# Study of specific requirements for LED lighting

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**Abstract**. The paper presents a study of the effect of the color temperature of LED light sources on human vision. The analysis of the current normative documents on lighting was conducted, justifying the application of high-efficiency LEDs. The estimation of visual fatigue in view of the correlated color temperature of light sources was made. The perception of LED lighting differs when performing works of different accuracy: for works of small and medium accuracy, the influence of the color temperature can be neglected, because the results of statistical data processing did not reveal any significant differences. When performing works of high accuracy, a significant difference is observed when illuminated by lamps with a color temperature of 4,000-5,000 K. The authors proposed the clarifications of the parameters of LED light in normative documents.

## 1. Introduction

Design of artificial lighting installations is carried out on the basis of sanitary and hygienic standards, providing for different requirements for each type of visual work. Requirements for lighting for premises of industrial enterprises, residential and public buildings (norms of natural, artificial and combined lighting) are established by Russian and international regulatory documents [1-5].

In Russia, the law "On energy efficiency" [6] in force since 2009, which restricts the use of incandescent lamps with a power of 100 watts or more. The law contains the basic concepts and definitions relating to energy efficiency and energy conservation. The law obliges all producers to provide the products (energy-consuming devices, computers and other types of office equipment) manufactured by them with a marking containing information on the class of their energy efficiency. Since 2017 "The requirements for lighting devices and electric lamps" [7]is in effect, which contains requirements for the energy efficiency of light sources, for example, this document recommends the use of energy-efficient light sources that have the greatest luminous efficiency and lifetime.

## 2. Requirements for LED lighting

Today, among the energy-saving lighting sources, the most common are fluorescent lamps and light-emitting diodes. The main advantages of fluorescent lamps in comparison with incandescent lamps are high luminous efficiency and a longer service life (up to 20,000 hours against 2000-3000 hours of incandescent lamps) [8]. But fluorescent lamps contain mercury, which is dangerous for human health and the environment, for this reason, fluorescent lamps require special disposal. In 2014, the Russian Federation signed the Minamata Convention, which regulates the phasing out of production of mercury containing devices, including fluorescent lamps, which will be banned by 2020. Therefore, we should consider an alternative to energy-saving fluorescent lamps – LEDs.

LEDs − the most modern light sources, based on the principle of electroluminescence. When electric current is passed through a boundary connecting two semiconductors of different types of conductivity (p-n junction), energy is extracted in the form of electromagnetic radiation of the visible spectrum − light. LEDs are widely used as sources of the set for outdoor and indoor lighting. Such a spread of light-emitting diodes became possible due to growth of their light flux and luminous efficiency [9,10]. To obtain a white glow, mainly phosphor light emitting diodes are used, consisting of a blue semiconductor emitter in combination with a yellow phosphor coating. The crystal is covered with a layer of gel with a phosphor powder so that part of its radiation is absorbed in the substance of the phosphor and excites it, and a part passes through the phosphor freely. As a result, the mixing of the original blue glow of gallium nitride with the yellow phosphor emission gives white light [10]. According to [9−12], the advantages of LEDs are high efficiency (luminous efficiency over 120 lm/W); service life of more than 50,000 hours; high color rendering index, Ra> 85; various color temperature 2700−6500 K; high strength; absence of inertia when on / off; ecological safety (absence of mercury compounds). The drawbacks include a concentrated light flux (high brightness), a difference in the radiation spectrum from the natural solar spectrum, and a fairly high cost.

Despite the fact that according to some statements, LEDs are able to solve most lighting problems, some researchers state the need for specific requirements for such lighting devices [13]. For example, according to [14], the color rendering index Ra is often not very consistent with the visual perception based on the color rendering in the case of LED light sources, and the illumination by phosphor LEDs of cold white light is potentially dangerous by violating the concentration norms of melatonin in the blood [15].

Russian regulatory documents contain an instruction of the use of light sources with a color temperature of 2400 K to 6800 K, without reference to specific types of light sources and recommendations for the use of light sources with different color temperatures when performing color discrimination operations. This instruction is advisory in nature and does not contain requirements for the color temperature of light sources depending on the accuracy of visual work.

### 3. Results of measurements and processing of received data

One of the tasks of the research conducted by the South Ural State University is to identify specific requirements for LEDs, including requirements for color temperature.

To assess the person's vision, the accommodation apparatus was checked (definition of absolute AVA and relative volume of accommodation RVA) using text tables for checking eyesight and a set of optical glasses.

For the research, an experimental lighting installation was created. In the course of the research, 25 volunteers took part, performing visual work of varying accuracy. The coefficient of pulsation of illumination was 0.2%. LED lighting sources had a color temperature from 3000 K to 6500 K [16]. Table 1 shows the results of a study of the accommodative vision apparatus.

**Table 1.** Indicators of the volunteers accommodative apparatus of the visual analyzer under the conditions of LED lighting with color temperature in the range from 3000K to 6500K.

| Color temperature, K (n=25) | Performing works of high accuracy | | Performing works of medium accuracy | | Performing works of small accuracy | |
|---|---|---|---|---|---|---|
| | AVA, dpt | RVA, % | AVA, dpt | RVA, % | AVA, dpt | RVA, % |
| 3000 | 8,4 | 10,6 | 9,6 | 9,5 | 9,39 | 9,52 |
| 4000 | 9,68 | 9,54 | 9,59 | 9,5 | 9,4 | 9,5 |
| 5000 | 9,65 | 9,52 | 9,57 | 9,52 | 9,36 | 9,36 |
| 5700 | 8,37 | 10,6 | 9,57 | 9,51 | 9,3 | 9,48 |
| 6500 | 8,31 | 10,4 | 9,56 | 9,5 | 9,42 | 9,52 |

Let's carry out statistical processing of experimental results.

1. According to [17-20], we find by formula (1) the average value of of the random variable:

$$\overline{X} = \sum_{i=1}^{n} \frac{x_i}{n},$$
(1)

where $x_i$– value of a random variable; $n$ – sample size.

$$\overline{x} = \frac{8,4 + 9,68 + 9,65 + 8,37 + 8,31}{5} = 8,882.$$

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

$$D = \sigma^2 = \frac{\sum_{i=1}^{n}(x_i - \overline{x})^2}{n-1},$$
(2)

where $x_i$– value of a random variable; $\overline{x}$ – mean value of a random variable; $n$ – sample size.

$$\sigma^2 = \frac{(8,4-8,882)^2 + (9,68-8,882)^2 + (9,65-8,882)^2 + (8,37-8,882)^2 + (8,31-8,882)^2}{5-1} = 0,51207.$$

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

$$\sigma = \sqrt{D} = \sqrt{\sigma^2},$$
(3)

where $D$ – Variance of a random variable.

$$\sigma = \sqrt{0,51207} = 0,71559067.$$

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

$$\overline{x} - Z_{\alpha/2} \cdot \frac{\sigma}{\sqrt{n}} < a < \overline{x} + Z_{\alpha/2} \cdot \frac{\sigma}{\sqrt{n}},$$
(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 $Z_{\alpha/2}$ equally 1,96.

$$8,882 - 1,96 \cdot \frac{0,715590665}{\sqrt{5}} < a < 8,882 + 1,96 \cdot \frac{0,715590665}{\sqrt{5}}$$

$$8,25475713 < a < 9,50924287$$

Based on the results of calculations with a probability of 95%, it can be argued that the values of AVA when performing works of high accuracy, equal to 9,68 dpt and 9,65 dpt, do not fall within the confidence interval, that is, they differ significantly from other values. A similar result was obtained for RVA 9,54% and 9,52%.

Statistical evaluation of the results of AVA and RVA performing works of medium and small accuracy shows, that all values do not go beyond the confidence interval, that is, they do not have significant differences.

## 4. Conclusion
Based on the studies conducted, it was established that the perception of LED lighting differs when performing works of different accuracy: for works of small and medium accuracy, the influence of the

color temperature can be neglected, because the results of statistical data processing did not reveal any significant differences. When performing works of high accuracy, a significant difference is observed when illuminated by lamps with a color temperature of 4000-5000 K, which is also confirmed by subjective feedback from the test volunteers. Such lighting is perceived as close to natural and helps maintain a high degree of efficiency. Restriction of the LEDs correlated color temperature is advisable only when performing works of high accuracy.

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