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A METHOD FOR CROSS-CHECKING THE RESULTS OF LIGHTING LOAD ESTIMATION WHILE PERFOMING ENERGY AUDITING OF INDUSTRIAL PREMISES

A method for cross-checking the results of lighting load estimation while performing energy auditing of industrial premises has been developed. It consists in the expansion of light intensity function in Fourier series and makes it possible to achieve higher reliability of the results obtained by the auditor.

Keywords: *light intensity curve, Fourier series, spatial isoluxes, light flux, luminaire.*

Review of the problem and statement of the task

Current importance of the problem. Lighting systems are an integral part of modern industrial and civil objects. Such systems must meet the criteria of reliability, economic efficiency and safety for human health. To test energy efficiency of lighting systems, audits are conducted at the enterprises. While conducting an energy audit, after the completion of preliminary assessment of energy consumption, energy auditors perform the so-called cross-checking of the data in order to ensure completeness and accuracy of the initial information [1]. Cross-checking is conducted by using another reliable method to obtain energy consumption data and comparing the results with estimated ones. Reliability of the input data, obtained by the energy auditor, is one of the main criteria of the audit study efficiency.

Statement of the research task**.** External and internal lighting systems of large industrial premises, where high-power light sources are used (e.g. mercury arc lamps working for long periods of time), are of great interest to energy auditors [2, 3].

Checking economic efficiency of such lighting systems involves estimation of actual energy consumption. Since the main part of the actually consumed energy is determined by the adopted lighting solutions, there is a necessity of their automated validation.

For calculations 0f lighting several methods are used, which are reduced to the two basic ones: a point method and utilization rate method [4]. Utilization rate method is expedient to be used for calculation of general uniform lighting when there are no shadows. Application of the point method is advisable in both cases: when shadows are present and when there are no shadows, as a rule, for direct-light luminaires.

For calculation of external lighting or lighting of large industrial premises, which is not always uniform, the point method is more expedient to be used. It is impractical for an auditor to use manual calculations for this method realization as it is a time-consuming procedure. It is more efficient to use modern software such as DIAlux, Calculux and others. On the other hand, for cross-checking the obtained results it is necessary to use the approaches that could be validated easily and are convenient for receiving input information [5]. It should be taken into account that usage of software, sometimes, involves complications when characteristics of the necessary luminaire are absent in the database, which is especially true for energy audit of industrial premises with long-used luminaires. Therefore, it is important to elaborate simple methods of audit cross-checking that, for ensuring quick realization, could be implemented using such applications as Microsoft Excel. It is important for these methods to allow using input information about parameters of the luminaires, obtained in any form by the auditor (e.g., light intensity curves found in literary or internet sources).

The main stage of lighting calculations using the point method is determining conditional illuminance e , using isolux curve, for the working surface point characterized by coordinates d (distance from the light source projection for the calculation point on the working surface), and calculation height h (to calculate lighting from circular-symmetrical luminaires).

In [4, 6] procedures for building spatial isoluxes are presented. Particularly, for circular-symmetrical luminaires such isoluxes are built using the expression

$$\mathrm{e} = \frac{\mathrm{I}_{\alpha} \cos^3 \alpha}{h^2}, \qquad (1)$$

where I_{α} is light intensity value for angle α.

A disadvantage of using such isoluxes is inconvenience (bulkiness) of their construction. It is especially noticeable during lighting system design or energy audit when many types of luminaires with different light intensity curves are offered for comparison.

Certainly, ready spatial isoluxes are often used in design practice. They are constructed for definite types of lamps and are given in reference books. However, the nomenclature of lighting products, available at the market, has been constantly expanded and there could be no necessary data for a chosen lamp. In such cases spatial isoluxes are used for lamps with similar character of light distribution. This leads errors in determining conditional horizontal illuminance e, which influences the design or auditing results.

Therefore, it is becoming important to determine e analytically, without using the curves of spatial isoluxes.

The work aims at the development of the method for cross-checking the information obtained about lighting system with circular-symmetrical light sources (luminaires with mercury arc lamps and the similar), which is characterized by the possibility of its implementation using software applications and input information about the parameters of lighting devices, obtained in any form by the auditor.

Substantiation of the results

Analysis of expression (1) shows that for analytical estimation of the conditional horizontal illuminance functional dependence $I_{\alpha}(\alpha)$ is necessary to be found. In the paper it is proposed to obtain relationship $I_{\alpha}(\alpha)$ by expansion of the light intensity values in Fourier series. [7].

Functional dependence of the light intensity can be presented by a trigonometric polynomial

$$I(\alpha) = \frac{\mathrm{a}_0}{2} + \sum_{n=1}^{N} \left(a_{\mathrm{n}} \cos n \frac{2\pi}{\alpha_{\max}} \alpha + b_{\mathrm{n}} \sin n \frac{2\pi}{\alpha_{\max}} \alpha \right), \qquad (2)$$

where N is the number of the polynomial members; $\alpha_{\max}$ – angle comprising the light intensity curve (the interval of the light intensity function approximation will be $[0 \ldots \alpha_{\max}]$); α – angle for which light intensity values are to be found $(0 \le \alpha \le \alpha_{\max})$; $a_n = \frac{2}{m} \sum_{k=0}^{m-1} I_k \cos n \frac{2\pi k}{m}$, here $k = 0,1,2 \ldots m-1$, where m – the number of light intensity values taken from the experimental curve within the period of $(0 \le \alpha \le \alpha_{\max})$; $b_n = \frac{2}{m} \sum_{k=0}^{m-1} I_k \sin n \frac{2\pi k}{m}$.

As an example, we propose to perform cross-checking the results of estimating economic efficiency of lighting loads in the industrial premises where 18 luminaires РСП-16-400-231, intended for general lighting of dusty and wet industrial premises, are used (Fig. 1).

Fig. 1. The exterior of luminaire РСП-16-400-231 and mercury arc lamp ДРЛ 400, used in it

Mercury arc lamps with the power of 400 W are used as a light source in such luminaries. Light intensity curve for this luminaire is presented in Fig. 2.

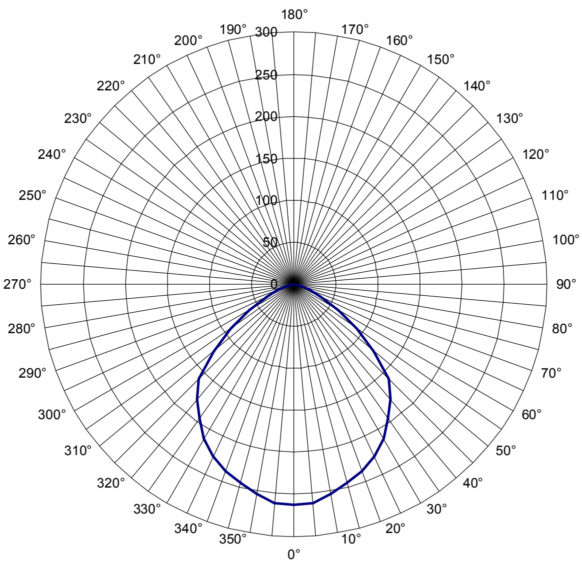

Fig. 2. Light intensity curve for the luminaire РСП-16-400-231

Parameters of the industrial premises, where energy audit of the lighting system was conducted, are as follows: width – 20 m, length – 30 m, calculation height – 5 m. Normalized minimal illuminance at the workplaces is 200 lx.

The values of the luminaire light intensity, corresponding to the curve (Fig. 2), are presented in Table 1.

Table 1

Light intensity values for luminaire РСП-16-400-231

α, °	0	5	10	15	20	25	30	35
$I\alpha$, cd	123	127	127	132	140	157	191	246
α, °	40	45	50	55	60	65	70	75
$I\alpha$, cd	268	285	382	429	314	183	34	8

The results of preliminary calculations by the utilization factor method have shown the expediency of using 18 luminaires, having the lamps with the power of 400W and normalized light flux of 24000lx, in these premises to provide the necessary minimal illuminance in the given points of the working surface. However, after measuring illuminance in the working point using a luxmeter, it was determined that actual illuminance exceeds 200 lx, which is the evidence of the lighting system excessive power.   .

For cross-checking the point method of calculations was used. For its realization spatial isoluxes were built (Fig. 3) for the luminaire РСП-16-400-231 on the basis of values taken from the actual light intensity curve (Table 1).

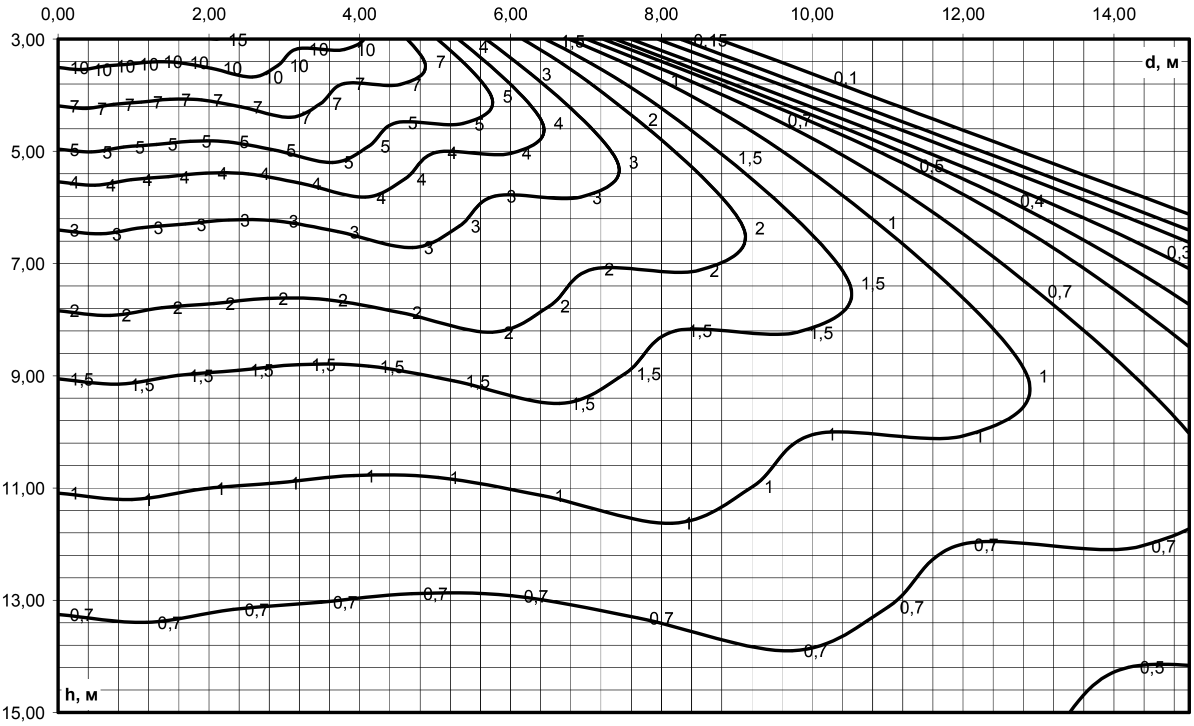

Fig. 3. Spatial isoluxes of the conditional horizontal illuminance for the luminaire РСП-16-400-231

The result, obtained after application of the point method for lighting calculation and the data from Fig. 3, shows that if 18 luminaires are used, it is sufficient to have lamps with a light flux within 18020 lx. Therefore, in the premises 18 lamps with lower power could be used with the light flux less than 24 000 lx. It is also possible to redesign the system for smaller number of luminaires, i.e. there is a possibility to increase the level of energy savings at the enterprise by reducing the lighting power consumption in the premises under study.

In order to check the efficiency of reducing the number of luminaires, it is necessary to redesign the lighting system, using the point method, as the distance between the luminaires has changed. This requires the use of new spatial isoluxes (Fig. 3), which involves spending additional time.

While performing energy auditing, it is necessary to save the time, especially if it is a pre-agreement stage of the auditing study that might not be paid for. In such a case it is important to use the methods, which enable automation of the calculation procedure and quick search for the input information.

For automated determination of the conditional horizontal illuminance *e* dependence $I_\alpha(\alpha)$ was built using expansion in Fourier series:

$$
\begin{aligned}
{}^{2}(\alpha) = {} & 196{,}6 - 113{,}2\cos\left(\frac{2\pi}{75}\alpha\right) - 63{,}9\sin\left(\frac{2\pi}{75}\alpha\right) - 28{,}6\cos\left(2\frac{2\pi}{75}\alpha\right) + 69\sin\left(2\frac{2\pi}{75}\alpha\right) + \\
& + 30{,}6\cos\left(3\frac{2\pi}{75}\alpha\right) + 37{,}8\sin\left(3\frac{2\pi}{75}\alpha\right) + 13{,}9\cos\left(4\frac{2\pi}{75}\alpha\right) - 7{,}9\sin\left(4\frac{2\pi}{75}\alpha\right)\ldots
\end{aligned} \quad . \tag{3}
$$

In this example six polynomial members are used.

As a result of computer simulation with the application of expressions (1) and (3), it was determined that in order to achieve minimal illuminance 200 lx in the most remote point of the working space in the premises, the calculated value of the luminaire light flux can be 19000 lm. It is considerably less than the value of 24000, which is used for calculations by the utilization factor method.

As after using dependence (3) it became easy to automate the calculation procedure, it was proposed to reduce the number of luminaires in the premises from 18 to 12. Quickly obtained result indicated that light flux of the lamps in luminaires must be 23120 lm. Light flux of the real 400W lamp exceeds this value by 3,8%, which corresponds to the permissible deviation of (+20%) [4, 6, 8].

Considering the lighting system calculation using experimentally built spatial isoluxes to be the most accurate method, we can say the following. With the application of analytical function of the light intensity curve (3) the error of determining the lighting flux of a lamp to be installed for achieving the required illuminance is 5,6 %.

Application of the proposed cross-checking method, based on the Fourier series expansion of the light intensity function, leads to positive economic consequences. If to assume that lighting in industrial premises is used 8 hours a day 240 days a year and the consumed energy cost is 1, 2 UAH / KW ·h, the calculated electric energy savings, achieved due to the number of luminaires being reduced from18 to 12, will be 5500 UAH / year.

Thus, the above cross-checking method could be used as a tool for energy auditing studies, especially when the use of modern lighting computation software is problematic due to insufficiency of the required input data. The proposed method is easy to automate using common software such as Microsoft Excel.

Conclusions

1. A method is proposed for cross-checking the results of estimating lighting loads in industrial premises with circular-symmetrical luminaires. The method could be used for energy auditing and makes it possible to obtain more accurate values of lighting loads. Input data for its implementation are light intensity curves for various light sources – both for modern luminaries and for those which are long in use.

2. The developed method implementation does not require building spatial isoluxes of the conditional horizontal illuminance as such illuminance is determined analytically using expansion of the light intensity function in Fourier series.

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