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Economic and Energy Efficiency of Artificial Lighting Control Systems for Stairwells of Multistory Residential Buildings

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Abstract

The aim of the research is to determine the economic and energy efficiency usage of the artificial lighting control systems, with the help of astronomical relays and motion sensors, by various types of light sources for the stairwells (stair landings and staircases) of multistory residential buildings. The analysis of the residents' monthly movement intensity of the 9-story residential buildings through the buildings entrance, doorways, and apartment doors was carried out. The economic and energy efficiency of use the artificial lighting control systems with an astronomical relays and motion sensors with different types of light sources was determined. Regardless of the light sources` type, the astronomical relay's use leads to reduction in the electricity consumption of artificial lighting in 43.31% – 50.52%. Moreover, the motion sensors' use on stairwells leads to a significant reduction in electrical energy consumption: in a case of halogen lamps – by 97.73%, compact fluorescent lamps – by 95.27%, light-emitting diodes lamps – by 93.98%. For the first time, the data of 9-story residential buildings inhabitants' traffic intensity through the first-floor doorway for the Ternopil city, Ukraine has been carried out. It has been proved the economic feasibility and energy efficiency of using combined lighting with an artificial lighting control system for stairwells of multistory residential buildings.

1. Introduction

The regulation of artificial lighting in premises for various purposes in the United States was considered in 2013, as a result of which the ASHRAE 90.1 [1] standard was developed. Standart was focused not only on reducing of the intensity and power of lighting, but also on finding the ways to achieve electrical energy savings through the using of additional lighting controls [2].

As the building industry is gradually moving towards the construction of "zero energy houses", the U.S. DOE under the Architecture 2030 program [3] acknowledged that lighting control plays a significant role in energy saving. According to the United States Energy Information Administration in 2019, the residential and commercial sectors of the United States consumed about 216 billion kWh of electricity for lighting. This was about 8% of total electricity consumption by both of these sectors and about 5% of total U.S. electricity consumption. Electricity consumption in the residential sector for lighting was about 75 billion kWh. It is about 5% of the total electricity consumption in the residential sector in 2019 [4]. The introduction of lighting control systems can reduce the consumption of electricity up to 60% without lowering the comfort and productivity.

The most energy-efficient LS is now LED, for which a fairly rigid form factor is installed. They commonly shaped as incandescent lamps (IL), with same base and socket, for relamping purposes. From a technical point of view, this requirement is absolutely not logical. We can not transfer the requirements that are optimal only for IL, on the LED lamps. The driver, which is located in the lamp body, simultaneously performs the role of the radiator. But its surface is not always enough for efficient cooling.

In multistory buildings lighting stairs (stair landings and staircases) and floor corridors is an important factor of the inhabitants' comfort and safety. Implementation of LED lamps and automatic lighting control systems can reduce the overall consumption of electricity in a several times. However, mistakes in design of such systems in terms of reliability and safety of use often lead to a violation of the requirements of normative

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Nomenclature

C_{AL}	*The cost of ownership of the lighting system, USD*
C_I	*Initial cost of necessary light source and control devices for stairwells artificial lighting, USD*
C_E	*Cost of the electricity, USD*
C_{IS}	*Control system installation and setup cost, USD*
C_{LS}	*Cost of a LS, USD*
C_R	*Replacement cost of a light source, USD*
E_{Fo}	*The cost savings from using the control system, USD*
I_{MoR}	*The intensity of residents motion, once/year*
N_{AR}	*Quantity of the astronomical relays, Qtv*
N_F	*Building floors quantity, Qty*
$N_{F.LS}$	*Number of the light source that failed during the year, Qty*
N_{MS}	*Motion sensors quantity, Qty*
$N_{N.S}$	*Nominal number of LS switching cycles, Qty*
N_S	*Number of LS switching cycles per chosen period, Qty*
N_{LS}	*Number of the light source that installed on the each floor, Qty*
P_{AL}	*Power consumption of the artificial lighting system, kW*
P_{AR}	*Electrical power consumed by the astronomical relay, kW*
P_{LS}	*Light source power consumption, kW*
P_{MS}	*Electrical power consumed by the motion sensor in standby mode, kW*
T_{OL}	*Lighting systems operating life time, h*
T_{LS}	*Light source service life, h*
$T_{N.LS}$	*LS nominal operating lifetime, h*
T_Y	*Annual duration of building stairwells light source glowing, h/year*
W_{AL}	*Total annualelectricity consumption of the artificial lighting system, kWh*
W_{AR}	*Astronomical relayselectricity annual consumption, kWh*
W_{MS}	*EE consumed by the motion sensors, kWh*
AL	*Artificial lighting*
AR	*Astronomical relay*
CFL	*Compact fluorescent lamps*
DOE	*Department of Energy*
HL	*Halogen lamp*
LED	*Light-emitting diode*
LS	*Light source*
MS	*Motion sensors*
OL	*Operating life*

documents for lighting, and to a decreasing safety of residents in general.

Another priority direction of development in the building industry is the construction of buildings with reduced operating costs. Within the scope of this diretion, the task of the cost reducing of lighting the buildings is especially important. The solution of this problem is provided by the implementation of daylight systems, when the house is built in such way that during the day sunlight is used to the maximum for lighting of the premises, including stairwells and corridors. Also, when it is necessary (in the evening and at night), when a person appears in the entrance area or in any other area inside the building, the artificial lighting would automatically turn on.

The study of the influence of buildings typology of the Erbil city for the quality and quantity of daylight entering into multi-storey residential buildings (apartments) was held in [5]. The study was conducted in five multi-storey buildings. In the process of researches three types of simulations were used: illumination level, LEED and daylight autonomy. It has been established that the typology of the building plan has a noticeable impact on the energy efficiency of daylighting in high-rise dwelling houses. The results showed that a point typology is the best type of plans for all cases in terms of ensuring optimal daily productivity, while a double-load typology was worse. The authors concluded that the typology of the plan has an obvious impact on the efficiency of daylight in multistory residential buildings.

The study, represented in [6], provides a computational method that allows to increase energy efficiency of exterior enclosing structures due to maximum use of sunlight. This allows to predict the duration of receipt and the quality of sunlight, which will come into the room, thus, the designer can simulate the enclosing structures on the solar side, optimized it for different purposes. The method aims to help architects and designers simulate ecological buildings and urban development. A striking example of energy-efficient development of entire microdistricts is a diagonal design of low-rise buildings (Fig. 1) [7]. Residential and industrial complexes with this method of construction resemble fractal natural formations, the properties of which depend on their size. Development and equipping of artificial lighting systems by automatic, which reacts not only to the presence of a person, but also on the condition of weather clearly promotes the economy of electricity in the operation of buildings.

The issue of energy efficiency in controlling the LED lighting system in the corridors of administrative buildings was considered in [8]. The author is designed and implemented lighting installation with dynamic regulation of LED lamps luminous flux. Operation of the studied lighting installation for two years proved the prospects of this approach. Energy savings for this period amounted to 57%. However, the author did not explore the issues of energy efficiency using different types of light sources for lighting stairs and floor corridors. Research of energy efficiency using daylight for illumination of multistory buildings was conducted in [9]. This article presents the calculation of thermal energy saving, as well as reducing the cost of artificial lighting due to daylighting for the building of SODHA BERS COMPLEX, located in Varanasi, India. Potentials of energy conservation, and consequently the reduction of CO_2 emissions have been determined for different operating terms of the building. However, studies of the daylight impact on electricity savings when lighting stairs and floor corridors were not held.

The results of the research of a large-scale model of a multistoried residential building on energy efficiency using light wells as an additional light source are presented in [10]. In this study, the authors presented the results of light measurements analysis in a large-scale model of energy-saving multistory residential building using light wells as an additional source of daylight. The structure of the building was placed on a compact longitudinal base. The apartment windows had east-west orientation. For additional natural lighting of the building central areas and, at the same time for controlling of the growth and heat

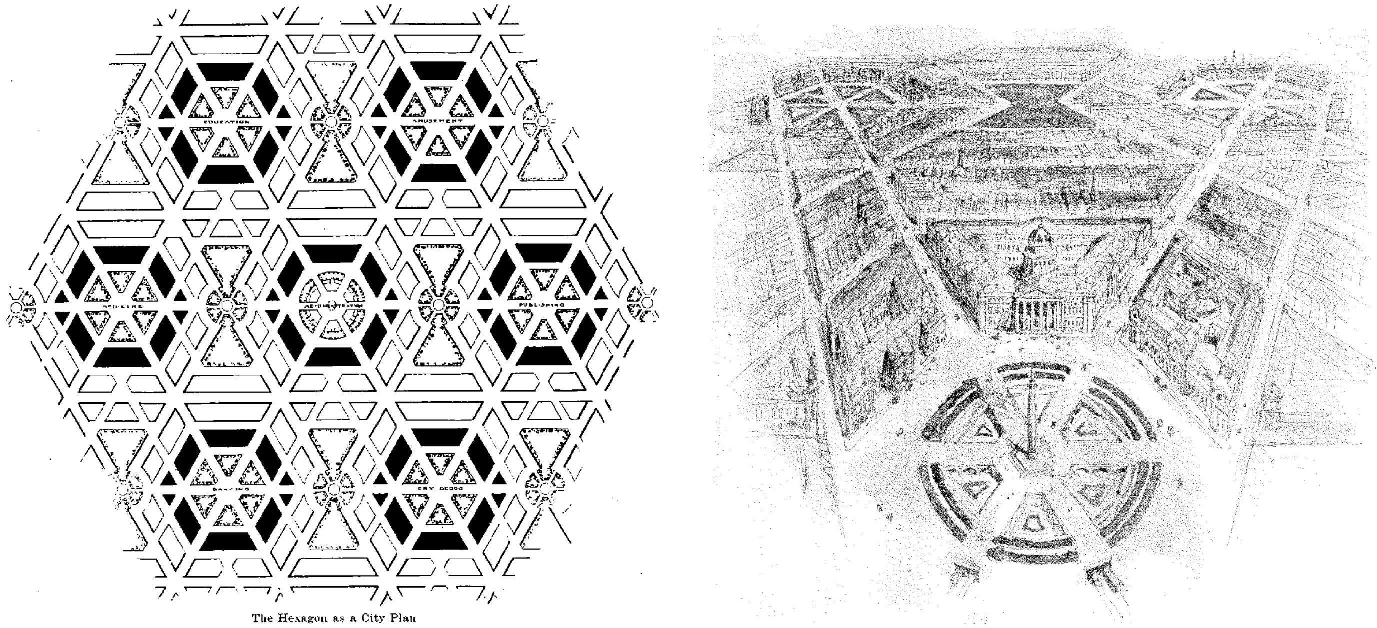


Fig. 1. The examples of diagonal planning of the city [7].

loss, have been developed three types of innovative lighting systems of various options. Measurement of illumination in scale models were conducted under artificial sky. The best results were obtained in the well with a mirrored inner surface, broad upper and narrow lower part. In all the cases the reference values were reached. However, they were not considered the issue of saving electricity by reducing the duration of artificial lighting's work. In the article [11], the authors examined employment schedules for 35 single-office premises in a large office building in San Francisco. They obtained average employment as a function of daytime. In addition, they had determined the influence of occupancy sensors on the frequency of on/off cycles and a service life of LS.

Studies of the energy efficiency of controlling the luminous flux of LS are given in [12]. The results presented in the article are based on the analysis and generalizing of the obtained and published experimental data, which are necessary for the determination of the energy efficiency regulation of the light source's luminous flux. The analysis of the energy efficiency was carried out by determining the specific costs of the light energy unit produced within the average duration of the glow by cheap, low-efficient thermal and highly energy efficient semiconductor LS. However, the issue of using LS control systems was not considered.

Solid State Lamps (SSL) is one of the most energy-efficient and environmentally friendly lighting technology. According to [13], SSL has already achieved a high level of energy efficiency (more than 276 lm/W) at costs that are constantly decreasing. In addition, the operation life of LED lamps in several times longer than in the gas discharge lamps. The study [13] provides an overview of current trends in SSL technology. SSL technology is developing rapidly, which can bring many benefits to the lighting market. However, there are still some market barriers that prevent the achievement of a high cost-effective potential for lighting energy saving. The article [13] presents several strategies and recommendations for overcoming the existing barriers and facilitating the faster penetration of SSL into the market. The estimated potential savings from the use of SSL lighting systems in the European Union is about 209 TWh, which corresponds to 77 million tons of CO_2 equivalent. Economic feasibility is expressed in the equivalent of annual electricity production by about 26 large power plants (1000 MW).

Using of daylight-linked controls (DLCs) reduce energy costs and maximize user comfort [14]. Despite the advantages, which it can bring, the use of the DLCs is rather limited due to the following factors: difficulties in designing, installing calibration, evaluating the received energy savings and the unwillingness of users to install them. Each phase of the DLC_s development process, from an early assessment of the possibility of installing a daylighting system to installing and calibrating the system and identifying the reasons that limit their distribution, is described in [14].

The methodology of a new structure of daylighting analysis of residential buildings is proposed in the works [15,16]. It consists of two parameters that reflect the daytime and seasonal availability of natural light, as well as the average duration of access to direct sunlight. It is shown, that using the proposed techniques can detect significant and effective qualitative differences between the flats, which in the design process were not taken into account. The framework also provides several levels of detail that range from a simple score to spatial plots that allow modelers to understand and optimize the daylighting characteristics of a room, apartment building or neighborhood. It also has several levels of granularity that range from simple calculation to spatial graphs and allows developer of models not only to understand but also to optimize the characteristics daylighting of room, residential buildings, or areas.

The method for determination not only the best placement of the photosensor on the ceiling, but also its optimum orientation based on the analysis of several criteria, presented in [17]. The following criteria were used: 1) ratio of illumination levels on the working surface and on the ceiling; 2) the resulting savings electricity; 3) The adequacy of the lighting, which was determined as the ratio duration of of normalized illumination from natural and artificial

LS to the duration of working time. The methodology [17] can be used as a tool for determination of the optimal operation of the photosensors system that react to daylight. It can also be used as part of the validation procedure before putting it into operation of system which react on a daylight. It is flexible, namely: 1 – In the calculation procedure, you can add new criteria (C_4, $C_{5\ ...}$ C_X); 2-it is possible to maximize or minimize the impact of each of the existing criteria using the appropriate weight coefficients. Although in the presented version, the weight of all three examined criteria was the same.

The reduction of electricity consumption when using four variants of daylighting control systems, with taking into account the use of standard switches, as well as their combination with automatic presence sensors, presented in [18]. During the study was observed several premises with different: 1-availability of daylight; 2- windows orientation; 3 – system of sunscreen devices, located at sites in different latitudes and climatic conditions, as well as taking into account two types of buildings: offices and educational classes. The results showed for which combinations of variables could achieve savings of 20% and 30% with the means of dimming and presence.

The article [19] discusses a number of lighting technologies (on alternating and direct current) together with the installation of two daylight-capturing systems for illuminance of a typical classroom in the Greek State School. The first one for assess the economy of the electricity and for the sufficient level of illumination uses one stand-alone sensor on the lamp, and the second one-in the control area It has been proved that the existing annual consumption of the electricity (90.5 kWh/m^2) for lighting can be reduced to 0.55 kWh/m^2. n recalculation of the whole country, it's 201929 tons of CO_2 equivalent. It has been underlined that the path to school buildings with zero energy consumption should be based not only on the use of artificial lighting control systems, but also on the maximum use of daylight.

In the literature review [20] has been showed the light efficiency of various components and light conductors for the entire lighting system. The auditory luminous flux of daylight, for various weather conditions and seasons throughout the year, has also been accounted in examined studies in accordance with the requirements for office lighting. On this basis, conclusions were drawn. Since studies were conducted mainly by architects, engineers-builders, or physicists, the lighting requirements were not rigid. The authors found that the lighting control system should adjust to the conditions of predominantly daylight. This is because the greatest energy savings arise when the natural light is connected with the control of artificial (turning-off), and diffuse - with the dimming of artificial LS.

The Smart Employment Sensors project that can adapt to the employee activity level changes is presented in [21]. It also proposes a model of "human movement" that works at the computer. A sensible employment sensor can set the employee activity level deviation by the time of day. According to this information, it can change the delay time of the artificial lighting control system according to the time of day. However, in both studies, all attention was focused on office premises; the illumination of stairs and floor corridors was left out of attention. The existence of a discrepancy between the predicted and measured electrical energy consumption was established in non-residential buildings [22]. The authors emphasized that a significant lack of information on the actual energy consumption in buildings may be the main cause of this discrepancy.

The study on identifying the presence of private residents' households was carried out in [23]. The purpose of the study was to study the relationship between total electricity consumption in private households and the presence of residents in it. The authors estimated the accuracy of the developed algorithms on the basis of analysis of three sets of data containing basic information about the real power consumption of households.

During studies of energy efficiency of the artificial lighting control systems [24], conducted in office premises the authors selected several approaches that will reduce energy consumption. The results of the study have shown that each tested system can be optimized in such way, that power savings was ranging from 50% to 70%.

The study of electricity consumption in multistory buildings for lighting of common areas during 2009 – 2010 is given in [25,26]. Authors considered energy consumption system of artificial lighting in 89 apartment buildings houses in Ternopil, Ukraine. As a result of the study, it is found out that the highest consumption of electro-energy is observed in the period from 01.11 to 01.03, as the duration of the lighting system work in this period reaches 18 hours/day. From 01.03 to 01.06 the average duration of the artificial lighting system work is 14 hours/day, from 01.06 to 01.09 – 8 hours/day and from 01.09 to 01.11 – 14 hours/day. Proceeding from this, there has been proposed a method of efficient use of electricity to illuminate the stairs and entrances to buildings by installing lighting switches with motion sensors.

Control of the artificial lighting system based on the use of presence sensors can lead to 40% savings in EE under condition of using a combination of modern management strategies, such as: 1 – the use of daylight; 2-determination of the employment regime of residents; 3 – Planning and disabling of excess load [27]. Despite the conceptual advantages of approaches to management of buildings, which take into account the presence of residents, their expediency should be confirmed by real research.

The literature review of the lighting control system, based on the use of motion sensors that will allow the creation of a sensor network for building control, carried out in [28]. Modern systems use separate measurement points to determine the presence, which leads to the uncertainty associated with the detection of human presence. The long delay and high sensitivity of the detector compensate for this uncertainty, but they reduce the energy savings that can be achieved with more accurate presence detection. Management that is more efficient can be ensured through broader probing, the use of the network of presence sensors and the analysis of received data in real time. The presented results indicate the feasibility of researching the efficiency of sensor networks to control artificial lighting.

In a review of the literature [29] it is shown that theoretical calculations, measurements in full-scale premises and modeling to approved lighting programs show that specific consumption of the electricity 10 kWh/(m^2·yr) is a realistic goal for electrical lighting in future office buildings with low energy consumption. This goal will lead to a significant reduction in energy consumption by at least 50% compared with the actual average electricity consumption for lighting (21 kWh/(m^2·yr) in Sweden). There has been presented and discussed strategies about reducing energy use for electric lighting, which include: increasing of LS energy efficiency, ballast and fixtures, natural light usage, improving technical Service, reasonable using of manual dimming and switch-off occupancy sensors. Strategies based on daylight harvesting are also presented and the relevant design aspects such as effects of window characteristics, properties of shading devices, reflectance of inner surfaces, ceiling, and partition height are discussed. This study indicates the need to optimize the parameters of artificial lighting to reduce the load on the energy system that is constantly growing due to the electrical classification of all processes and devices used both in enterprises and in everyday life. A striking example of this is electric cars, which are increasingly winning the automotive market, and increasing loads on the electricity system of all countries.

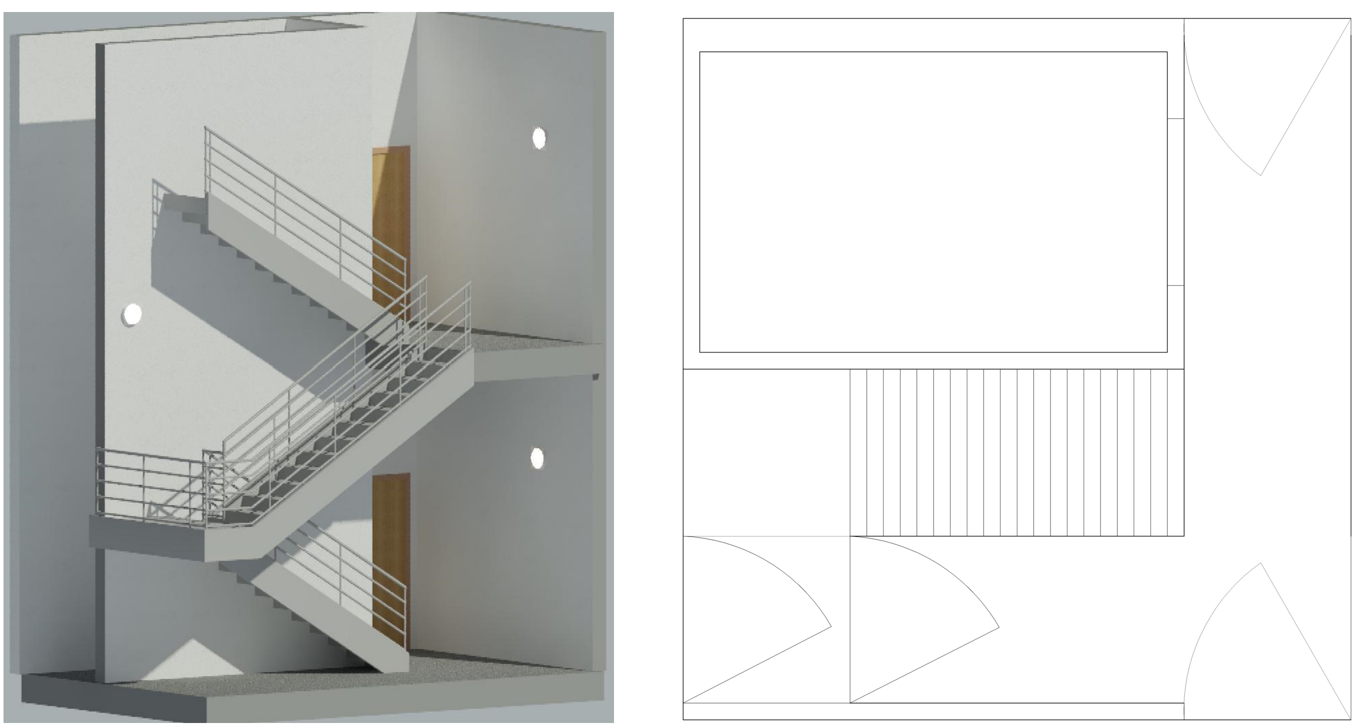
Paper [30] presents a literature review about energy-efficient retrofit of electric lighting and daylighting systems in buildings. The review, which covers about 160 scientific articles, discusses the following topics: a) retrofitting electric lighting in buildings, b) electric lighting energy use and saving potential and c) lighting retrofit strategies Modernization strategies described in the survey: replacing the bulb, ballast or luminaire; using a given design of ambient lighting; improvement of service; reduction of supported illumination levels; improving color transmission of light sources; residents ' well-being improvement; using of control systems and daylight systems. This review shows that existing general knowledge about lighting modernization is currently very limited and there is a significant lack of information on the actual energy characteristics of lighting systems installed in the existing building fund.

Review [31] shows that lighting control systems can provide significant energy savings and result in reduction in electricity costs. Decrease in electricity demand also has a positive environmental impact resulting from reduced carbon footprint. But each of the control technologies has various properties that affect their performance. Behavior pattern of the occupants, geometric properties of the room or building, daylight entrance, type of work performed, etc. have profound effects on the lighting control systems, as seen from the discussions in this paper. Only with proper study of these factors can perform appropriate technology implementation, which can lead to significant energy saving, as well as to ensure the comfort of residents.

The influence of lighting on the feeling of comfort at workplaces of office workers was analyzed in [32]. The study was conducted on typical working days, comparing the illumination at eye level and on the working surface, some daylight performance indexes were also taken into account (Useful Daylight Illuminance and Daylight Glare Probability). It has been underlined that such phenomena can be observed in certain weather conditions. Discomfort is also associated with specific moments of the day and weather conditions. Correspondence between the daily performance figures and employee feedback were not always observed.

In the article [33], the authors present research of lighting control systems, the principle management of which depended from the mode of workers, in a 12-week experiment by real conditions in six offices with ten participants. Users were satisfied with the results, except for those who consider automatic lighting control is not important. Enabling light was always done on time, and the timely shutdown was recorded only in 75% of cases. This enabled to save 13.4% of electricity without a significant impact on employee comfort. The result is that received economy of electrical energy on 13.4% without a significant impact on the comfort of residents.

From the foregoing it follows that the issue of economic and energy efficiency of artificial lighting control systems for



(**a**) (**b**)

Fig. 2. (**a**) Visual image of a typical stairwell and (**b**) the first floor stairwells plan.

stairwells of multistory residential buildings in the existing publications is not fully covered. This is precisely what indicates the need for research to determine the economic and energy efficiency of using artificial lighting control systems using astronomical relays and motion sensors with various types of LS for stairwells (stair landings and staircases) of multistory residential buildings.

2. Method

In previous studies, main focus was on the raising the efficiency of daylight using [34] and the impact of the translucent structures of exterior wall envelope on the energy balance of the premises [35]. The next step in the study of ways to increase the energy efficiency of lighting systems was to determine the effect of artificial lighting control systems on the electricity consumption of stairwell lighting.

Assessment of the feasibility of using artificial lighting control systems carried out taking into account the electricity consumption of LS (Table 1), namely: when using halogen lamp (HL), compact fluorescent lamps (CFL) and LED. According to the building standard of Ukraine “Natural and artificial lighting” [36], the illumination of stair landings and staircases should be at least 20 lx. The power of the LS was chosen in that way, when their luminous fluxes were close in a value. For the HL it is 30 W [37,38], for the CFL – 7 W [39,40] and 5 W for the LED lamp [41,42]. The cost of their replacement was received from the [43]. There are installed two luminaires with one LS on each floor (Fig. 2).

2.1. Artificial lighting system with astronomical relay

For making calculations on energy efficiency using of astronomical relay, we have to determine the duration of the dark and light periods of day, according to which a control system for artificial lighting in the stairwells will work. For Ternopil city the duration of dark and light periods of the day for each month according to the site data [44] is shown in Fig. 3.

According to the Fig. 3, daylight hours vary from 8 hours 11 minutes in December to 16 hours 13 minutes in June. The share of daylighting in the structure of the day during the year for the Ternopil city is 51% from the total year duration, which indicates the necessity and feasibility of using a system of combined lighting not only for the living spaces, but for the stairwells too.

It has been chosen the astronomical time relay REV-225 (Fig. 4) for controlling the system of artificial lighting. Its cost, specifications, installation and setup costs were taken from the internet resource [45] according to the site's data [43]. For Ternopil city, Ukraine, they are summarized in Table 2.

2.2. The intensity of residents' movement in 9-storey buildings through the doorway of the first floor

It is necessary to determine a daily average movement of building residents' for evaluation of electricity consumption of the artificial lighting control systems with motion sensors. There has been observed the 9-storey buildings. Research results are presented in the actual units of measurement (occupants per hour). To ensure reproducibility of research results, the number of objects (buildings), according to Cohren's statistical G-criterion, should

Table 1. LS specification.

Parameters	The name of the LS (LS type)		
	Classic A eco pro (HL)	Delux mini full spiral (CFL)	Global G45 F (LED)
Power, kW	0.03	0.009	0.005
Luminous flux, lm	405	440	400
Luminous efficacy, lm/W	13.5	48.9	80
Color temperature, K	2700	4200	3000
Service life, h	2000	8000	20000
Cost, USD	1.77	0.56	1.34
Replacement cost, USD	0.76	0.76	0.76
Number of on-cycle cycles to failure	8000	8000	10000

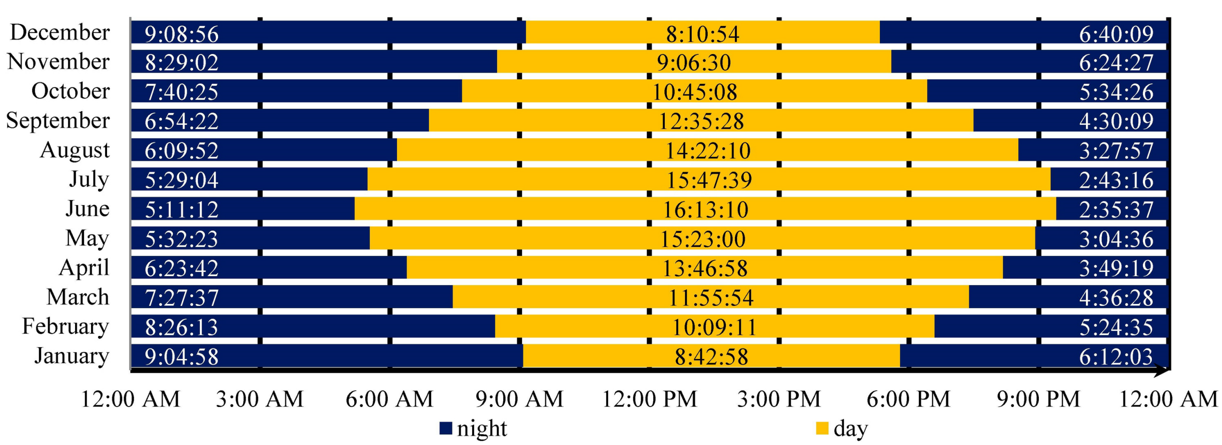


Fig. 3. Average monthly duration of dark and light periods of the day for the Ternopil city, Ukraine.

Fig. 4. Average monthly duration of dark and light periods of the day for the Ternopil city, Ukraine.

Table 2. Specifications of the astronomical time relay REV-225.

Parameters	Value
Power consumption (from the grid ~230 B), in standby mode, W	Not more than 1.3
Program	Astronomic
Modes of operation	Automatic; manual
Allowed time tolerance	≤ 1 s/day
Degree of protection	IP20
Cost, USD	31
Installation/setup cost, USD	4/4

be equal to nine [46]. To summarize the research results, it was decided to use non-specific hours of the beginning and end of the day (Fig. 3) but with a three-hour time interval (from 7:00 a.m. to 10:00 p.m.) and nine-hour time interval (from 10:00 p.m. to 07:00 a.m. for taking of the indications. Measurements were carried out during the year. For this research were used mechanical attendance counters. The studies were carried out at the following time intervals: from 7:00 a.m. to 10:00 a.m.; from 10:00 a.m. to 1:00 p.m.; from 1:00 p.m. to 4:00 p.m.; from 4:00 p.m. to 7:00 p.m.; from 7:00 p.m. to 10:00 p.m.; and from 10:00 p.m. to 7:00 a.m. Obtained data within the frame of fixed timespan were averaged. This made it possible to construct a corresponding histogram (Fig. 5).

The results of the average daily movement intensity calculations of the buildings residents through a doorway within the specified time intervals (see Fig. 5) are summarized in Table 3.

From Table 3 follows that the highest movement intensity is observed in the range of 4:00 p.m. to 7:00 p.m. The lowest – from 10:00 p.m. to 7:00 a.m. This suggests on the suitability of implantation of the automated control in the moments of turning on/off the lighting system on stairwells at night periods instead of their continuously lighting.

Motion sensors F&F DR-08 (Fig. 6) were selected to control the artificial lighting system. A specification of the motion sensor has taken from internet resources [47,48], as well as the cost of installing it, according to [43] for the Ternopil city, are shown in Table 4.

According to the data of research [49], in 95% of cases, the duration of residents being in the corridor does not exceed 60 seconds, and on the stairs - 20 seconds. As a resault of [49], the LS duration of glow recommended by 30 s, i.e. 30/3600 = 0.0083 h, because with such lamp glowing time, the maximum energy efficiency of the artificial lighting system of both corridors and stairwell would be achieved.

3. Results

Based on the obtained data, it was determined the electricity consumption of the following stairwells lighting control systems of 9-story buildings: 1 – without control systems (continuous lighting mode); 2 – in the presence of one astronomical relay, programmed so that the light turns on when astronomical twilight begins in the evening and turns off when it ends in the morning; 3 – when installing motion sensors on each floor of nine-story buildings.

3.1. Expense of costs and electric energy when using an artificial lighting system, in a continuous glow mode

The power consumption of the artificial lighting system has determined by the Eq. (1):

$$P_{\mathrm{AL.LS}} = P_{\mathrm{LS}} \cdot N_{\mathrm{LS}} \cdot N_{\mathrm{F}}, \mathrm{kWh} \quad (1)$$

where P_{LS} is the LS power consumption, kW; N_{LS} is the number of the LS that installed on each floor; and N_{F} is the building floors quantity, Qty.

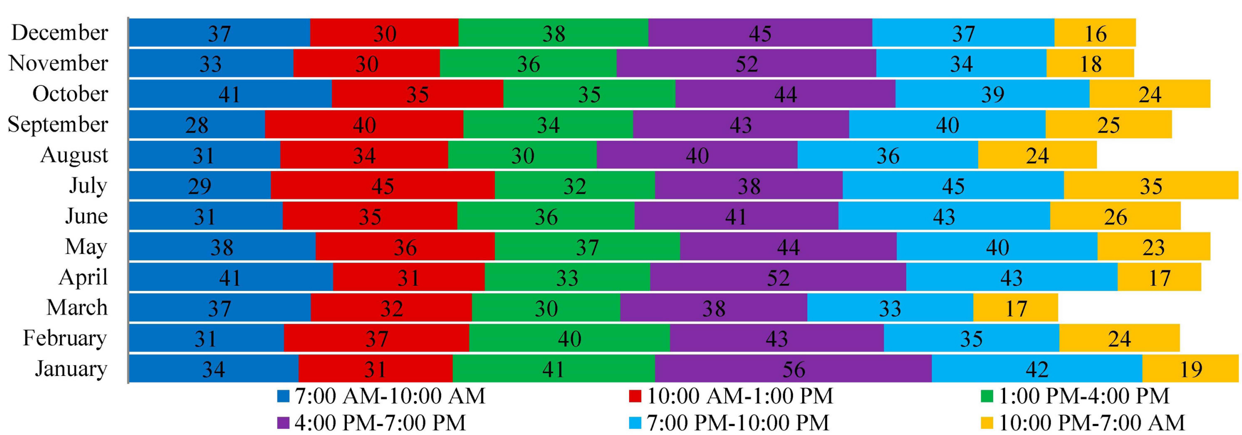


Fig. 5. The average occupants' traffic histogram of 9 floors buildings; they were passing through the doorway of the first floor, within 3-hour time intervals, starting from 7:00 AM to 10:00 PM and 9 hours interval from 10:00 PM to 07:00 AM.

Table 3. Occupants' average movement intensity through the first floor doorway, residents per day.

Month	The average occupants' traffic	Month	The average occupants' traffic	Month	The average occupants' traffic
January	223	May	218	September	210
February	210	June	212	October	218
March	187	July	224	November	203
April	217	August	195	December	203

Fig. 6. Infrared motion sensor DR-08 [47].

Table 4. F&F DR-08 motion sensor's specifications.

Parameters	Value
Power consumption, W	0.45
Response time, s	10
Degree of protection	IP 20
Detection distance, m	2
Detection angle, °	360
Shutdown delay, s	3-540
Temperature operating mode, °C	from -10 to +40
Cost, USD	22.18
Installation cost, USD	8.8

Table 5. Artificial lighting system power and annual electricity consumption for each LS type.

LS type	P_{AL}, kW	W_{AL}, kWh/year
HL	0.540	4730.400
CFL	0.162	1103.760
LED	0.090	788.400

The total annualelectricity consumption of the artificial lighting system has determined by the Eq. (2):

$$W_{AL} = P_{AL.LS} \cdot T_Y, \text{kWh} \quad (2)$$

where T_Y is the annual duration of building stairwells LS glowing, h/year.

For artificial lighting system 1, without using a control system, the duration of its operation in continuous glowing mode during the year will be equal to $T_Y = 365 \cdot 24 = 8760$ h. For each of the selected LS the annual consumption of electricity by the artificial lighting system is calculated and shown in Table 5.

The ownership costs of the lighting system (C_{AL}), when used in continuous glowing mode, was determined by the following Eq. (3):

$$C_{AL} = C_I + \left((C_{LS} + C_R) \cdot N_{F.LS} + P_{AL} \cdot T_Y \cdot C_E\right) \cdot N_F, \text{USD} \quad (3)$$

where C_I is the initial cost of necessary LS and control devices for stairwells artificial lighting, USD; C_{LS} is the cost of a LS, USD; C_R is the LS replacement cost, USD; $N_{F.LS}$ is the number of the LS that failed during the chosen period, Qty; and C_E is the cost of theelectricity, USD/(kWh);

Number of the LS that failed during the chosen period is determined by the Eq. (4)

$$N_{F.LS} = \frac{T_{N.LS}}{T_{LS}}, \text{Qty} \quad (4)$$

where $T_{N.LS}$ is the LS nominal operating lifetime, h.

According to the Ukrainian National Commission for State Regulation of Energy and Utilities, the electricity cost (C_E) of the energy supply company JSC "Ternopiloblenergo" for consumers of the 2nd voltage class (which include legal entities paying for the stairwell lighting) is 0.0966 USD/kWh.

As can be seen from Fig. 7, the costs of artificial lighting system with HL (8578.53 USD) (Fig. 7, p. *A*) through ten years of operation, would be in 81.58% more than with CFL (1580.31 USD) (Fig. 7, p. *B*) and in 87.57% more than with LED (1066.15 USD) (Fig. 7, p. *C*).

3.2. Economic and energy efficiency of artificial lighting control system with the astronomical relay

Next consider an option of using the astronomical relay, which turns on the artificial lighting system in the absence of daylight and turns off when it is available.

EE, which would be used by the astronomical relay for the year (W_{AR}) is determined by the Eq. (5):

$$W_{AR} = P_{AR} \cdot T_Y, \text{kWh/year} \quad (5)$$

where P_{AR} is the electrical power consumed by the astronomical relay, kW.

For a year, the astronomical relay REV-225, with a maximum electricity power consumption of 1.3 W, would consume: $W_{AR} = 0.0013 \cdot 8760 = 11.388$ kWh/year.

The total annualelectricity consumption of the artificial lighting system with the astronomical relay has determined by the Eq. (6):

$$W_{AL.AR} = P_{AL} \cdot T_{LS} + W_{AR}, \text{kWh/year} \quad (6)$$

where T_{LS} is the LS service life, h/year.

The calculation results of the monthly consumption of electricity by a lighting system with the astronomical relay are shown in Fig. 8.

The annual electricity consumption for each type of LS, when using an artificial lighting system with one astronomical relay, according to Fig. 8 are: $W_{AL.AR.HL} = 2340.824$ kWh/year; $W_{AL.AR.CFL} = 554.923$ kWh/year; and $W_{AL.AR.LED} = 399.627$ kWh/year.

As we can see, with the combined illumination of stairs and floor corridors of astronomical relay, can reduce the consumption of electricity on 50.52% for HL (4730.400/2340.824 kWh/year),

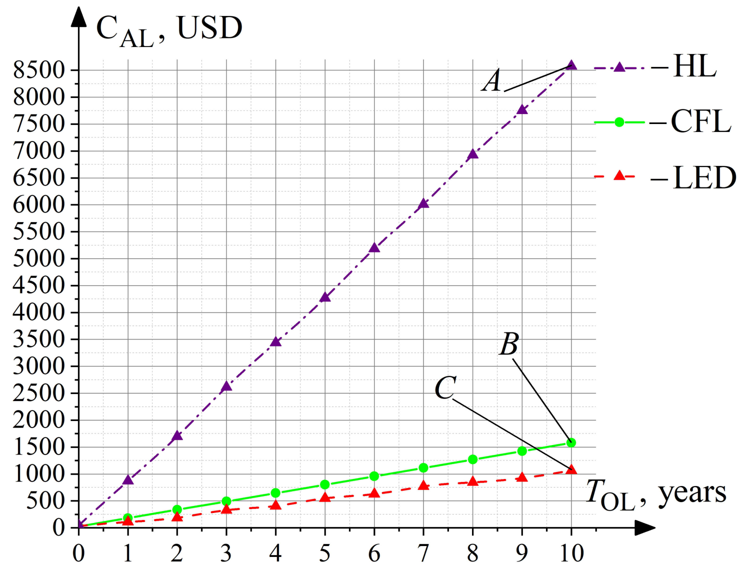


Fig. 7. Dependence on the cost of the artificial lighting system (C_{AL}, USD) from its operating life (T_{OL}, years) for various types of LS in continuous glowing mode.

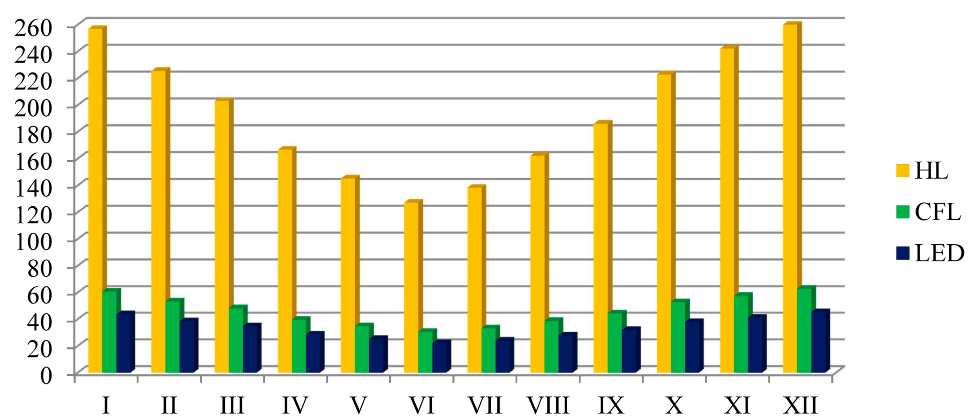


Fig. 8. Monthly electricity consumption by artificial lighting system for each LS type, with use of the control system by the astronomical relay, kWh/month.

on 49.72% to the CFL (1103.760/554.923 kWh/year) and on 49.31% to the LED (788.400/399.627 kWh/year).

Let's consider the electricity consumption of the astronomical relay for controling of stairwells' artificial lighting at night. One astronomical relay turns on the light at the entrance in the evening at the end of daylight hours and turns off at the moment of its beginning (see Fig. 3).

The ownership's cost of the lighting system, when used with control by the astronomical relay, is determined by the following Eq. (7):

$$C_{\mathrm{AL.AR}} = C_{\mathrm{I}} + \left((C_{\mathrm{LS}} + C_{\mathrm{R}}) \cdot N_{\mathrm{F.LS}} + P_{\mathrm{AL}} \cdot T_{\mathrm{LS}} \cdot C_{\mathrm{E}}\right) \cdot N_{\mathrm{F}} + (C_{\mathrm{IS.AR}} + W_{\mathrm{AR}} \cdot C_{\mathrm{E}}) \cdot N_{\mathrm{AR}}, \mathrm{USD} \quad (7)$$

where N_{AR} is the quantity of astronomical relays, Qty; $C_{IS.AR}$ is the astronomical relays installation and setup cost, USD; and W_{AR} is the astronomical relays electricity annual consumption, kWh/year.

According to the results presented in Fig. 9, cost of ownership of the artificial lighting system controlled by the astronomical relay with the HL (4284.68 USD) (Fig. 9, p. *A*) after ten years of operation life, would be in 80.22% more than with the CFL (847.34 USD) (Fig. 9, p. *B*) and in 86.06% more, than with the LED (597.24 USD) (Fig. 9, p. *C*).

3.3. Economic and energy efficiency of artificial lighting control system with the motion sensors

Consider the option of use the stairwells artificial lighting system controlled by motion sensors. Calculations are carried out for multistorey building with a lift. To determine the energy consumption of the artificial lighting system with motion sensors, it is necessary to determine the number of their responses. The data from Fig. 5 used to assess the movement of residents by floors (Table 6).

When using motion sensors, to determine the energy consumption of the artificial lighting system, it is necessary to determine the number of its operations.

As can be seen from the Table 6, in total during the year, residents of 9-story buildings turn on lighting (pass by a motion sensor) 144 210 times. This is taking into account the fact, that residents of floors 2 to 9 from the first floor and back move exclusively by elevator. Given that the average number of residents in the cases considered was 71, we find that on average each inhabitant passed through the entrance to the house 2.95 (76346 / (365·71)) times/day.

EE consumed by the motion sensors per year (W_{MS}) was determined by the Eq. (8):

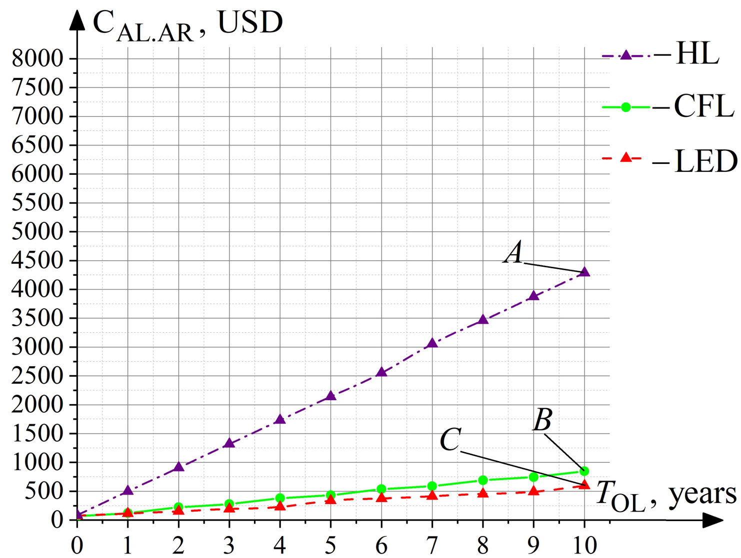


Fig. 9. Dependence of the artificial lighting systems ownership cost, which is controlled by the astronomical relay ($C_{AL.AR}$, USD), from its operating life (T_{OL}, years) for various types of LS.

$$W_{MS} = P_{MS} \cdot N_{MS} \cdot T_Y, \text{kWh/year} \tag{8}$$

where P_{MS} is the electrical power consumed by the motion sensor in standby mode, kW, and N_{MS} is the motion sensors quantity, Qty.

Over year, nine motion sensors F&F DR-08, which consumes power 0.45 W in standby mode, consumes following amount ofelectricity: $W_{MS} = 0.00045 \cdot 9 \cdot 8760 = 35.478$ kWh/year.

To determine the energy consumption by the artificial lighting system within a year used the Eq. (9):

$$W_{AL.MS} = N_{LS} \cdot P_{LS} \cdot I_{MoR} \cdot T_{LS} + W_{MR}, \text{kWh/year} \tag{9}$$

where I_{MoR} is the traffic intensity of residents, Qty/year; $W_{AL.MS.IL} = 107.295$ kWh/year; $W_{AL.MS.CFL} = 52.235$ kWh/year; and $W_{AL.MS.LED} = 47.447$ kWh/year.

So, when lighting stairwells using motion sensors as a control system, it is possible to reduce electricity consumption in 97.73% for HL (4730.400/107.295 kWh/year), in 95.27% (1103.760/52.235 kWh/year) for CFL and in 93.98% for LED (788.400/47.447 kWh/year). You should also pay attention to the fact that the artificial lighting control system based on motion sensors consumes more electricity (35.478 kWh/year), while selected for research LS: HL – 71.816 kWh/year; CFL – 16.757 kWh/year and LED – 11.969 kWh/year).

Table 6. The average occupants' traffic of 9 floors buildings, occupants per month.

Month	1*	2**	3***
January	6 923	6 152	13 075
February	5 922	5 264	11 186
March	5 797	5 152	10 949
April	6 473	5 752	12 225
May	6 529	5 800	12 329
June	6 350	5 648	11 998
July	6 921	6 152	13 073
August	6 038	5 368	11 406
September	6 296	5 600	11 896
October	6 746	6 000	12 746
November	6 068	5 392	11 460
December	6 283	5 584	11 867
Per year	76 346	67 864	144 210

1* – average occupants' traffic of 1st floor.
2** – average occupants' traffic of 2nd-9th floors.
3*** – total occupants' traffic per month.

According to [50], since the operating time of the LS is not significant through the short duration of the delay in the glow of the LS, the number of on/off cycles was used in this study. Data on the LS that failed, taking into account the safety factor are given in Table 7. In this case, the number of the LS that failed during the chosen period is determined by the Eq. (10)

$$N_{F.LS} = \frac{N_{N.S}}{N_S}, \text{Qty} \tag{10}$$

where N_S is the number of LS switching cycles per chosen period, Qty, and $N_{N.S}$ is the nominal number of LS switching cycles, Qty.

According to the Eq. (10), the number of LSs that fail during each of ten years of operation has been calculated. The calculation results are presented in Table 7.

Cost of ownership of the lighting system, when used with control by motion sensors ($C_{AL.MS}$) during a year determined by the following Eq. (11):

$$C_{AL.MS} = C_I + ((C_{LS} + C_R) \cdot N_{F.LS} + P_{LS} \cdot T_{LS} \cdot C_E + (C_{IS.MS} + W_{MS} \cdot C_E) \cdot N_{MS}, \text{USD} \tag{11}$$

where $C_{IS.MS}$ is the motion sensors installation cost, USD.

Figure 10 shows the dependence of the ownership costs of the artificial lighting system controlled by motion sensors on the duration of its operating life.

As can be seen from Fig. 10, the cost of ownership of the artificial lighting system controlled by motion sensors with HL (1338.41 USD) (Fig. 10, p. *A*) after ten years of operation, would be in 36.97% more than with CFL (843.62 USD) (Fig. 10, p. *B*) and in 32.85% more than with LED (898.75 USD) (Fig. 10, p. *C*).

Table 7. The number of LS that fail in a year, Qty.

LS type	Artificial lighting systems operating life, year									
	1	2	3	4	5	6	7	8	9	10
HL	70,00	70,00	70,00	70,00	70,00	70,00	70,00	70,00	86,00	70,00
CFL	34,00	36,00	34,00	36,00	34,00	36,00	34,00	36,00	34,00	36,00
LED	34,00	36,00	34,00	36,00	34,00	36,00	34,00	36,00	34,00	36,00

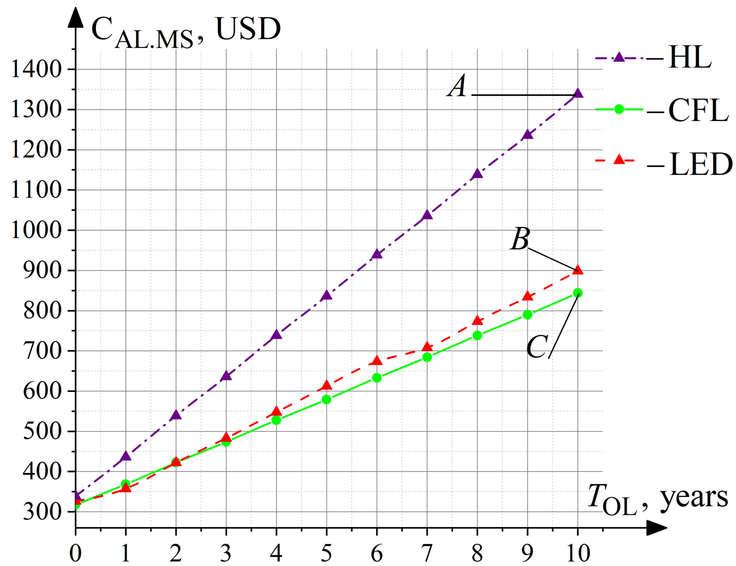


Fig. 10. Dependence of the artificial lighting systems ownership costs, which is controlled by the motion sensors ($C_{\text{AL.MS}}$, USD), from its operating life (T_{OL}, years) for various types of LS.

Table 8. Parameters of artificial lighting control systems.

Type	Duration of glow of the LS, h/year	The cost of the control system, USD	Electricity consumed by the control system, kWh/year	Number switching cycles per year, Qty/year
Without control system	8760	0	0	1
With 1 astronomical relay	4313.77	32.45	11.388	365
With 9 motion sensors	265.98	225.36	35.478	144210

3.4. Economic efficiency of using the artificial lighting control systems

In this section, we consider the economic effect of installing/replacing control systems: 1) when installing an astronomical relay to an artificial lighting system, in which there was no control system for various LS; 2) when installing motion sensors to an artificial lighting system, in which there was no control system for various LS; 3) when replacing an astronomical relay with motion sensors for various LS.

Data on power consumption, the cost of control systems, the duration of the glow of the LS and the number of on/off cycles per year are given in Table 6.

The efficiency of using the motion sensors with the astronomical relay was not considered, since the share of daylight in the structure of the day during the year for Ternopil is 51% of the total duration of the year (see Fig. 2).

If we consider the compatible operation of motion sensors with twilight switch, it will also not bring significant savings due to the fact that the cost of electricity consumed by LS is negligible (6.94 USD for HL, 1.62 USD for CFL and 1.16 USD for LED).

The cost savings from using the control system with the astronomical relay ($E_{\text{Fo.AR}}$) determined by the Eq. (12):

$$E_{\text{Fo.AR}} = C_{\text{AL}} - C_{\text{AL.AR}}, \text{USD} \quad (12)$$

The cost savings from using the control system with the motion sensors ($E_{\text{Fo.MR}}$) was determined by the Eq. (13):

$$E_{\text{Fo.AR}} = C_{\text{AL}} - C_{\text{AL.MS}}, \text{USD} \quad (13)$$

The results of calculating the artificial lighting systems ownership cost, with various types LS, are given in the Table 9.

To determine the payback period of artificial lighting systems presented in Table 8 we will use the digital data of this table. To determine the payback period of artificial lighting control systems from the cost of ownership of the system without artificial lighting control, subtract the cost of ownership with the control system. In Fig. 10, the payback periods of artificial lighting control systems correspond to the point at which the graphs cross the abscissa axis, which passes through zero. This is due to the cost of buying and installing control devices. The intersection points of the graphs in Fig. 10 indicate the period after which the artificial lighting system with motion sensors will provide greater total cost savings than when using an astronomical relay.

Figure 11 shows the graphs of the cost savings of using stairwell lighting control systems for multistory buildings versus their operating life, compared to the case without using a control system. In Fig. 10, the following notations are used: a – cost of installing and maintaining the artificial lighting system with HL, that are controlled by the AR; b – cost of installing and maintaining the

Table 9. The number of LS that fail in a year, Qty.

LS type	The duration of the artificial lighting system operation life, years									
	1	2	3	4	5	6	7	8	9	10
Without control system										
HL	46.08	871.68	697.27	2615.03	3440.63	4266.22	5183.98	6009.58	6927.33	7752.93
CFL	24.48	180.06	335.65	491.23	646.81	802.40	957.98	1113.56	1269.15	1424.73
LED	33.84	110.00	186.16	330.00	406.16	550.00	626.16	770.00	846.16	922.31
With the astronomical relay										
HL	88.08	498.52	908.97	1319.41	1729.85	2140.30	2550.74	3053.35	3463.79	3874.23
CFL	66.48	120.09	222.65	276.26	378.82	432.43	534.99	588.60	691.16	744.77
LED	75.84	114.44	153.05	191.65	230.26	336.54	375.14	413.75	452.35	490.96
With motion sensors										
HL	338.76	436.16	538.69	636.09	738.62	836.02	938.55	1035.95	1138.48	1235.88
CFL	317.16	368.45	422.45	473.74	527.74	579.03	633.04	684.32	738.33	789.61
LED	326.52	357.42	422.17	483.15	547.89	612.64	673.62	708.28	773.03	834.01

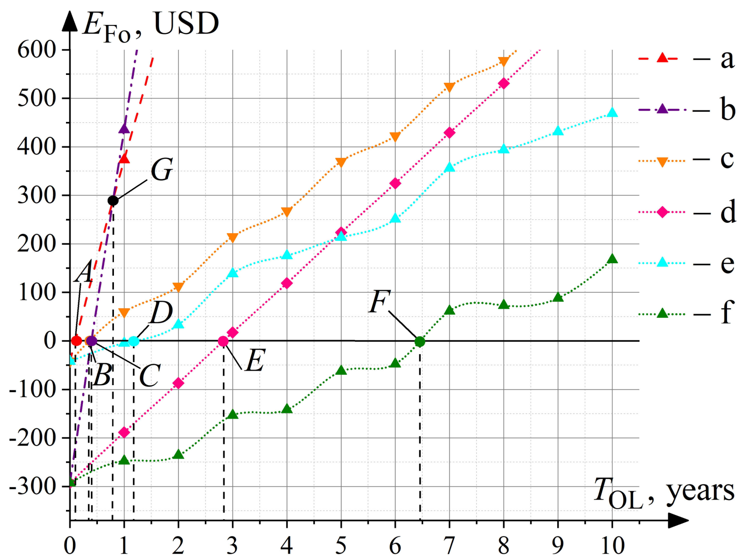


Fig. 11. The dependence of the cost savings of using control systems for stairwells lighting of multistory buildings with using of: a) HL, c) CFL, e) LED with astronomical relay and b) HL, d) CFL, f) LED with motion sensors from its operating life (T_{OL}, years).

artificial lighting system with HL, that are controlled by the MS; c – cost of installing and maintaining the artificial lighting system with CFL, that are controlled by the AR; d – the cost of installing and maintaining the artificial lighting system with CFL, that are controlled by the MS; e – the costs of installing and maintaining the artificial lighting system with LED, that are controlled by the AR; f – the cost of installing and maintaining the artificial lighting system with LED, that are controlled by the MS.

As can be seen from Fig. 11, the payback period of the lighting control system with the astronomical relay is 0.10 years for HL (Fig. 11, p. *A*), 0.41 years for the CFL (Fig. 11, p. *C*) and 1.12 years for the LED (Fig. 11, p. *E*). The payback period for installing motion sensors on all floors is 0.40 years for HL (Fig. 11, p. *B*), 2.85 years for the CFL (Fig. 11, p. *D*) and 6.43 years for the LED (Fig. 11, p. *F*). If we compare the lighting control system with motion sensors with a system with an astronomical relay, then when using HL, the first becomes economically profitable after 0.80 (Fig. 11 p. G), while for CFL after 9.92 years for CFL (Fig. 11 p. H), and for LED the best option, from the point of view of economic efficiency, is the astronomical relay. As can be seen from the obtained results, due to the low electric power of the LED, the use of the control system with both motion sensors and an astronomical relay has a long payback period. At the same time, for HL it does not exceed one year in all cases.

4. Discussion

The feasibility of this study is due to the fact that it is currently difficult to assess the feasibility of establishing an artificial lighting control system. Usually, it is sufficient to just replace the existing LSs with more energy-efficient ones and entrust the residents to manage their work and monitor their shutdown at a time when lighting is not necessary. The results presented in this article make it possible to assess the possible economic and energy effect not only from the use of energy-efficient LS, but also when implementing artificial lighting control systems. Also, in the case of an astronomical relay, we can evaluate the effectiveness of the use of daylighting for a given object.

To identify efective energy conservation measures in multifamily housing, the New York State Division of Housing & Community Renewal funded a study to investigate the energy saving efects of lighting controls given real-life occupancy patterns in multifamily residences. Taitem Engineering, PC, located in Ithaca, New York, conducted the study in 2012 [49]. During the study, monitoring and registration of the intensity of movement of residents in three multistory buildings (5, 6 and 15 floors) was carried out to determine the attendance of corridors and stairwells. Occupancy sensors were installed in two locations in each of three multi-story senior citizen housing units. One sensor was installed in a stairwell, about the middle floor. The other sensor was placed near the elevator serving the same floor. All sensors were placed at about 1.8 m above the floor. Data of the movement intensity of the building's residents was collected continuously for only four weeks. Therefore, the research results cannot be extended to the all year long.

The resident population for any particular building has its own unique occupancy patterns. For example, a building occupied primarily by professionals will likely have fewer people in the corridors or stairways from 9 am to 5 pm, with peaks between 7 am and 9 am and between 5 pm and 7 pm. Younger professionals may have another peak between 10 pm and 2 am when returning from socializing [49]. It is also importent to consider that all residents pass through the first floor every day, because the entrance to the building is also located on it.

To calculate the electricity costs for lighting of different floors stair landings and staircases we assume that the residents who appears on all floors are identical, that is, residents walk the same number of times on each floor. This is necessary, because in different houses the intensity of the movement of residents for different floors varies in different ways due to the variuos areas of residents' employment. It is also necessary to consider that all residents pass through the first floor, since the entrance to the building is located on it. The average number of residents in the cases under consideration was 71. The luminare at the entrance to the stairs was not considered in the framework of this study. This is because the energy that it consumes is constant, regardless of which lighting control system is used.

The study found that the use of motion sensors guarantees a reduction in electricity consumption (up to 97.92%). While the tandem of an astronomical relay with LED lamps allows you to minimize the cost of ownership of an artificial lighting system (up to 50.05%). A significant effect on the magnitude of the economic effect has both the cost of the control devices of the lighting installation, and the influence of the mode of frequent switching on the average duration of the glow of the LS.

With the popularization of motion sensors and LED, their cost will decrease, the service life will increase, which will positively affect their economic efficiency. In any case, the payback period of the astronomical relay is less, since only one relay is needed to control the lighting system, and motion sensors - 9.

It should be noted that the economic feasibility of combined lighting (a mixture of natural and artificial) with the growth of tariffs for energy efficiency will also grow. Since the efficiency of using an astronomical relay is calculated only for a specific region, it is likely that in areas with a longer daylight hours from the point of view of economic costs, an astronomical relay will be appropriate. In the long run, due to a significant reduction in electricity costs, motion sensors will be the best option. In addition to economic benefits it also gives environmental benefits. With a decrease in electricity consumption, the need for its generation, which is accompanied by greenhouse gas emissions at thermal power plants, will decrease.

5. Conclusion

In the article experimentally determined the residents' movement intensity through the doorway of the 9-story buildings first floor for three-hour time intervals from 7:00 to 22:00 and a 9-hour interval from 22:00 to 07:00 during the year. The obtained data make it possible to determine the energy and economic efficiency of using the artificial lighting control system with motion sensors. The study found that using of motion sensors on stairwells leads to a significant reduction inelectricity consumption: when using HL – in 97.92%, CFL – in 95.27%, LED – in 93.98%, while regardless of the type of the LS, using the astronomical relay leads to a reduction in the electricity consumption of artificial lighting in 49.31% - 50.52%.

From the point of view of economic efficiency, the situation is somewhat different. Due to the need to install nine motion sensors, the economic effect of their use is significantly reduced. So, when an astronomical relay is installed, the cost of ownership decreases from 10 years: for HL – by 50.05% CFL – by 46.38%, LED – 43.98%, whereas when using sensors movements - with HL – by 84.40%, CFL – by 46.62% and LED – 15.70%.

From this we can conclude that when implementing on the stairs and floor corridors of multi-storey buildings, lighting systems with motion sensors and LED lamps are the most energy-efficient option. At the same time, from an economic point of view, a combined lighting system with an astronomical relay can minimize the costs of ownership, since the use of a control system with motion sensors, despite a significant reduction in electricity consumption, has a high payback period even if such energy-efficient LS as CFL and LED lamps.

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Contributions

The authors have contributed equally.

Declaration of competing interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

References

[1] ASHRAE. Available online: https://ashrae.iwrapper.com/ViewOnline/Standard_90.1-2013_I-P (accessed on 20 March 2020).

[2] M. Halverson et al. ANSI/ASHRAE/IES Standard 90.1-2013 Determination of Energy Savings: Quantitative Analysis.

[3] Architecture 2030. Available online: https://architecture2030.org (accessed on 20 March 2020).

[4] EIA, U. S. Energy Information Administration, Accessed on 20 March 2020, Available online: https://www.eia.gov/tools/faqs/faq.php?id=99&t=3.

[5] M. Nadhim Majeed, F. Ali Mustafa, H. Ali Husein, Impact of Building Typology on Daylight Optimization Using Building Information Modeling: Apartments in Erbil City as a Case Study, Journal of Daylighting 6 (2019) 187-201.

[6] F. De Luca, T. Dogan, A novel solar envelope method based on solar ordinances for urban planning, Building Simulation 12 (2019) 817-834.

[7] C. R. Lamb, City plan, The Craftsman 6 (1904) 3-13. Available: http://urbanplanning.library.cornell.edu/DOCS/lamb.htm.
[8] V. Koval, Energy efficient dynamic lighting of long-term corridors, Materials 6th International Scientific Conference "Lighting and power engineering: history, problems and perspectives" (Ternopil, January 30 – February 02, 2018) (2018) 30-31, Available: http://elartu.tntu.edu.ua/handle/lib/24278.
[9] M. Sudan, G. N. Tiwari, Daylighting and energy performance of a building for composite climate: An experimental study, Alexandria Engineering Journal 55(4) (2016) 3091-3100.
[10] Z. Kristl, A. Krainer, Light wells in residential building as a complementary daylight source, Solar Energy 65 (1999) 197-206.
[11] F. Rubinstein, N. Colak, J. Jennings, D. Neils, Analyzing occupancy profiles from a lighting controls field study, Conference: CIE Session 2003, San Diego, CA (US), Available: https://www.osti.gov/biblio/813377.
[12] M. Karpiński, K. Kozak, Energy efficiency regulation of the light source's luminous flux, Pomiary Automatyka Robotyka, 11 (2013) 79-83, Available: http://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-fb3e2200-0af1-42be-87f0-cde56ce87232.
[13] Almeida et al, Solid state lighting review – Potential and challenges in Europe, Renewable and Sustainable Energy Reviews 34 (2014) 30-48.
[14] L. Bellia, F. Fragliasso, E. Stefanizzi, Why are daylight-linked controls (DLCs) not so spread? A literature review, Building and Environment 106 (2016) 301-312.
[15] T. Dogan, Y. C. Park, A new framework for residential daylight performance evaluation, In: Proceedings of the International IBPSA Building Simulation Conference, San Francisco, USA (2017) 170-178.
[16] T. Dogan, Y. C.Park, A critical review of daylighting metrics for residential architecture and a new metric for cold and temperate climates, Lighting Research & Technology 51 (2018) 206-230.
[17] L. Doulos, A. Tsangrassoulis, F. V. Topalis, Multi-criteria decision analysis to select the optimum position and proper field of view of a photosensor, Energy Conversion and Management 86 (2014) 1069-1077.
[18] Valerio R.M. Lo Verso, Anna Pellegrino, Energy Saving Generated Through Automatic Lighting Control Systems According to the Estimation Method of the Standard EN 15193-1, Journal of Daylighting 6 (2019) 131-147.
[19] L.T. Doulos, A. Kontadakis, E.N. Madias, M. Sinou, A. Tsangrassoulis, Minimizing energy consumption for artificial lighting in a typical classroom of a Hellenic public school aiming for near Zero Energy Building using LED DC luminaires and daylight harvesting systems, Energy and Buildings 194 (2019) 201-217.
[20] B. Obradovic, B. Szybinska Matusiak, Daylight Transport Systems for Buildings at High Latitudes. Journal of Daylighting 6 (2019) 60-79.
[21] V. Garg, N. K. Bansal, Smart occupancy sensors to reduce energy consumption, Energy and Buildings 32 (2000) 81-87.
[22] A. C. Menezes, A. Cripps, D. Bouchlaghem, R. Buswell, Analysis of electricity consumption for lighting and small power in office buildings, CIBSE Technical Symposium, DeMontfort University, Leicester, UK, 6 - 7 September, 2011. Available: https://repository.lboro.ac.uk/articles/Analysis_of_electricity_consumption_for_lighting_and_small_power_in_office_buildings/9424484.
[23] V. Becker, W. Kleiminger, Exploring zero-training algorithms for occupancy detection based on smart meter measurements, Computer Science - Research and Development 33 (1-2) (2018) 25-36.
[24] D. T. Delaney, G. M. P. O'Hare, A. G. Ruzzelli, Evaluation of energy-efficiency in lighting systems using sensor networks, Conference: BuildSys First ACM Workshop On Embedded Sensing Systems For Energy-Efficiency In Buildings (2009).
[25] Yu. V. Dzyadykevych, B. R. Hewko, Yu. S. Nykeruy, Current consumption in a housing and municipal ORB. Energy saving. Power engineering, Energy audit 83(1) (2011) 20-23.
[26] Yu. V. Dzyadykevych, B. R. Hewko, Yu. S. Nykeruy, Ways to save power in public housing, Energy saving. Power engineering. Energy audit 88(6) (2011) 21-24. Available: http://eee.khpi.edu.ua/article/view/21819.
[27] Tuan Anh Nguyen, Marco Aiello, Energy intelligent buildings based on user activity: A survey, Energy and Buildings, 56 (2013) 244-257.
[28] X. Guo, D. K. Tiller, G. P. Henze, C. E. Waters, The performance of occupancy-based lighting control systems: A review, Lighting Research & Technology 42 (2010) 415-431.
[29] M-C. Dubois, A. Blomsterberg, Energy saving potential and strategies for electric lighting in future North European, low energy office buildings: A literature review, Energy and Buildings 10(43) (2011) 2572-2582.
[30] M-C. Dubois, F. Bisegna, N. Gentile, M. Knoop, B. Matusiak, W. Osterhaus and E. Tetri, Retrofitting the Electric Lighting and Daylighting Systems to Reduce Energy Use in Buildings: A Literature Review, Energy Research Journal 1(6) (2015) 25-41.
[31] A. Haq Mohammad, M. Yusri Hassan, H. Abdullah, H. Abdul Rahman, M. Pauzi Abdullah, F. Hussin, D. Mat Said, A review on lighting control technologies in commercial buildings, their performance and affecting factors, Renewable and Sustainable Energy Reviews 33 (2) (2014) 268-279.
[32] L. Bellia, F. Fragliasso, E. Stefanizzi, Daylit offices: a comparison between measured parameters assessing light quality and users' opinions, Building and Environment 113 (2017) 92-106.
[33] Z. Nagy, F. Y. Yong, A. Schlueter, Occupant centered lighting control: A user study on balancing comfort, acceptance, and energy consumption, Energy and Buildings 126 (2016) 310-322.
[34] V. Burmaka, M. Tarasenko, K. Kozak, V. Khomyshyn, Definition of a composite index of glazing rooms, Eastern-European journal of enterprise technologies 4 (10) (2018) 22-28.
[35] M. Tarasenko, V. Burmaka, K. Kozak, V. Khomyshyn, Impact of the translucent structures of exterior wall envelope orientation on the energy balance of the premises, Scientific Journal of TNTU (Tern.) 94(2) (2019) 92-103.
[36] State building codes of Ukraine. Available online: https://dbn.co.ua/load/normativy/dbn/dbn_v_2_5_28/1-1-0-1188 (accessed on 20 March 2020).
[37] Elektrolight. Available online: https://www.elektrolight.ru/lampy/galogennye-v-kolbe/lampa-galogennaya-64542-p-eco-30w-e27-osram-4008321998286 (accessed on 20 March 2020).
[38] IEC 60357:2002 – Tungsten halogen lamps (non vehicle) - Performance specifications.
[39] ElectroMarket. Available online: https://electro-market.com.ua/ctproduct/ljyminescentnaya-lampa-fs-7-4200-27-7w-4200k-e27-spiral-220v-evrosvet.html (accessed on 20 March 2020).
[40] IEC 60969 – Self-ballasted compact fluorescent lamps for general lighting services - performance requirements
[41] Maxus International Corporation. Available online: https://maxus.com.ua/led-lampa-global-g45-f-5w-teplyj-svet-e14-1-gbl-143.html (accessed on 20 March 2020).
[42] IEC 62612:2013+AMD1:2015+AMD2:2018 – CSV Consolidated version Self-ballasted LED lamps for general lighting services with supply voltages > 50 V – Performance requirements
[43] Domovii. Customer Service. Available online: https://domoviy.com/elektrik/cini-na-elektromontazni-roboti-ternopil&l=ua (accessed on 20 March 2020).
[44] 365.wiki. Available online: https://365.wiki (accessed on 20 March 2020).
[45] Novatek Electro. Available online: https://novatek-electro.com/en/products/programmable-timers-with-photo-relay-and-voltage-monitor/astronomical-timer-for-street-lighting-rev-225.html (accessed on 20 March 2020).
[46] B.O. Palchevskyi. Research of technological systems (modeling, designing, optimization), Svit, Lviv, 2001, pp. 232.
[47] F&F domestic and industrial automation. Available online: https://www.fif.com.pl/en/motion-sensor-switch/509-infrared-motion-sensor-dr-08.html (accessed on 20 March 2020).
[48] https://axiomplus.com.ua/datchiki-dvizheniya/product-69508/ (accessed on 20 March 2020).
[49] C. Rubin, T. Ruscitti, I. Shapiro, Boosting multifamily energy savings through lighting control settings, Home Energy 129(3), (2013) 38-42. Available: http://www.homeenergy.org/show/article/id/1904.
[50] C. Jump, J. J.Hirsch, J.S. Peters, D. Moran, Welcome to the Dark Side: The Effect of Switching on CFL Measure Life, in: ACEEE Summer Study on Energy Efficiency in Buildings, Vol. 2, American Council for an Energy Efficient Economy, Pacific Grove, California 2 (2008) 138-149.
[51] V. Burmaka, M. Tarasenko, Energy efficiency using of combined indoor lighting for stair cells, Materialy IV Mizhnarodnoi naukovo-tekhnichnoi konferentsii "Teoretychni ta prykladni aspekty radiotekhniky, pryladobuduvannia i komp'iuternykh tekhnolohii" prysviachena 80-ty richchiu z dnia narodzhennia profesora Ya.I. Protsia (Tern., 20-21 June 2019) (2019) 273-277. Available: http://elartu.tntu.edu.ua/handle/lib/28856.