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To cite this article: A V Kudryashov et al 2017 IOP Conf. Ser.: Mater. Sci. Eng. 262 012092

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Justification of Natural Lighting Management for Workplaces with Displays

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Abstract. The article is devoted to the study of the influence of the orientation of light apertures (windows) on the distribution of illumination in a room inside the workplaces equipped with displays. The measurements of natural light were carried out in two similar rooms, in the first room the windows are oriented to the north and in the second - to the south. The normative illumination value in a workplace equipped with a personal computer or display must be between 300 and 500 lux. However, during the daytime, the value of natural illumination at the workplace can exceed the normalized value by several times, and in the morning and evening hours is not sufficient. Such distribution of illumination involves the use a combined lighting control system (with daylight time control and switching on artificial lighting in the morning and evening hours). In the article it is justified that the orientation of the windows in the room does not have a significant effect on the distribution of illumination throughout the room which makes it possible not to take into account the restrictions concerning the orientation of the room's light apertures when combined lighting control systems are used.

1. Introduction
Properly designed workplace lighting is a prerequisite for a person's comfortable work activity, mistakes in lighting design can lead to quick fatigue and poor performance. Natural lighting, in contrast to artificial lighting, has several advantages. First, natural light is more familiar and comfortable for human eyesight than light of artificial lighting installations. And secondly, natural lighting requires minimal monetary costs.

A feature of natural lighting is that the values of illumination in a room created by the sun's rays are in fairly wide ranges. These values may depend on the time of the year, the time of day and the meteorological factors.

The main purpose of this work is to evaluate the effect of the influence of the windows orientation in the room (relative to the sides of the world) on the distribution of natural light in this room. Also in the course of the work, measurements of natural light were made at workplaces equipped with a PC and conclusions were drawn about the compliance of the values obtained with the values established by regulatory documents.

Research methods. Measurements of natural light were carried out in accordance with the [1]. For measuring the illumination was used the luxmeter which has a basic relative error of measurements of illumination no more than ± 8%, which also meets the requirements [1,2]. During the measurement of illumination, the requirements of [3] were also met, according to which measurements of natural
illumination are necessary on days with continuous uniform ten-point cloud cover. The number of control points for the measurement (15) was chosen in accordance with [3].

2. Requirements for natural lighting
The introduction of natural light management systems makes possible to increase the comfort and safety of people staying in the illuminated premises, and obtain additional opportunities for energy saving [4]. At present, with the purpose of creating a light environment that is comfortable for human eyesight, as well as for energy saving, a number of artificial and natural light management systems have been created [5-13].

This system is equipped with special sensors that automatically track the position of the sun, and then calculate the parameters of the lighting management system and the position of the blinds. Also, along with mechanical devices, special composite materials are used, which are applied to the glass and can change the degree of light transmission [14]. A feature of this system is automatic control of the level of natural light in the room through window openings, comparison of this level with a given level of illumination of the working surface and ensuring an appropriate level of illumination.

A normative document in the Russian Federation aimed at preventing the adverse effect of harmful factors of the working environment and the work process on human health when working with a personal computer is [15]. According to this, the presence of natural and artificial lighting in a workplace equipped with a PC is necessary and must comply with the requirements of the current regulatory documents. Also, according to [15], the windows in the rooms should be oriented mainly to the north and north-east, and the window openings should be equipped with adjustable shutters, blinds, curtains, etc. This document regulates the following values of illumination in the workplace with a PC: 300–500 lux on the table surface, and the illumination of the screen surface should not exceed 300 lux.

In accordance with the international standard EN 12464–1: 2011 [16], in workplaces equipped with monitors or technological displays, the required minimum illumination value is 500 lux, and the illumination in workplaces where people permanently reside must be not less than 200 lux. At the same time, lighting requirements apply to workplaces in the premises, regardless of the type of light used – daylight, light of electric light sources or a combination (combined natural and artificial lighting).

We measured the natural light in two similar rooms. The windows in the first room are oriented to the north, and in the second to the south. In each room there are 3 light apertures (windows). The measurements were carried out in the autumn, winter, spring and summer period of the year from 8:00 to 16:00 every hour.

3. Results of measurements and processing of received data
After the measurements, the distribution of the natural illumination distribution in both premises was constructed from the time of the day from 08:00 to 16:00. Graphical dependencies are presented in Figures 1 and 2.

The yellow plane represents the lower limit of the normalized illumination indices in workplaces equipped with a PC of 300 lux. The red plane is the upper limit of 500 lux.

From these dependencies, it can be seen that the level of natural light from 08:00 to 10:00 is insufficient and does not meet the requirements of regulatory documents (300–500 lux).

In the time interval from 11:00 to 16:00 the level of illumination exceeds the standardized level several times. Graphic dependencies show that the orientation of the windows does not have a significant effect on the distribution of illumination. In the absence of direct sunlight, there is no dazzling effect in rooms oriented to the south.

Below is an example of calculating the processing of the results of measuring the illumination at 10:00 in the first and second premises in the autumn period of time (Table 1).
Figure 1. Hourly distribution of the illumination in workrooms "to the north".

Figure 2. Hourly distribution of the illumination in workrooms "to the south".

Table 1. Results of measurement of illumination.

|                | Illumination in the room windows to the north (lx) | Illumination in the room windows to the south (lx) |
|----------------|-----------------------------------------------------|---------------------------------------------------|
|                | 1 window | 2 window | 3 window | 1 window | 2 window | 3 window |
| 1 line         | 241      | 254      | 260      | 220      | 259      | 262      |
| 2 line         | 121      | 130      | 142      | 96       | 147      | 132      |
| 3 line         | 70       | 62       | 70       | 61       | 65       | 68       |
| 4 line         | 38       | 36       | 40       | 39       | 39       | 38       |
| 5 line         | 30       | 30       | 21       | 27       | 32       | 28       |

1. According to [17-20], we find by formula (1) the average value of the illuminances in the first row from the window (horizontally) in both rooms:
\[ \bar{X} = \frac{\sum_{i=1}^{n} x_i}{n} \]  \hspace{1cm} (1)

where \( x_i \) – value of a random variable; \( n \) – sample size.

\[ \bar{x} = \frac{241 + 254 + 260 + 220 + 259 + 262}{6} = 249.333 \]

2. We calculate the variance by the formula (2):

\[ D = \sigma^2 = \frac{\sum (x_i - \bar{x})^2}{n-1} \]  \hspace{1cm} (2)

where \( x_i \) – value of a random variable; \( \bar{x} \) – mean value of a random variable; \( n \) – sample size.

\[ \sigma^2 = \frac{(241 - 251,666)^2 + (254 - 251,666)^2 + (260 - 251,666)^2 + (220 - 251,666)^2 + (259 - 251,666)^2 + (2762 - 251,666)^2}{6-1} = 263,867 \]

3. We find the standard deviation by formula (3):

\[ \sigma = \sqrt{D} = \sqrt{\sigma^2} \]  \hspace{1cm} (3)

where \( D \) – Variance of a random variable.

\[ \sigma = \sqrt{263,867} = 16,244 \]

4. We define the confidence interval for the available values by the form (4):

\[ \bar{x} - Z_{\alpha/2} \cdot \frac{\sigma}{\sqrt{n}} < a < \bar{x} + Z_{\alpha/2} \cdot \frac{\sigma}{\sqrt{n}} \]  \hspace{1cm} (4)

where \( a \) – average value; \( Z_{\alpha/2} \) – value of the function from the standard normal distribution table; \( \sigma \) – standard deviation; \( n \) – sample size.

Since the significance level for the confidence probability of 95\% is 0.05, according to the table of the standard normal distribution, the value \( Z_{0.025} \) equally 1.96.

\[ 249,333 - 1.96 \cdot \frac{16,244}{\sqrt{6}} < a < 249,333 + 1.96 \cdot \frac{16,244}{\sqrt{6}} \]

\[ 236,335 < a < 262,331 \]

The measured values of natural light in the first row from the window in both rooms are within the confidence interval. This indicates that the measured values of illuminances in rooms whose windows are oriented to the north and south form a single general population, and hence the orientation of the window openings does not have a significant effect on the distribution of illumination.

Similarly, measurements were made and calculations were carried out for the remaining rows from the window and time intervals (from 8:00 to 16:00) during the winter, spring and summer.

4. Conclusion

The distribution of natural illumination as a whole does not meet the requirements [16], i.e. the regulated value of illumination of 300-500 lux is not fulfilled, because the illumination value during the period from 08:00 to 10:00 is not enough, and in the period from 10:00 to 16:00 exceeds the
normalized values by 1.5-2 times. For optimal and energy-efficient lighting control, it is advisable to use the lighting management system of a combined type (with the restriction of natural light from 10:00 to 16:00 and the inclusion of artificial lighting in the period from 08:00 to 10:00).

About 84% of all measured values of illumination form one general population. We were able to conclude that the orientation of the light apertures (to the north and to the south) in the rooms does not significantly affect the distribution of natural illumination, and the use of a combined type of lighting management system allows not to take into account the restrictions concerning the orientation of the windows in workplaces equipped with monitors or technological displays.

Acknowledgments
The work was supported by Act 211 Government of the Russian Federation, contract № 02.A03.21.0011.

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