way or another accurately calculate the distribution of illuminance in the scene, their error is lies within the range of specified tolerances (–10 % ÷ +20 % of the normalized illuminance value). The most accurate results were obtained in two programs of Autodesk and DIALux companies.

Reliability of the results of determination of illuminance

To assess the accuracy of the results of the modeling of the light environment — mainly the horizontal illuminance and its distribution on the working surfaces — it is necessary on the basis of a detailed analysis of the parameters of light environment and lighting system, as well as features of the computer program algorithm, on which the reliability of reproduction and calculation of light environment parameters depends, to introduce a criterion of reliability of program results for their correction in order to increase the probability.

The reliability of the results of computer simulation is influenced by the following factors:

1. Factors δ_i' that depend on the method of calculation:

• Degree of accuracy of the used interpolation methods;

• Necessary mathematical accuracy of the calculations (given accuracy of the calculated results of the program is determined by the number of re-reflected photons);

• Degree of accuracy of the determination of angular parameters;

• Accounting for the fraction of reflected light (for directional radiation, the contribution of this component is maximum);

• Determining the size of the calculated surface, which is set by the value of the edge zone;

• Accuracy of expression of a luminaire's LIDC in *.ies or *.ldt files;

• Uniformity of distribution of illuminance on a working surface;

• Optical characteristics of the furniture and surfaces of the object.

2. Factors δ_i'' that affect the reliability of the calculation results and do not depend on the method of calculation:

• Deviation of light engineering characteristics of LSs from calculated ones [19];

• Deviations of the efficiency values of light-emitting diodes and their LIDC, correction of the luminous flux of luminaires, if the characteristics of LDs being used differ from those prescribed in the program by default [19];

• Minimum information on photometric data of the calculated surfaces;

• Fluctuations of electrical parameters of the network;

• Inaccuracy of the data on the characteristics of the absorbing medium through which the light propagates;

• Degree of accuracy accepted for calculating the values of the operating coefficient;

• Taking into account the possible component of natural light.

Setting of the calculated parameters depending on the complexity of the scene and the tasks is performed by the user and can significantly affect the accuracy of calculation results. On the basis of studies on the parameters of lighting systems and environment scenes, the following intervals of values for the coefficients of simulation accuracy were proposed in accordance with the above group of factors (Table 1).

Thus, for the approximation of the illuminance values calculated in the program to real ones, it is proposed to introduce a generalized error coefficient, which is determined by the formula:

$$K = \frac{\delta_i''}{\delta_i'} > 1, \qquad (1)$$

where δ_i' — error with the account of components that depend on the method of calculation; δ_i'' — error with the account of components that don't depend on the method of calculation and shown in Table 1.

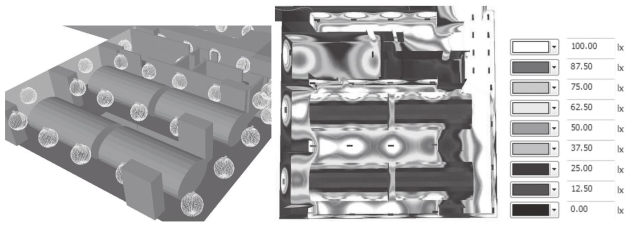
Table 1

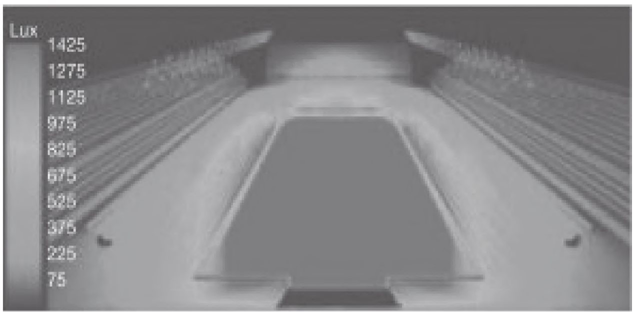
The values of the error coefficients

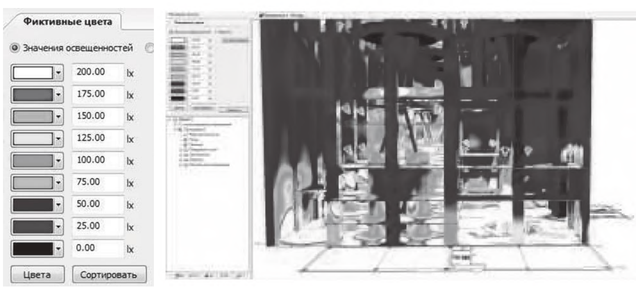
Type of lamp	Halogen lamp	Fluorescent lamp T8 with electromagnetic ballast	Fluorescent lamp T5 with electronic ballast	Compact fluorescent lamp	LEDs	Metal halide lamp	Xenon arc lamp
Deviation of light technical characteristics of LSs for reference ones over 2000 hours, relat. un.	0,5 [5]	0,2–0,3 [19]	0,05–0,15 [5]	0,1–0,3 [23]	0,05–0,1 [22]	0,25 [5]	0,1 [5]
Deviations of the efficiency values of light-emitting devices and their LIDCs, relat. un.	0,10 [19]	0,25 [22]	0,20 [22]	0,47 [22]	0,49 [22]	0,10 [26]	0,20 [26]
Fluctuations of electric network parameters (influence on luminous flux), relat. un.	0,35 [20]	0,50 [21]	0,1 [25]	0,3 [23]	0,09–0,12 [24]	0,25–0,37 [21]	0,25–0,37 [21]
Effect of temperature on stability of work	0,15–0,28 [21]	0,2 [20]	0,2 [25]	0,2 [23]	0,1 [24]	0,1 [21]	0,05 [5]
Combined maximum error value, relat. un.	1,23	1,25	0,65	1,27	0,81	0,82	0,72

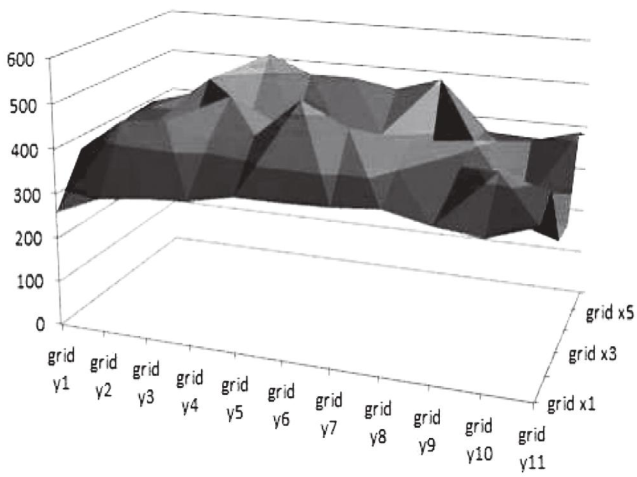
Table 2

Examples of application of the method of the refinement of the results of simulation the lighting environment of constructions for different functional purpose

<table>
<tr><td>Type of the construction</td><td>Results of calculation (distribution of illuminance in fictitious colors, minimum illuminance, type of light sources)</td><td>Illuminance values: A) normalized (plane and height of normalization);
B) measured;
C) corrected with allowance for K coefficient of error (K_δ)</td></tr>
<tr><td>Nuclear power plant
[9]</td><td>

E min = 62 lx; xenon arc lamp</td><td>A) 80 lx (H 0,8)
B) E meas = 102 lx
C) E cor = 106,6
(K_δ=7,2)</td></tr>
<tr><td>Hockey ice arena
[10]</td><td>

1125 lx; metal halide lamp</td><td>A) 1500 lx (H 0,0)
B) E meas = 2020 lx
C) E cor = 2047 lx
(K_δ=8,2)</td></tr>
<tr><td>Room of blast furnace
[11]</td><td>

200 lx; LEDs</td><td>A) 200 (Г 0,8)
B) E meas = 370 lx
C) E cor = 362 lx
(K_δ=8,1)</td></tr>
<tr><td>Classroom
[13]</td><td>

E min =380 lx; fluorescent lamp T5</td><td>A) 400 (Г 0,8)
B) E meas = 585 lx
C) E cor = 577,5 lx
(K_δ=6,5)</td></tr>
</table>

With the account of the accepted accuracy, the maximum value δ_i' can be accepted equal to 0,1. Since when estimating the error we take maximum value δ, its value can reach the sum $\Sigma\delta_i''$. Then the expression for the coefficient takes the form:

$$K \leq 10 \cdot \Sigma\delta_i''. \quad (2)$$

The value of the coefficient K according to the inequality (2) is significantly greater than 1, as can be seen from Table 1.

Taking into account this method, the illuminance values determined by the computer program DIALux for premises of constructions of different functional purpose were refined and compared with those measured by digital luxmeter DE-3350 with an uncertainty of + (4 % rdg + 5 dgt). The results are shown in Table 2.

The data of Table 2 show that when introducing an error coefficient for lighting systems according to its parameters (LSs, LDs, environment conditions and operation), the results of calculations coincide with the measurement results of illuminance, that is, due to the expansion of the error when introducing the coefficient K, the reliability of the results of computer simulation is provided. In the future it is possible to determine the uncertainty budget.

Conclusions

The purpose of increasing the reliability of the results of computer simulation of LIs was achieved by solving the following tasks:

identifying the reason for the unreliability of the results of existing calculation methods in comparison with the measured and set values of the errors of determining the parameters of lighting systems on the basis of analysis of existing calculation methods;

introduction of the generalized coefficient of maximum error, which takes into account the coincidence of the simulation results with the experimental values obtained when measuring the illuminance at the control points of the room with a digital luxmeter;

proposed expansion of the error of determining the quantitative parameters of the light environment ensures an increase in the reliability of the results obtained using light engineering computer programs, which, in turn, determines their effective application and reduction of the period of reconstruction of obsolete lighting systems.

The future area of research is the possibility to determine the uncertainty budget.

Підвищення достовірності розрахункових методів визначення освітленості

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Анотація

Застосування сучасних комп'ютерних програм є необхідним для швидкого створення якісного освітлення, гнучкого трансформування систем на етапі проектування з метою отримання найкращого в кожному конкретному випадку інженерного рішення — надійного, безпечного, комфортного для виконання зорових робіт і прийнятного для реального виконання монтажу й наступного обслуговування. Ключовим критерієм вибору світлотехнічних програм є достовірність розрахункових значень, яка виражається збігом освітленості в контрольних точках у результаті вимірювань і комп'ютерного розрахунку. У цьому випадку важливо, з яким ступенем достовірності програма розраховує розподіл освітленості у сцені.

Досягнуто мети підвищення достовірності результатів комп'ютерного моделювання освітлювальних установок за рахунок вирішення таких завдань: на основі аналізу існуючих розрахункових методів виявлено причини недостовірності їх результатів порівняно з виміряними і встановлено значення похибок визначення параметрів освітлювальних систем; введено узагальнений коефіцієнт максимальної похибки, при урахуванні якого забезпечується збіг результатів моделювання з дослідними значеннями, отриманими при вимірюванні освітленості в контрольних точках приміщення цифровим люксметром. Запропоноване розширення похибки визначення кількісних параметрів світлового середовища забезпечує підвищення достовірності результатів, отриманих за допомогою світлотехнічних комп'ютерних програм, що, у свою чергу, обумовлює їх ефективне застосування і скорочення терміну реконструкції застарілих систем освітлення.

Ключові слова: достовірність розрахункових значень, освітленість, методи визначення освітленості.

Повышение достоверности расчетных методов определения освещенности

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Аннотация

Применение современных компьютерных программ необходимо для быстрого создания качественного освещения, гибкого трансформирования систем на этапе проектирования с целью получения лучшего в каждом конкретном случае инженерного решения — надежного, безопасного, комфортного для выполнения зрительных работ и приемлемого для реального выполнения монтажа и последующего обслуживания. Ключевым критерием выбора светотехнических программ является достоверность расчетных значений, которая выражается совпадением освещенности в контрольных точках в результате измерений и компьютерного расчета. В данном случае важно, с какой степенью достоверности программа рассчитывает распределение освещенности в сцене.

Достигнута цель повышения достоверности результатов компьютерного моделирования осветительных установок за счет решения следующих задач: на основе анализа существующих расчетных методов выявлены причины недостоверности их результатов по сравнению с измеренными и установлены значения погрешностей определения параметров осветительных систем; введен обобщенный коэффициент максимальной погрешности, при учете которого обеспечивается совпадение результатов моделирования с опытными значениями, полученными при измерении освещенности в контрольных точках помещения цифровым люксметром. Предложенное расширение погрешности определения количественных параметров световой среды обеспечивает повышение достоверности результатов, полученных с помощью светотехнических компьютерных программ, что, в свою очередь, обусловливает их эффективное применение и сокращение срока реконструкции устаревших систем освещения.

Ключевые слова: достоверность расчетных значений, освещенность, методы определения освещенности.

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