Automation of artificial lighting design for dairy herd cows

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Abstract. The article presents the results of experiments with the use of the developed energy-efficient LED-based lighting device for illuminating the horizontal working surface in livestock houses. The implementation of maintaining the magnitude and mode of illumination was carried out using programmable logic controllers. The results of the effect of the developed LED luminaire on the health and productivity of black-and-white dairy cows are given. The main indicators of the quality of milk in the control and experimental group after 30, 60 and 90 days were determined. It has been established that the use of the visible spectrum of artificial light emission with an adjustable amount of light does not adversely affect the cows' organism, but rather stimulates its activity, which contributes to more abundant feed consumption and an increase in milk yield, and, accordingly, a reduction in production costs. The maintenance of the magnitude and mode of illumination using programmable logic controllers of the German company Schneider Electric has been implemented.

1. Introduction

According to the results of the analysis of the state and prospects of development of the dairy farming industry, it has been established that the most expensive energy carrier in dairy farming is electricity [1, 2, 3]. Cows are long-day animals, so they are sensitive to the effects of light, and for them the rhythm of changing day and night is very important. In particular, during the daytime in the open air, as soon as the light reaches the sensitive eye shell, the cow's nervous system sends a signal to the pituitary gland in the brain so that it reduces the production of the hormone melatonin. This hormone causes drowsiness, increases the percentage of body fat and inhibits the animal's ability to produce milk [4, 5]. The diurnal rhythm of cow activity and physiological processes are closely related by reflex to the natural mode of day and night lighting. If during the summer period the illumination and the duration of the daylight correspond to the physiological needs of the cows, then in the autumn-winter time there is a lack of natural light, which they are trying to compensate by using artificial sources. It has been established that properly selected lighting has a positive effect on health, fecundity, and metabolism, provides an increase in animal productivity, but is energy-intensive. Taking into account the Federal Law of the Russian Federation on November 23, 2009 No. 261 (Ed. 10.08.2018) “On Energy Saving and Improving Energy Efficiency and Making Amendments to Certain Legislative Acts of the Russian Federation”, it is necessary to solve energy saving issues, develop new electrical technologies and use the latest scientific advances for efficiency [6, 7]. For the implementation of energy-saving electrical technologies...
in the lighting of livestock enterprises, a program has been developed based on the graphical programming language of the FBD standard.

2. The object and method of research
In one of the farms of the Republic of Tatarstan, studies were conducted to analyze the effect of artificial radiation of a LED luminaire on the health and productivity of black-and-white dairy cows while maintaining the length of daylight hours according to physiological activity and daily rhythm of the cows. The implementation of maintaining the magnitude and mode of lighting was carried out with the use of programmable logic controllers (PLC) of the German company Schneider Electric. The lighting mode control program is developed on the basis of the graphical programming language of the FBD standard of the international standard IEC 6-1131/3. The FBD language solves the problems of process control, is a visual tool for programming control and regulation circuits. The program implements a circuit consisting of a set of functional blocks interconnected through inputs and outputs, which allows the use of a project visualization to simulate various situations of controlling the parameters of illumination.

For the experiment two groups of dairy cows were formed on the principle of pairs of analogues, each with three heads. For lighting, 85 W compact fluorescent lamps were used in the control group, and an experimental LED luminaire was used in the experimental group [8]. According to the proposed design and calculation methodology of the LED-based lighting device [10, 13], a prototype LED luminaire was manufactured with the following parameters: 600 mm long, seven LED lines, 10 mm distance between LEDs on one line, angle between lines - 15 °, LED axial light intensity - $I_0 = 20$ cd and radiation angle - $a_0 = 30$ ° [4, 11, 12].

![Image of FBD program for Schneider Electric PLC](image_url)

**Figure. 1** A fragment of the program for the Schneider Electric PLC, written in FBD, to control the operation of LED-based lighting devices.
The duration of daylight hours averaged sixteen hours, which corresponds to the physiological needs of dairy cows. There are two working and main lighting switches “B33” and “B43”, if it is necessary to turn on the lighting during a period not specified in the process, the lighting can be switched on using the switches (Fig. 1).

The controller regulates the amount of lighting. Depending on the amount of illumination set by the parameters “B23”, “B24” and “B25”, the illumination time will vary, the time periods are set in the program by the timers “B55”, “B56” and “B57” that work on the principle of switching off after a certain time. The timer is included in the work after performing a comparison of the actual value of the illumination "IG" and the specified parameters "B23", "B24" and "B25". Comparisons are produced by the “B20”, “B21” and “B22” comparators. Comparison of the dose occurs according to the principle (the actual dose of illumination from the set illumination parameter): if the condition is met, a certain timer enters into operation, based on the fact that the actual illumination can be greater than all the set parameters of the illumination value – the countdown will start for all timers. Depending on the need to adjust a certain amount of illumination, it is necessary to change the dose parameters “B23”, “B24” and “B25” and the time of the timers “B55”, “B56”, and “B57”.

The system of keeping animals in the farm is stall-grazing. In the stall period, animals are kept in typical barns in stalls on a leash. The feed is distributed by a mobile feeder, the watering is automatic, the manure is removed by a SMC-type scraper manure conveyor. Milking of cows is carried out directly in the stalls by portable milking machines into the linear milk line. To estimate the productivity of cows once a month, the average daily milk yield, mass fraction of fat and protein in milk, nonfat milk solids and density were determined. To estimate the physiological status of the animals, blood samples were taken at the beginning and at the end of the experiment, which were examined using a Mindrey BC2800Vet hemoanalyzer.

At the beginning of the experiment, the daily yield of cows in the control and experimental groups was the same and amounted to 10.43 kg, with a content of fat mass fraction of 3.53-3.55% and protein 3.04-3.06%, nonfat milk solids and density also differed slightly and amounted, respectively, to 8.29-8.30% and 28.61-28.65 kg/l [7, 9]. After installing the LED luminaire at a height of 2.0 m above the aft table, the illumination was 130 lx, which does not exceed the standard values. After installing the LED luminaire, the main indicators of the milk of cows of the control and experimental groups were determined in the following periods: after 30, 60 and 90 days (Fig. 2).

![Figure 2](attachment:image.png)

**Figure 2.** Dynamics of average daily milk yield for three months

The increase in milk yield in the control group, a month after the luminaire was installed, was 0.28% or 0.03 kg, whereas in the experimental group it was 1.62%, which was 0.17 kg. After 60 days, the cow
yield in the control group increased by 0.07 kg or 0.67%, and in the experimental group this increase was 0.37 kg or 3.54%. The increase in the amount of milk was due to greater feed intake and the irritant effect of light on the retina, which, in turn, affects the behavioral reactions of cows. In the third month of the experiment in these groups, there was a slight decrease in milk yield (0.1 kg). This is due to the physiological state of the cows (7 months pregnancy). During the experiment, the average daily milk yield of experimental cows increased by 2.58% and amounted to 10.7 ± 0.2 kg, while in the control group it increased and amounted to 10.45 ± 0.19 kg, which is statistically significant ($P < 0.95$) (Fig. 3).

![Figure 3](image)

**Figure 3.** Dynamics of the average daily change in the mass fraction of fat

On average, over the entire study period, the content of fat mass fraction in the milk of the control group was 3.56 ± 0.04%, and in the experimental group – 3.60 ± 0.03%. The content of the mass fraction of protein, nonfat milk solids and the density of milk remained almost unchanged. The physiological status showed that at the beginning and at the end of the experiment all the cows were clinically healthy. The evaluation of economic efficiency showed that in the experimental group the milk yield of cows increased, on average, by 3.54% or 0.37 kg, and in the control group - only by 0.67% or 0.07 kg. At the same time, the cost of electricity for the production of one liter of milk in the control group amounted to 32.53 rubles, while in the experimental group – 6.72 rubles.

3. **Conclusion**

The use of LEDs allows you to get almost any dose of spectral components, but the adjustment of the spectrum is carried out mainly manually. The use of a PLC would improve the efficiency of LED-based lighting devices, due to the possibility of controlling the amount of illumination, which will lead to an increase in productivity. It was established that light source in question does not have a negative effect on the organism of cows, but on the contrary stimulates its activity. This effect is manifested in increasing the productivity of animals. Artificial illumination at the proper level imitates long summer days, the natural activity of cows increases, which contributes to a more abundant feed intake and an increase in milk yield and, accordingly, a reduction in production costs.

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