Measuring the energy efficiency of workplace lighting in industrial enterprises

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Abstract. A model for evaluating the energy efficiency of workplace lighting in industrial enterprises is proposed. The energy efficiency of workplace lighting facilities in industrial enterprises should be understood as the ratio of the power of the artificial lighting object, necessary to bring the workplace illumination to normal, to the power consumed at a given time. An approach to monitoring the energy efficiency of workplace lighting in industrial enterprises is proposed.

1. Introduction
Industrial production according to energy balances is the most energy-intensive, since it consumes more than half of the total volume of energy resources [1]. Specific energy costs in the cost of products produced by Russian enterprises are 1.5-2 times higher than in developed countries [2]. The tendency for a constant increase in resource intensity is inextricably linked with the growth of energy and information saturation of production [3].

Manufacturing has historically been one of the largest sources of carbon dioxide emissions in the world. It accounts for about 38% of global CO2 emissions [4,5].

Growing demand for energy resources, combined with limited supply on world markets, leads to a constant increase in energy prices. Together with the dynamics in pricing, they generate uncertainties for market organizational schemes based on precisely calculated energy costs [6]. Therefore, the increase in energy efficiency becomes a driving force for manufacturing companies in terms of reducing energy intensity and production costs and, as a result, reducing carbon dioxide emissions into the atmosphere.

The structural composition of modern production systems is subordinated to the hierarchical principle [7]. Each level contributes to the conversion of labor items into finished products, is characterized by a certain percentage of non-production energy losses, and also performs background work necessary to maintain the conversion process. Therefore, to assess the energy characteristics of the transformation of labor items at each hierarchical level and at each stage of the production process, it is necessary to identify the useful work performed during this transformation [8, 9].

Lighting is one of the main items of electric energy consumption in industrial enterprises. Electricity consumption for lighting industrial enterprises is constantly growing and is on average 5-30% of their total consumption by industry [10]. In the design of buildings and premises for industrial and domestic purposes, and the subsequent organization of the workplaces, guided by two governing documents: the building regulations – SNiP (used with the direct design of buildings, lighting
requirements they laid at the stage of working drawings) and sanitary rules and norms - SanPiN (applied to jobs in specific buildings).

2. **Energy efficiency of the workplace lighting process**

Energy efficiency should be understood as the ratio of usefully used energy (useful work) to spent energy resources. When considering the issue of workplace lighting in industrial enterprises, useful work should be understood as the illumination of the workplace, i.e. the brightness (the ratio of the luminous flux to the area of the illuminated surface). Exceeding or reducing the level of illumination from a certain norm set by the relevant documents leads to a decrease in lighting efficiency. In addition to natural lighting, artificial lighting is installed in the workplace, which uses energy resources. The lighting scheme for the workplace surface is shown in Figure 1.

![Figure 1. The scheme of illumination of the workplace.](image)

If we assume that artificial lighting of the workplace is able to create a luminous flux $\Phi_s$, while consuming power equal to $N$, then the amount of energy that is usefully used can be considered the amount at which the luminous flux created by it is able to compensate for the deviation of illumination from the norm.

Therefore, the energy efficiency of workplace lighting facilities in industrial enterprises should be understood as the ratio of the power of the artificial lighting object required to bring the workplace illumination to normal to the power consumed at a given time.

The lighting mode depends not only on the characteristics of the lamps, but also on the place where they are installed. Therefore, the dependence of the illumination of the workplace on the power consumption will be considered known in advance (see Figure 2). It can be obtained experimentally.

![Figure 2. The characteristic of lighting equipment is the dependence of illumination on the energy consumed.](image)
The standard of illumination $E_n$ of the surface of the workplace also depends on the time. During non-working hours and on weekends, lighting is not required or should be provided at a minimum level, for example, due to on-duty lighting (see Figure 3).

Then the energy efficiency of the workplace surface lighting process can be expressed as follows

$$\eta = \frac{N(E_n(t) - E)}{N}$$

where $N$—power consumption, Вт; $E_n(t)$—the rate of illumination at a given point in time, Лк; $E$—the current value of the light, Лк; $N(E)$—function that returns the value of the power of the light source, at which the luminous flux created by it is able to compensate for the deviation of illumination from the norm $|E_n(t) - E|$, Bm.

3. Monitoring the energy efficiency of the workplace lighting process
To monitor the energy efficiency of workplace lighting, it is necessary to measure the level of illumination and control the cost of energy resources.

The diagram of the organization of the energy efficiency monitoring process is shown in Figure 4.
In this figure, the following designations are introduced: LS – light sensor; DPD – data processing device; EEMS – enterprise energy efficiency monitoring system. The DPD calculates the performance indicator. After that, its value is transmitted to the EEMS, which monitors the energy efficiency of not only lighting processes, but also production processes.

4. Conclusion
At the highest hierarchical level, one of the main barriers to improving energy efficiency and, as a result, improving the competitiveness of products is also the conservatism of management in this area. Business leaders often underestimate the high degree of savings from energy efficiency programs. They believe that there is a certain degree of technical and financial risk in their implementation. These programs have a lower priority compared to traditional commercial offers. In addition, with relatively low energy costs, it is difficult to convince management of the need to implement complex projects to improve energy efficiency. Although it is known that programs for efficient energy consumption are also necessary in enterprises where the cost of energy is about 5% of the cost of production [4, 5, 6].

Automatic smooth regulation of artificial lighting will increase its energy efficiency, especially in the daytime, when the norm of illumination of the workplace is achieved by natural lighting of the premises.

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