IMPROVING ENERGY EFFICIENCY IN RESIDENTIAL BUILDINGS THROUGH THE APPLICATION OF ADAPTIVE LED LIGHTING SYSTEMS BASED ON MOTION SENSORS

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Abstract

This thesis examines the reduction of electricity consumption, the decrease in operating costs, and the provision of visual safety in common areas of residential buildings through the application of adaptive LED lighting systems controlled by motion sensors. The entrance and stairwell areas of a four-storey residential building located in the Yunusabad district of Tashkent were selected as the research object. The study compares traditional incandescent lamps, fluorescent lamps, and LED luminaires equipped with motion sensors in terms of energy consumption, operating time, service life, and economic efficiency. In addition, the scientific importance of measurement approaches using a goniophotometer, spectroradiometer, and integrating sphere for evaluating the photometric and colorimetric parameters of LED luminaires is discussed. The calculation results show that LED lighting systems controlled by motion sensors make it possible to reduce the actual operating time of luminaires, decrease electricity consumption, and maintain safety and comfort in the residential environment. The research results confirm that the implementation of adaptive lighting systems in residential buildings is a technically, economically, and socially feasible direction of energy saving.

Keywords: LED lighting, motion sensors, adaptive control, energy efficiency, residential building, entrance lighting, goniophotometer,

spectroradiometer, integrating sphere, visual comfort.

Introduction

In global energy practice, reducing energy consumption in buildings and ensuring the rational use of resources are regarded as important conditions for sustainable development. In particular, in residential buildings, a certain share of electricity is consumed for lighting common areas such as entrances, stairwells, corridors, entrance groups, and technical rooms. People are not continuously present in these areas but move through them for short periods. Therefore, the continuous long-term operation of lighting systems in such spaces is often inefficient from an energy point of view.

In traditional lighting systems, the main problem is not only the high-power consumption of luminaires but also the fact that their operating mode is not controlled in accordance with actual human needs. For example, keeping luminaires switched on even when there are no people in an entrance or stairwell leads to excessive electricity consumption, increased utility costs, and faster ageing of lighting devices. Therefore, in a modern energy-saving approach, it is not sufficient merely to replace lighting systems with low-power LED sources; it is also important to control them automatically according to motion, occupancy, and the level of natural illumination.

LED luminaires equipped with motion sensors are an effective technical solution to this problem. In such systems, lighting devices operate only when movement is detected or when a person is present. After movement stops, the lighting is automatically switched off after a preset delay or shifted to a low-power mode. This solution reduces energy consumption while maintaining the required illumination level for safe movement in entrances and stairwells.

The aim of this thesis is to substantiate the technical, operational, and economic significance of improving energy efficiency in residential buildings through the application of adaptive LED lighting systems controlled by motion sensors.

Research methodology

The study carried out a comparative analysis of the existing lighting system in a residential building and the proposed adaptive LED lighting system. Particular attention was paid to luminaire power, operating time, electricity consumption, lighting quality, visual comfort, safety, and economic efficiency indicators.

The methodological approach includes the following stages: analysis of the lighting mode of common areas in the residential building; comparison of the energy consumption of incandescent, fluorescent, and LED luminaires; assessment of the possibility of reducing the actual operating time of lighting through motion sensors; justification of the use of a goniophotometer, spectroradiometer, and integrating sphere for evaluating the photometric and colorimetric characteristics of LED luminaires; and calculation of energy consumption and economic effect for 32 luminaires in a four-storey residential building.

The electricity consumption in the lighting system is determined by the following expression:

$$A = P \cdot t$$

where A is electricity consumption, kWh; P is the luminaire power, kW; and t is the operating time, hours.

This relationship shows that there are two main ways to reduce energy consumption: decreasing the power of the luminaire and reducing its operating time. LED luminaires fulfil the first task, while motion sensors fulfil the second. Therefore, combining these two solutions provides a high result in terms of energy efficiency.

The cost of electricity is calculated using the following expression:

$$C = A \cdot T$$

where C is the cost of electricity, UZS; A is consumed electricity, kWh; and T is the electricity tariff, UZS/kWh.

Main part

In residential buildings, entrance and stairwell lighting systems are continuously operated environments, although people are not continuously present in them. Therefore, maintaining lighting in such areas in a constant operating mode is inefficient from an energy point of view. For this reason, LED lighting systems with adaptive control are among the most appropriate energy-saving solutions for residential buildings.

LED luminaires have a much higher luminous efficacy than traditional incandescent lamps. In incandescent lamps, a large part of electrical energy is converted into heat and only a small part is used for light generation. Although fluorescent lamps are relatively energy-saving, they are limited in comparison with LED luminaires in terms of environmental safety, starting characteristics, service life, and disposal issues. LED luminaires, in contrast, are characterised by high efficiency, long service life, fast start-up, low heat generation, mechanical durability, and environmental safety.

Motion sensors provide adaptive functionality to the lighting system. In other words, the lighting system operates in accordance with human movement. When the sensor detects motion, it activates the luminaire; when motion stops, the luminaire is switched off after a preset time. This is especially effective in areas such as entrances, corridors, and stairwells, where people usually move only for a short time.

According to their type, sensors may be infrared, microwave, or combined. Infrared sensors detect changes in thermal radiation emitted by the human body. They are simple, inexpensive, and convenient for use in entrances. Microwave sensors operate on the basis of the Doppler effect and detect movement over a wider area. Combined sensors integrate two physical principles and reduce the probability of false triggering.

The combined use of LED luminaires and motion sensors creates a twofold energy-saving effect. First, the LED luminaire itself consumes low power. Second, the

sensor limits unnecessary operation of the lighting. Therefore, an adaptive LED lighting system is not merely lamp replacement, but intelligent control of the lighting process.

The research object was a four-storey residential building located in the Yunusabad district of Tashkent. A total of 32 luminaires were considered for lighting the common areas of the building. In the traditional case, the lighting system was assumed to operate for an average of 10 hours per day. In the LED system controlled by motion sensors, the actual operating time of lighting was estimated at approximately 3 hours per day.

In experimental studies, evaluation of the photometric and colorimetric parameters of LED luminaires is of great importance. A goniophotometer makes it possible to determine the luminous intensity of a luminaire in different directions and its light distribution. A spectroradiometer is used to assess the spectral composition of light, colour temperature, and colour rendering index. An integrating sphere is important for determining the total luminous flux and luminous efficacy of the luminaire.

Such measurements show that when evaluating an energy-efficient lighting system, not only electricity consumption but also lighting quality must be taken into account. This is because lighting in residential buildings is directly related to safe movement, visual comfort, correct colour perception, and psychological comfort.

Results and discussion

According to the calculation results, the use of traditional incandescent lamps for 32 luminaires in a four-storey residential building leads to high energy consumption. Although fluorescent lamps reduce energy consumption, their efficiency remains lower when compared with LED luminaires and motion sensors.

When LED luminaires equipped with motion sensors are used, electricity consumption decreases due to two factors: the luminaire power is lower, and the

operating time is reduced. This makes it possible to significantly reduce monthly and annual costs.

A general comparison of different lighting options is presented below.

Table 1. Comparison of lighting options in terms of energy efficiency

Lighting option	Luminaire power	Operating time	Monthly energy consumption	Main characteristic
Incandescent lamp	100 W	10 hours/day	960 kWh/month	Very high energy consumption
Fluorescent lamp	23 W	10 hours/day	220.8 kWh/month	Relatively energy-saving, but with operational limitations
LED + motion sensor	11 W	3 hours/day	31.68 kWh/month	Highest energy efficiency

As can be seen from the table, the LED lighting system controlled by motion sensors sharply reduces energy consumption compared with traditional incandescent lamps. Additional savings are also achieved compared with fluorescent lamps. This demonstrates the significant impact of adaptive control on energy efficiency.

According to the calculations presented in the thesis, the transition from incandescent lamps to LED luminaires with motion sensors provides considerable monthly economic savings and enables a large reduction in annual costs. At the same time, the payback period of the project may be less than one year when incandescent lamps are replaced. When replacing fluorescent lamps, the payback period is longer; however, in terms of operational convenience, safety, and service life, the LED system remains advantageous.

The discussion results show that the main advantage of adaptive LED lighting systems is not limited to energy saving. They improve safety in entrances, reduce the risk of movement in dark zones, extend the service life of lighting systems, and reduce maintenance costs. Therefore, this solution can be evaluated as an energy-efficient, economically justified, and socially acceptable technology for residential buildings.

Conclusion

The application of adaptive LED lighting systems based on motion sensors in residential buildings is an effective and practically justified direction for improving energy efficiency. In such systems, energy saving is achieved in two ways: the installed power is reduced through LED luminaires, and the actual operating time of lighting is reduced through motion sensors.

The analysis carried out using the example of a four-storey residential building shows that the combination of LED luminaires and motion sensors significantly reduces electricity consumption compared with traditional lighting systems. The experimental approach using a goniophotometer, spectroradiometer, and integrating sphere makes it possible to evaluate the lighting system not only economically but also in terms of photometric and colorimetric quality indicators.

Thus, LED lighting systems controlled by motion sensors are a technically appropriate solution for reducing energy consumption, lowering operating costs, improving safety, and forming a modern energy-efficient infrastructure in residential buildings.

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