DOI: 10.35598/mcfpga.2026.012

Programmable Lighting Control for Improving Energy Efficiency in Smart Buildings

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***Abstract*—The paper explores the possibilities of programmed control of LED lighting systems to increase the energy efficiency of buildings. An adaptive algorithm for changing lighting parameters depending on the time of day, the level of natural light, and the presence of users is proposed. The advantages of using microcontroller platforms to create energy-saving lighting systems are determined. The prospects for integrating programmable lighting systems into the Smart Grid concept and the infrastructure of smart buildings are considered.**

Keywords—programmable lighting, light-emitting diode systems, energy efficiency, adaptive control, microcontroller, smart building, Smart Grid.

I. Introduction

Modern requirements for energy consumption of buildings involve the use of technologies aimed at reducing electricity consumption and reducing operating costs [1, 2]. One of the most promising areas is the implementation of programmable lighting systems capable of automatically changing operating parameters depending on environmental conditions [3].

Light-emitting diode (LED) light sources are characterized by high light output, long service life and wide adjustment capabilities [4]. The combination of LED technologies with modern microcontroller platforms creates the basis for the formation of intelligent lighting systems and their integration into the concept of smart buildings [2, 5].

At the same time, modern research shows that the efficiency of lighting systems is determined not only by the level of energy consumption, but also by light quality indicators. Important characteristics are the stability of color parameters, color rendering quality, flicker level and photobiological safety [6]. According to the results of research on LED products, it was found that most modern luminaires provide high energy efficiency indicators, but some samples require additional control of light quality parameters [6]. In this regard, programmable lighting control becomes particularly important, since it allows maintaining the necessary light and color characteristics in accordance with the functional purpose of the room and the needs of users.

The purpose of the work is to study the features of programmable control of LED lighting systems to improve the energy efficiency of buildings.

An important direction for implementing energy saving strategies and increasing energy efficiency is the development of the concept of intelligent buildings focused on the rational use of energy resources. In world practice, this approach has become widespread within the framework of the concept of "smart home". The relevance of its implementation is growing in the context of urbanization, which is accompanied by an increase in the number of urban population and an increase in the level of energy consumption in the residential sector. Modern intelligent devices are integral elements of the residential environment and perform the functions of monitoring, accounting and management of life support systems.

Comprehensive control of equipment operating parameters and resource consumption allows you to reduce energy consumption, increase the level of user comfort, increase the service life of technical equipment and ensure a high level of reliability and safety of the functioning of building engineering systems.

II. Research Methods And Equipment

The research methodology involved the analysis of the principles of designing a smart home system for an individual residential building and the selection of key hardware and software components for implementing an energy-efficient lighting control system.

The structural features of a typical detached residential building were examined, the main electricity consumers were identified, and a general energy supply scheme was developed. Particular attention was paid to the role of lighting systems in the overall energy consumption of the building.

The proposed lighting control system is based on a programmable logic controller that collects and processes data from sensors and generates control signals for lighting devices. As a hardware platform, the Beckhoff CX8080 controller and corresponding expansion modules were considered. The system architecture also includes switching devices, occupancy sensors, ambient light sensors, and user interfaces required for automated operation.

For implementing adaptive control algorithms, the following input parameters were used:

- daylight level;
- time of day;
- occupancy information;
- functional purpose of the room;
- predefined lighting scenarios.

Both wired and wireless communication technologies were considered to ensure reliable data exchange between system components. Local and remote control modes were implemented to improve operational flexibility and user convenience. Brightness control of LED luminaires is performed using pulse-width modulation, enabling smooth adjustment of luminous flux with minimal energy losses [7]. The interaction algorithms between the controller and executive devices, including relays, dimmers, electromechanical actuators, valves, and other building automation components, were analysed. The integration of these elements into a unified smart building infrastructure enables adaptive energy management and supports interaction with Smart Grid systems [5].

The application of programmable lighting control solutions contributes to reducing energy consumption, improving user comfort, and enhancing the safety and operational efficiency of residential buildings.

III. Results And Discussion

Programmed control of LED lighting systems is an effective tool for increasing the energy efficiency of buildings. The use of adaptive algorithms allows to reduce electricity consumption, increase user comfort and ensure rational use of resources.

An important condition for the implementation of intelligent lighting systems is to ensure not only high energy efficiency, but also proper light quality, which includes control of color rendering, flicker, and photobiological safety.

Along with the advantages of implementing programmable lighting control systems, it is necessary to take into account a number of practical limitations. In particular, the efficiency and reliability of the system largely depend on the quality of the components used, the level of technical support for the equipment and the qualifications of the personnel who perform its setup and maintenance. The implementation of adaptive control algorithms requires basic knowledge in the field of programming and electronics, since errors during configuration or connection of equipment can lead to incorrect operation of individual elements of the system. In addition, the use of budget components can negatively affect the durability and overall reliability of the system. Despite these limitations, the proposed approach to programmable control of LED lighting systems is an effective, flexible and cost-effective solution for increasing the energy efficiency of buildings and developing intelligent control systems in the Smart Building concept.

A promising direction for further research is the development of lighting systems using wireless communication technologies, cloud services, and energy consumption forecasting tools based on artificial intelligence methods.

Acknowledgment

The authors express their sincere gratitude to the staff of the Department of Lighting Engineering and Light Sources of the O.M. Beketov NUUEKh, as well as to O. G. Litvinov for the consultations provided, valuable scientific.

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