# Designing and Implementing Intelligent Lighting Control System

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**Abstract**
The article is devoted to the study of the modes of light source operation as control objects in intelligent lighting control systems. The article analyses the characteristics of light sources that should be taken into account when developing a control algorithm. The modes of operation in intelligent lighting control systems that can achieve the lowest power consumption are determined. It was found that the most critical for the control system and the observer (human) are the transient processes of switching on light sources. To study these processes in electrical circuits with light sources, a measuring information system was constructed. An analytical dependence of the maximum frequency with which a fluorescent lamp can be switched on in the supply network so that the light from it is perceived by a person as separate flashes are obtained. The duration of visual fixation of the human eye was taken into account. To research the operation of semiconductor light sources in lighting systems with an intelligent control system, an experimental lighting system based on the ATmega328 microcontroller was constructed. It implements a dynamic lighting control algorithm based on signals from motion and light sensors. Using this lighting system, the modes of smooth switching on of LED lamps were studied. By interviewing respondents, the most comfortable time for a person to switch on the lighting smoothly was determined.

**Keywords 1**
Smart homes, intelligent lighting control systems, LED lamps, fluorescent lamps

## 1. Introduction

Smart Lighting is one of the key control components in the Smart House intelligent system [1]. Its main task is to provide comfortable conditions for people and reduce their role in managing processes in the house. Such systems allow for automatic or remote control via Wi-fi or the Internet [2,3,4] of the illumination of objects, the spectral composition of lighting, the direction of the light flux, switching off depending on external programmed actions, and many other user-defined functions. A smart system can be centralized or decentralized [5]. The first variant of the system involves the management of a special controller that is used to process information received from sensors and generate control commands. If a decentralized type of lighting is installed in a Smart House, each lighting device is equipped with individual memory and a microcontroller. Centralized Smart systems are the most common, as they take into account a greater number of factors that affect the required lighting level [6]. They can be used both for one room and for the entire building.

Light sources are the objects of control in Smart Lighting [7]. Currently, there are mainly two types of light sources used in residential or office premises. LED lamps prevail in residential buildings and fluorescent lamps in office buildings. Each has its own advantages and disadvantages. For example, fluorescent lamps are large, require special starting and control equipment, and switch on at rated power after a certain time [8]. LED lamps do not have these disadvantages, but they are very bright, which can cause glare, are sensitive to overheating, and have a lower colour rendering factor [9]. Given this, both the first and second lamps can be used in intelligent lighting control systems, depending on the tasks at hand.

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Lighting office spaces, corridors, basements and warehouses require significant energy resources. Even with energy savings using modern gas-discharge fluorescent lamps, lighting costs are still significant. Lighting technologies based on LED light sources can solve this problem and save energy [10]. The use of intelligent lighting control systems also provides significant energy savings. This is especially noticeable in rooms where people are not constantly present.

Intelligent lighting control systems use two main methods to reduce energy consumption. The first is to adjust the brightness of light sources. The second is switching off lighting in places where people are no present. Light-level sensors are most often used to control the brightness of light sources. In the second case, motion or presence detectors are used. The combination of these two methods provides a significant energy-saving effect [11].

In intelligent lighting control systems that operate in rooms with dynamic lighting, light sources can be in frequent switching on/off modes. In this case, the transient processes that occur when they are switched on and the reaction of people to switching on the light should be taken into account. If the switch-on process parameters are correctly selected, people will feel comfortable and the light sources will last longer. However, there are currently no clear recommendations for intelligent dynamic lighting control systems that take into account the physical processes in light sources, human physiology, and lighting quality that does not cause discomfort to people.

## 2. Materials and methods

The operation of fluorescent lamps in cases of frequent switching on and off was studied using a measuring information system based on a personal computer with an analog-to-digital converter module. This allows creating signals of measurement information about several physical quantities simultaneously within arbitrary time limits and saves them to the hard drive for further viewing and processing.

To convert the physical quantities under study, which occur during lamp operation, into signals of measured information, voltage, current and illumination transducers were developed and constructed.

The switching of the research electrical circuits and their branches is carried out in accordance with a given algorithm by electronic switching devices connected to a computer port.

Information about current, voltage, and illumination is transmitted from the measuring transducers (Figure 1) to the analog-to-digital converter and stored on the hard drive of a personal computer. Depending on the state of the system under study and the specified algorithm of the experiment, the MIC switches the electrical circuit and its branches. In this way, the MIC comprehensively controls the onset of transient processes and records and digitally stores data on the behavior of measured physical quantities in electrical circuits of any configuration.

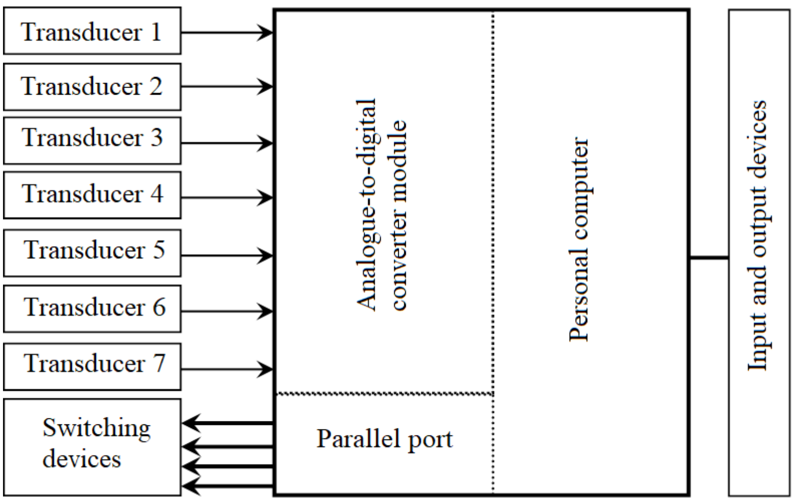



**Figure 1**: Block diagram of the measuring information system

Experimental studies of the peculiarities of transient processes of preheating fluorescent lamp electrodes were carried out in the circle shown in Figure 2. The preheating current was changed using a specially manufactured ballast throttle.

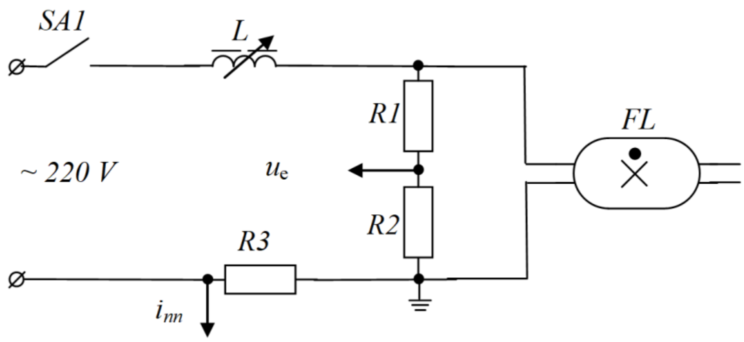



**Figure 2**: Electrical schematic diagram for studying transient processes of preheating of fluorescent lamp electrodes

To obtain reliable research results, the measurements were carried out repeatedly. The statistical processing of the results was based on the theory of errors. According to this theory, to obtain reliable results, it is enough to make 6 measurements at each point for each lamp.

From the obtained voltage oscillograms on the electrode $u_e$ (Figure 3), the duration of the preheating transient process was determined, which begins when the voltage is applied to the electrode (closing of SA1 key) and ends when the voltage on it reaches a steady-state value [12].

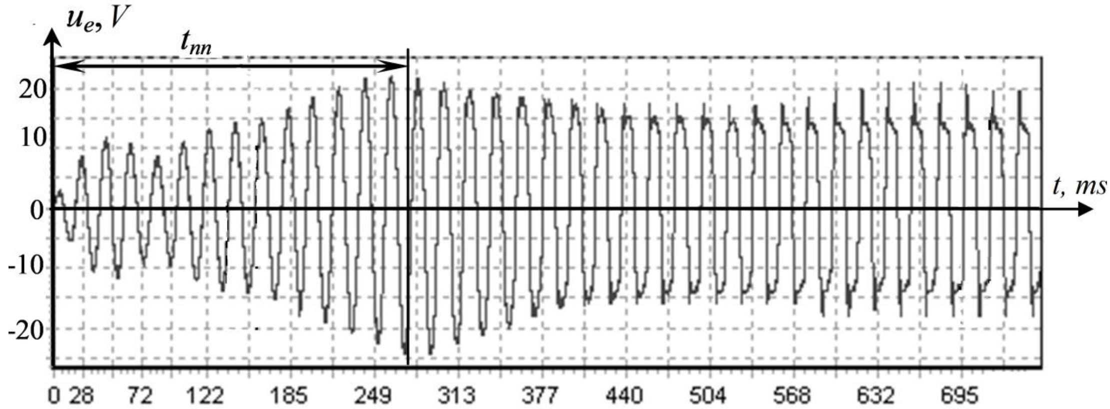



**Figure 3**: Voltage waveform on the electrode of a fluorescent lamp

To study the operation of semiconductor light sources in lighting systems with an intelligent control system, an experimental lighting system was made. It operates on the basis of the ATmega328 microcontroller (Figure 4) and is located in a 35-meter-long corridor. In this experiment, linear LED lamps were studied. The lighting is switched on based on signals from motion sensors when a person appears in the area of their action [11]. The lights are switched off after a time delay, provided that there are no people in the area of motion detection. The intelligent control system also responds to the level of natural light measured by the light sensor [13]. If it meets the standards, the lighting will not be switched on and no electricity will be consumed.

This lighting system implements a dynamic lighting control algorithm. When a person is detected by the motion sensor, a signal is sent to the microcontroller (Figure 4). The motion sensor is bi-directional and detects the movement of people both towards and away from the luminaire. This makes it possible to determine the direction of human movement. Based on the sensor signals, the microcontroller switches on the corresponding luminaires. Figure 5 shows a lighting system with LED lamps switched on.

Since the greatest distance to the controlled light sources and motion sensors was 17 m, information cable lines were used to transmit control signals (Figure 5, b)

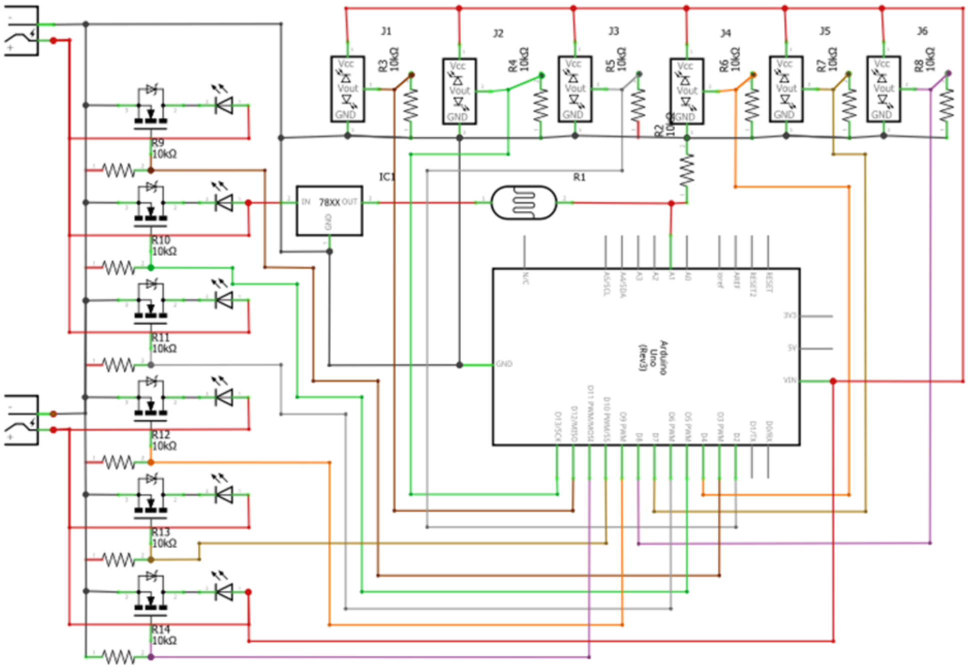
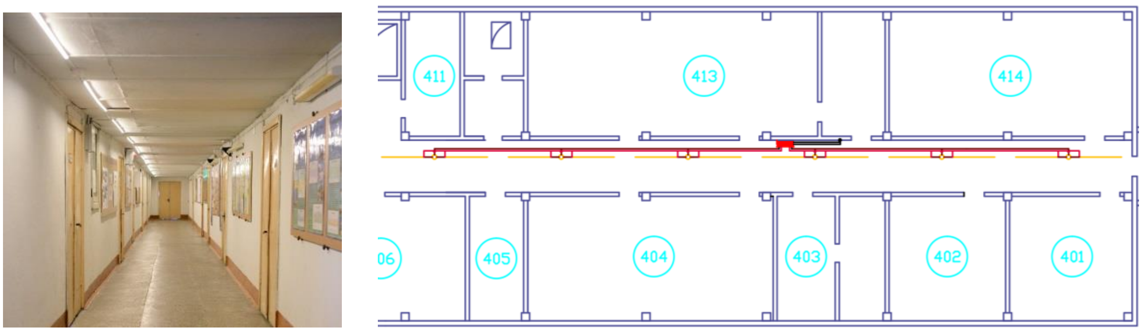



**Figure 4**: The electrical circuit of the experimental installation of the LED lighting control system




a) b)

**Figure 5**: Experimental lighting system for a straight corridor: (a) appearance and layout of LED luminaires (b)

## 3. Experiment and results

The use of fluorescent lamps in lighting system with a control system faces a number of challenges. One of them is the short-term preheating of the lamp electrodes before switching on. Its presence creates a delay before switching on [14]. This should be taken into account when designing intelligent lighting control systems. Therefore, experimental studies were carried out to determine the duration of the preheating mode of fluorescent lamp electrodes. The lamps were switched on according to the scheme in Fig. 2. After closing the SA1 key, the time of the preheating transient was measured. These measurements were performed for different values of preheating currents. Their main results are shown in Table 1. To summarize the results, the value of the preheating current multiplicity ($k_I$) was specified. This value is dimensionless and equal to the ratio of the preheating current to the rated operating current of the lamp. Due to the fact that the duration of the transient processes of preheating the electrodes of fluorescent lamps of different wattages at the same current multiplicity is different (Table 1), a dimensionless value of the multiplicity of the duration of the transient process of preheating the electrodes was specified to determine the absolute values of the preheating duration (1).

$$k_t = \frac{t_{ph}}{t_{ph.n}}, \qquad (1)$$

where $t_{ph}$ – is the duration of the transient process during electrode preheating at a preheating current multiplicity other than 1, s;

$t_{ph.n}$ – is the duration of the transient process when preheating the electrodes with the nominal current ($k_I = 1$), s.

**Table 1**

Results of studying the duration of the transient process of preheating lamp electrodes

| | **Fluorescent lamp 6 Watt** | | | | | **Fluorescent lamp 8 Watt** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Current, A | 0,160 | 0,200 | 0,240 | 0,280 | 0,320 | 0,145 | 0,181 | 0,218 | 0,254 | 0,290 |
| $k_I$ | 1,00 | 1,25 | 1,50 | 1,75 | 2,00 | 1,00 | 1,25 | 1,50 | 1,75 | 2,00 |
| $t_{ph}$, s | 2,65 | 1,35 | 0,76 | 0,55 | 0,30 | 2,10 | 1,25 | 0,62 | 0,28 | 0,27 |
| | **Fluorescent lamp 13 Watt** | | | | | **Fluorescent lamp 15 Watt** | | | | |
| Current, A | 0,165 | 0,206 | 0,247 | 0,288 | 0,330 | 0,33 | 0,412 | 0,495 | 0,577 | 0,66 |
| $k_I$ | 1,00 | 1,25 | 1,50 | 1,75 | 2,00 | 1,00 | 1,25 | 1,50 | 1,75 | 2,00 |
| $t_{ph}$, s | 3,31 | 1,91 | 0,95 | 0,62 | 0,38 | 2,45 | 1,42 | 0,77 | 0,34 | 0,24 |
| | **Fluorescent lamp 18 Watt** | | | | | **Fluorescent lamp 36 Watt** | | | | |
| Current, A | 0,370 | 0,463 | 0,555 | 0,648 | 0,740 | 0,43 | 0,538 | 0,645 | 0,753 | 0,86 |
| $k_I$ | 1,00 | 1,25 | 1,50 | 1,75 | 2,00 | 1,00 | 1,25 | 1,50 | 1,75 | 2,00 |
| $t_{ph}$, s | 2,64 | 1,65 | 0,95 | 0,56 | 0,26 | 4,36 | 2,30 | 1,25 | 0,63 | 0,40 |

Based on the results of calculating the $k_t$ value for lamps with power from 6 to 36 W, a graph was constructed (Fig. 6). The graph (Fig. 6) shows that the multiplicity of the duration of the transient process of electrode preheating for a given value of $k_I$ does not depend on the lamp power and there is a large convergence of $k_t$ values for lamps of different power at the same current multiplicity. Using an exponential curve approximation, the dependence of $k_t$ on $k_I$ was obtained (2) with a standard deviation of 0.09.

$$k_t = 9,48 \cdot \exp(-2,26 \cdot k_I), \qquad (2)$$

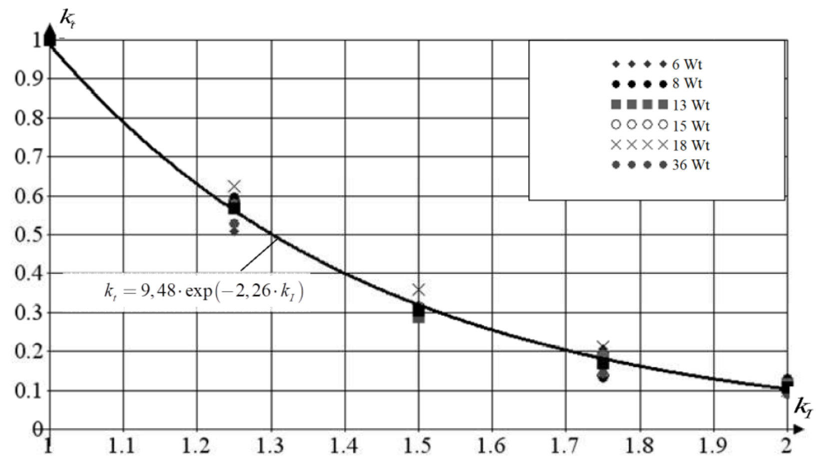



**Figure 6:** Experimental dependences of $k_t = f(k_I)$ for lamps of different power

For the convenience of determining the duration of the preheating transient preheating, let us substitute expression (1) into (2):

$$t_{ph} = a \cdot \exp(-b \cdot k_I) \cdot t_{ph.n}\ , \tag{3}$$

where $a = 9,48$; $b = 2,26$.

Figure 7 shows all the measurement results and the approximation curve.

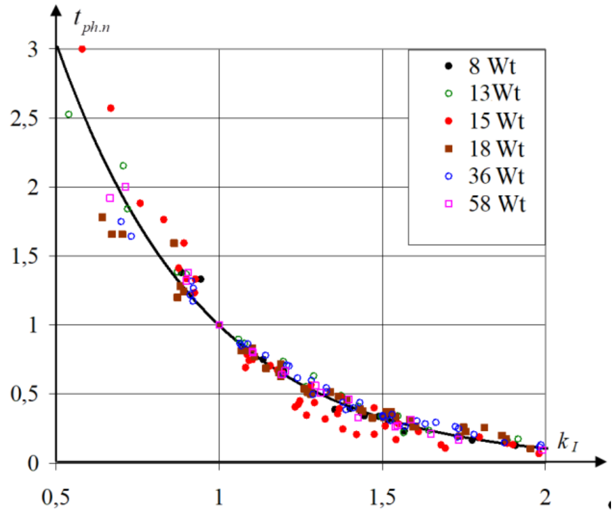



**Figure 7:** Dependence of the summary values of the duration of the transient processes of electrode preheating on the multiplicity of the preheating current

The maximum frequency $f_{\max}$ at which the lamp can be switched on so that the light from it is perceived by a person as separate flashes is also set. It is obvious that this frequency is inversely proportional to the duration of the transition process $t_{ph}$ and the duration of visual fixation of the human eye $t_f$ ($t_f$ = 0.8 s [15]) both when the lamp is flashing and when it is extinguished (4).

$$f_{\max} = \frac{1}{t_{ph} + 2 \cdot t_f}. \tag{4}$$

Substituting expression (3) into (4), we obtain:

$$f_{\max} = \frac{1}{a \cdot \exp(-b \cdot k_I) \cdot t_{ph.n} + 2 \cdot t_f}, \tag{5}$$

where $f_{\max}$ – is the maximum frequency at which the lamp can be switched on so that the light from it is perceived as separate flashes, Hz;

$t_f$ – is the duration of visual fixation of the human eye, sec.

Using the formula (5), it has been established that the maximum limiting frequency at which a fluorescent lamp can be switched on so that the light from it is perceived by the human eye as separate flashes when using lamps with a power of 8 to 58 W, is between 0.18 and 0.58 Hz (Figure 8).

This data should be taken into account when using fluorescent lamps in an intelligent lighting control system. Namely, the fact that the duration of the transient process of switching on the lamps ranges from 1.7 seconds for an 8 W lamp to 5.5 seconds for a 58 W lamp.

When using LED luminaires in dynamic mode in an intelligent lighting control system, two main problems arise. The first is their high brightness. The second is that people feel discomfort when the lights are switched on. These statements were confirmed by experimental studies during the operation of the intelligent lighting control system in an educational institution (see Figure 5). In a survey of students, 98 percent of them were negative about the dynamic lighting mode. The main comment was about discomfort when switching on the lamps. Therefore, it was decided to use a smooth switching on of the lamps. However, the time of the smooth switch-on remained unknown.

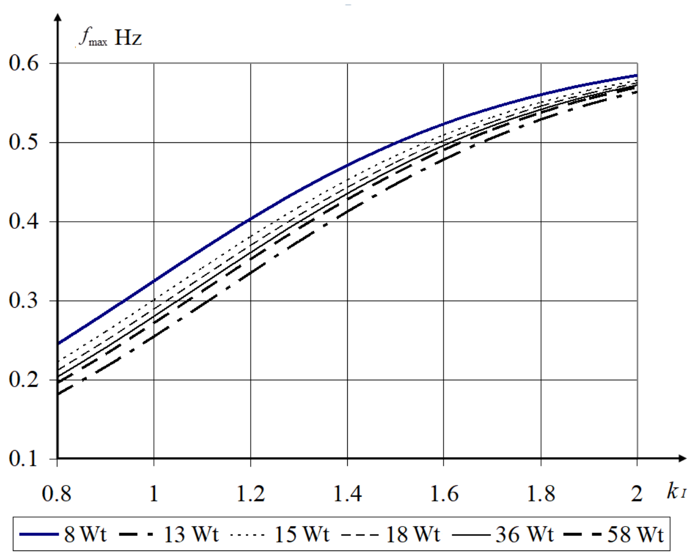



**Figure 8**: Dependence of the maximum switching frequency on the multiplicity of the electrode preheating current and fluorescent lamp power

The smooth switch-on time depends on the following factors. When a person moves along the corridor, the time for the lamp brightness to increase should be no more than the time from the moment the signal is received from the motion sensor to the moment the person approaches the illumination zone. And also not less than the reaction and adaptation time of the human eye. Since these data are individual for each person, we conducted an experiment.

During the week, a specific soft start time is programmed for each day. It has been set to be the same throughout the day. For example, for Tuesday it was 1 second, for Wednesday it was 2 seconds, and so on. At the end of the day, the same respondents were surveyed about the comfort and quality of the dynamic lighting system. The questionnaire contained only one question: "Is it comfortable to walk along the corridor with this lighting?". The expected answers were "Yes" or "No".A total of 86 students and teachers took part in the survey. The results of the survey are shown in Figure 9.

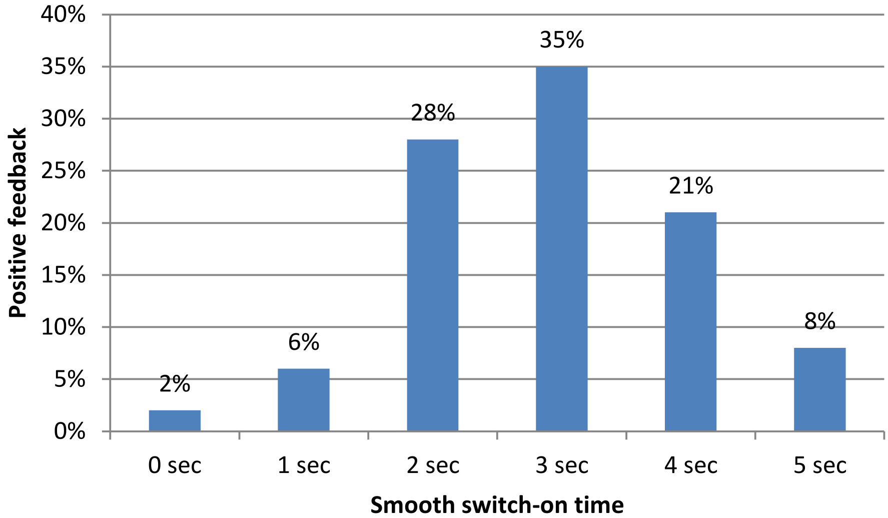



**Figure 9**: The results of respondents' positive "Yes" answers regarding the comfort of smooth switching on of lights

As can be seen from the survey results, the most positive response was given to the switch-on time of 3 seconds. However, in the case of rooms where the speed of movement of people will be higher, the switch-on time can be reduced to 2 seconds.

The issue of security of smart devices when building lighting systems should be highlighted separately. Uncontrolled changes in parameters can harm the use of such systems or create conditions for inefficient operation. For this purpose, it is necessary to consider appropriate architectures [16] that take into account security issues for such systems.

## 4. Conclusion

1. A measuring information system with the ability to switch electrical circuits in which measurements are made was manufactured. It was used to research transient processes in electrical circuits when fluorescent lamps are switched on.

2. As a result of the research of transient processes when fluorescent lamps are switched on, the time of preheating of electrodes was obtained. Based on these data and the characteristics of the human eye, the maximum frequency at which a fluorescent lamp can be switched on so that the light from it is perceived by the human eye as separate flashes. So, in intelligent lighting control systems with fluorescent lamps with a power of 8 to 58 W, the maximum frequency of flashes is between 0.18 and 0.58 Hz (respectively). That is, the duration of the control signal should not be less than 1.7 seconds for an 8 W lamp and 5.5 seconds for a 58 W lamp.

3. An experimental lighting system with an intelligent system for controlling the switching on of LED lamps based on the ATmega328 microcontroller was designed and constructed. This lighting system implements a dynamic lighting control algorithm based on data from motion and natural light sensors.

4. Based on the research data, by interviewing respondents about the modes of operation of the intelligent control system, the most comfortable time for a person to switch on the lighting from individual lamps was established. Most of the respondents responded positively to a smooth switch-on time of 3 seconds. The switch-on times of 1 and 5 seconds received negative feedback. At the same time, respondents felt uncomfortable with a quick or very slow increase in brightness. The latter factors had a negative impact on people's well-being at the end of the working day. Therefore, the recommended time for smooth switching on of LED lighting by an intelligent control system should be between 2 and 4 seconds, depending on the light intensity. The higher the lighting intensity, the longer the soft-on time should be.

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