Methods for assessing the parameters of LED-based lighting in livestock houses

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Abstract. In connection with the massive transition to energy-efficient equipment in livestock and production facilities of the agro-industrial complex, in order to save electricity, the creation and development of modern scientifically-based LED lighting devices is one of the pressing problems of technological lighting. The article presents the methodology and the calculation algorithm on the basis of which the program for calculating the main design parameters of the LED lighting device for livestock houses has been developed. The program and the algorithm of the program allow you to calculate and evaluate the design parameters of the lighting device that ensures uniform distribution of illumination at the lowest cost of electricity in livestock houses. The methodology can be adapted to assess the effectiveness of the application of the LED-based lighting in the livestock, poultry and crop facilities with a linear longitudinal lighting system.

1. Introduction
Light has a positive effect on the body of an animal and a bird. Visible rays of light affect the functions of the central nervous system through the visual apparatus and through it reflexively to the functions of other organs. Often, daylight hours are less than 7–8 hours, especially in winter, which adversely affects animals. The properly organized lighting system allows you to influence the age of puberty, to ensure an optimal mode of development of animals, to increase productivity [1, 2]. Therefore, to increase the daylight and the quality of lighting in livestock houses sources of artificial light are used. In recent years, there has been a massive transition to energy-efficient equipment in livestock and production facilities of the agro-industrial complex, in order to save electricity [3, 4]. For technological lighting in order to save energy, LED-based lamps are used [5, 6].

2. The object and method of research
Creating optimal lighting conditions with minimal power consumption is an urgent problem of technological LED-based lighting. The properly organized lighting system allows you to influence the age of puberty, to ensure an optimal mode of development of animals, to increase productivity [11, 14, 15].

One example of such luminaire is a LED-based lighting device [7, 8], which provides normalized illumination on a horizontal working surface. However, the calculation of LED-based lighting devices providing normalized illumination with minimal power consumption is quite complicated and time-
consuming. For the calculation of the parameters of the lighting system, a methodology and a calculation algorithm have been developed on the basis of which the program has been worked out that allows evaluating the distribution of the luminous flux taking into account the configuration and geometry of the LED-based lighting device [9, 10, 13]. The program is developed in a software environment in a graphical programming language standard C++. The task of the calculation is the selection and calculation of the parameters of LED-based lighting devices providing the smallest deviation of the values of the maximum value of illumination ($E_{\text{max}}$) and unevenness of illumination ($Z$) from their required specified values $E_{\text{req}}$ and $z_{\text{req}}$, assessment of the optimal number of LEDs located linearly in one luminaire integrated into the system of the livestock house.

The quality of lighting is estimated by the maximum value of illumination and unevenness and is determined by:

$$Z = \frac{E_{\text{min}}}{E_{\text{av}}}$$

(1)

where $E_{\text{av}}$ - the average value of illumination, $E_{\text{min}}$ - the minimum value of illumination.

As the variable parameters, we choose:

1. Distance $d$ between the lamps.
2. Height $H$ of the suspension of the lamp.
3. Distance $a$ from the edge of the luminaire to the first lines of LEDs.
4. Angle $\alpha$ from the inclined part of the lamp and its upper surface.
5. Length $b$ of the sloping part of the lamp.
6. Angle $\varphi$ setting the position of the first line on the lamp.
7. Number of $N_i$ LEDs on the $i$th line, $i = 1, 2, ..., k$.

For the selection of parameter values, the task of minimizing the function is presented:

$$F = \left( \frac{E_{\text{max}} - E_{\text{req}}}{E_{\text{req}}} \right) + \left( \frac{z_{\text{max}} - z_{\text{req}}}{z_{\text{req}}} \right) \rightarrow \min.$$  

(2)

Considering that the luminaires in the cattle-breeding premises are located at the same height and at an equal distance, the distribution of illumination can be considered periodic, with the exception of the limits of the room. Therefore, the assessment of the quality of illumination is carried out on the contributions of three luminaires located linearly for the site area.

Since the function $F$ depends both on the continuous variables $d, H, a, b, \varphi$, and on discrete $N_i$, $i = 1, 2, ..., k$, it is non-differentiable. To solve the problem (2), the genetic algorithm method with real coding was used [12]. A genetic algorithm is a mathematical method of numerical heuristic search used to solve problems of finding a minimum of a function and imitating the properties of biological systems such as the reproduction of progeny from strong ancestors, mutation, adaptation, etc. This method has several advantages: the possibility of finding a global minimum in the field of search, no deterioration of the solution at each iteration, the simplicity of setting corridor constraints.

Each light fixture is described by a set of values that characterize the configuration of the lighting system. For example, when using a luminaire with seven lines of LEDs, the lighting device $F$ consists of 10 elements:

$$F = (d, H, a, b, \varphi, N_1, N_2, N_3, N_4)$$

(3)
To automatically calculate the configuration of the lighting device, it is necessary to set the lower $F_{\text{low}}$ and the upper $F_{\text{up}}$ limits of the change of each element. Then the $i$th element $\zeta_i$ will be calculated as follows:

$$\zeta_i = \frac{F_i - F_i^{\text{low}}}{F_i^{\text{up}} - F_i^{\text{low}}} \in [0...1]$$  \hspace{1cm} (4)

where $F_i$ – the $i$th configuration element.

The final settlement is as follows:

$$F_i = F_i^{\text{low}} + \zeta_i (F_i^{\text{up}} - F_i^{\text{low}}).$$  \hspace{1cm} (5)

When calculating the integer elements of the lighting device, rounding to the nearest integer is used. When generating the initial optimization, each parameter is given by a random number in the range from 0 to 1. The optimality of the lighting device is calculated using function (2). Moreover, the smaller the value of the function $F$, the more optimal the lighting device is. The described method of the calculation is presented in the form of a block diagram (Fig. 1).
3. Conclusion
A certificate of state registration of the computer program [10] was obtained on the proposed calculation program which allows you to significantly simplify the calculations of the parameters of the LED lighting device that provides normalized illumination on a horizontal working surface with minimal energy consumption. The program allows evaluating the distribution of luminous flux, taking into account the configuration and geometry of the LED-based lighting device. The technique can be adapted to assess the effectiveness of the application of the LED-based lighting in the livestock, poultry and crop facilities with a linear lighting system.

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