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RESEARCH ARTICLE

The Effect of Lighting and Curtain Automation on Energy Performance

[1]Orhun Celil Özen, *[2]Onur Akar, and [3]Nazmi Ekren

[1]Marmara University, Faculty of Technology, Electrical-Electronic Engineering Department, Istanbul, Türkiye
orhunozen@marun.edu.tr, Orcid.0009-0005-6007-708X
[*2]Marmara University, Vocational School of Technical Sciences, Electronics and Automation, Istanbul, Türkiye
onur.akar@marmara.edu.tr, Orcid.0000-0001-9695-886X
[3]Marmara University, Faculty of Technology, Electrical-Electronic Engineering Department, Istanbul, Türkiye
nazmiekren@marmara.edu.tr, Orcid.0000-0003-3530-9262

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HIGHLIGHTS

- *Energy efficiency in office room lighting automation system has been examined annually.*
- *Different devices have been installed on the KNX system and programmed with ets6 and a test environment has been prepared*
- *It has been focused on how lighting automation affects work performance.*
- *A new approach has been introduced by using both natural and artificial light to keep work performance at a maximum level.*
- *Experiments have been carried out in 2 similar environments and energy performance has been evaluated.*

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***Corresponding Author:**
Onur AKAR
onur.akar@marmara.edu.tr
Phone: +90 216 7774099

ABSTRACT

Energy efficiency in buildings has become a crucial factor in sustainable design and energy management. This study investigates the effects of lighting and curtain automation on energy performance, aiming to optimize energy consumption while maintaining indoor comfort. To achieve this, an automation system was developed to enhance the energy efficiency of lighting systems and prevent inefficient usage. The system, designed to address excessive or insufficient lighting in working and living areas, utilizes sensors to detect and automatically control light intensity through curtain blinds and brightness-adjustable lamps. This ensures that the environment remains at an optimal brightness level, reducing energy waste. The study employs an experimental approach, comparing two rooms—one equipped with the automation system and the other controlled manually—under similar environmental conditions. Light intensity and energy consumption were measured in both cases. In the automated room, light levels were adjusted dynamically using automated shutter movements and brightness-adjustable lamps, while in the non-automated room, manual control was used. The data comparison revealed that the automated system maintained a more stable light intensity and led to energy savings. Specifically, the manually controlled system consumed an average of 10.98 W, whereas the automation system consumed 10.09 W, resulting in an energy reduction of 0.9 W. Over six days, this led to a total energy saving of 130 W in a 20m² room. These findings highlight the potential of intelligent automation in reducing energy consumption and improving lighting efficiency in buildings. By integrating automation into lighting and shading systems, significant energy savings can be achieved, contributing to sustainability efforts and more efficient energy management.

Keywords: *Automation, KNX, Energy Efficiency, Sensor-based control, Smart Home System*

I. INTRODUCTION

The fact that energy use in buildings accounts for a significant proportion of global final energy consumption emphasizes that energy management is an essential part of long-term strategies focused on reducing energy consumption in buildings [1, 2]. The importance of improvements in this area becomes even more evident, especially in Europe, where buildings account for approximately 40% of energy consumption. With the revisions made within the framework of the European Green Deal, it reveals that the construction sector should play an important role in emission reduction by 2030. In order to achieve this target, buildings should be made more environmentally friendly and energy efficient [3].It has been determined that approximately 35% of electrical energy is used for lighting in buildings [4]. Many studies reveal that new buildings are not designed to reduce energy use. In most cases, building lighting systems cannot be managed efficiently. Even in some integrated lighting technology systems, energy efficiency cannot be achieved [5].According to the World Bank's 2008 building energy consumption report, building energy consumption is divided into various areas. According to this report, the lighting system of the building accounts for 31% of the total energy consumption, while other building components consume a total of 69%, including heating/cooling 36%, kitchen appliances 19% and entertainment 14% [6].The selection of the right light source, effective control systems and the use of energy efficient equipment provide significant energy savings. Multidimensional problems such as electrical lighting design and control of glare for visual comfort still persist [7]. Scientists have been working for many years to reduce this problem. Nowadays, people spend about 80% of their time inside buildings. Therefore, it is important to ensure lighting comfort [8-9]. In this context, there are many methods to increase energy efficiency today. However, in recent years, it is observed that building automation systems have become prominent in reducing electricity consumption. It is stated that the global market of automation systems is increasing and this trend continues [10]. Building automation systems not only optimize energy consumption, but also offer a number of advantages such as increasing comfort, ensuring safety an d reducing operating costs. In automation applications, heating and cooling systems can be managed more effectively thanks to smart thermostats. With motion sensors, lights can be switched off automatically and building security can be increased with security cameras. In addition, thanks to automation systems, functions such as indoor and outdoor lighting, curtain and shutter control become easily manageable. These features not only increase energy efficiency, but also significantly affect people's quality of life and work performance [11]. These values are calculated between 350-500 lx for most work areas [12]. Because the right lighting conditions are one of the important factors that determine people's mood, attention and productivity [13].

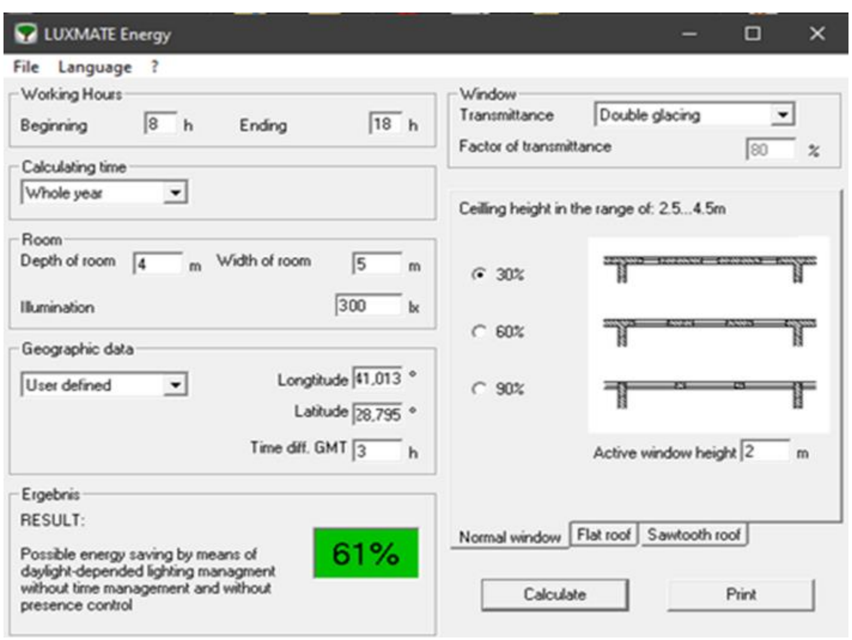

Figure. 1. Luxmate energy programmer calculation.

The designed automation system can automatically respond to changing lighting needs at different times and in different areas, taking these factors into account. It can adjust indoor lighting by adapting to changes in sunlight throughout the day or provide softer lighting in meeting rooms. This increases the comfort and productivity of employees while saving energy [14]. In the working model conducted with the luxmate energy programmer in Istanbul, it was calculated that possible energy savings can be up to 61%. As shown in Figure 1, the calculation is based on the assumption that employees work from 8:00 to 18:00 in a 4x5 m room with a window-to-wall ratio of 30%. Assuming a reception in this area, a total of 6000 lumens is required for this size of space. 8 lamps with approximately 700 lumens were determined to be suitable for this area. This arrangement brings the level to 300 lux, which is ideal for working when it is dark. When similar studies are analyzed, complex automation systems provide significant energy savings between 30% and 77% [15].As a result of automation studies in different sectors, it has been observed that automation systems used in the transport sector increase storage capacity by 27.27% [16]. Automated public transport lighting systems are more efficient than those in conventional rail systems, with around 35% traffic efficiency compared to under 20% for traditional systems [17]. In another study, consumption was drastically reduced from 400 W to 100 W with the PLC, indicating an energy saving potential of 75% with the proposed lighting control system [18]. A mixed automation study on a hotel showed that cascaded lighting control can reduce total annual energy consumption by 30-40%, [19].

In a similar study, artificial neural networks (ANN) and fuzzy logic were used to optimize the energy consumption of HVAC systems, achieving up to 20% savings. Additionally, genetic algorithms were employed to determine the optimal operating scenarios for smart building systems, improving efficiency. Machine learning models analyzed indoor temperature and user habits to develop automated energy management strategies[20]. In this study, unlike other studies, other efficiencies provided by air conditioning and automation were not taken into account, and the employee performance in a workplace was tried to be maximized by using the maximum natural light source. energy savings were calculated with experiments. This calculated energy saving was not calculated over 24 hours but was kept between real working hours. This working model shows that energy saving in the big picture can make a major contribution to global energy savings and climate change, considering the offices worldwide.

II. MANUSCRIPT PREPARATION

In the working model, 2 rooms with the same features on the same facade were selected and the lighting arrangement was made as in Figure 2. In the model without automation, a manual switch and 8 Ledwance brand 8W dimmable 700lm Dali compatible lamps were used. This system was operated with classical switching. In the 2nd room with similar features, KNX system was installed and curtain automation Dali dimming light intensity sensor and motion sensor were used. In the system, if there is no presence in the room, the lights are set to be switched off within 5 minutes if they are on. The data was recorded for 1 week. Since there are 2 rooms in the working environment, one room was used only to record lighting values and manual control was added later according to usage.For this working model, Legrand brand 002699 Dali controller 003507 KNX power supply and 002672 8 output actuator for curtain control were used. All devices were programmed and configured with KNX ETS6 software. Module connections for this model were used as shown in Figure 2.

A. KNX

KNX is a new European open standard approved by CENELEC in 2003 and adopted as an international standard in 2006. The KNX protocol is based on a decentralized architecture using negative logic to represent the bit structure. It uses four different media for data transmission: Twisted pair cable (TP), power line (PL), radio frequency (RF) and internet protocol (IP), the most widely used being KNX TP and KNX IP [20] . KNX is a globally recognized and used standard for building automation systems. This system has the ability to integrate various building automation applications such as energy management, lighting, security, heating, ventilation and air conditioning over a single network. The importance and advantages of KNX have been widely recognized in the building automation sector.
The KNX system enables devices manufactured by various manufacturers to work in harmony with each other. This

compatibility allows users to use products from different brands together. [21].KNX has a wide range of applications. This system can be used in both residential and commercial buildings. In residential buildings, it can fulfil various functions such as lighting control, integration of heating and cooling systems, security systems and energy management. In commercial buildings, KNX is widely used for energy monitoring, building management systems and integrated security solutions [22]. With its increasing integration with IoT in the future, KNX is expected to become even more widespread and continue to play a leading role in building automation [23].

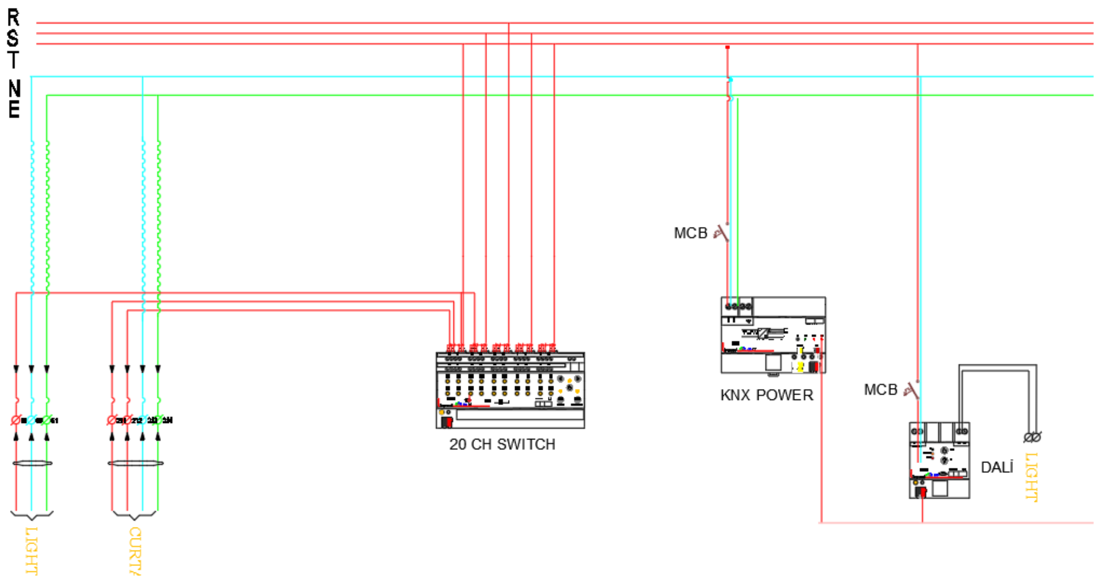

Figure. 2. KNX Modules electrical connection diagram.

B. DALI

DALI (Digital Addressable Lighting Interface) is a protocol that has become widespread especially in recent years for the management of modern lighting systems. This protocol is used to enable the communication of lighting luminaires and control devices and enables lighting systems to be more flexible, efficient and user-friendly [24]. DALI allows lighting luminaires to be controlled individually or in groups, so that different lighting scenarios can be created and energy savings can be achieved. Furthermore, the DALI protocol can be integrated with sensors and other automation devices, which increases automatic lighting control and user compliance. Used in both commercial and residential buildings, [25]. In this working model, the control of lighting was provided via DALI .In this study, while programming the selected DALI lighting power supplies, modules produced by Legrand brand and DALI programming software produced by EAE brand were used. With this software, DALI transformers were automatically addressed and then grouped from within the application and module to work together. Then, connection with the sensor was established via ETS and autonomous operation was ensured.

C. ETS6

ETS6 is a widely used building automation software in Europe, specially designed for the design, configuration and integration of KNX-based systems. This software covers all phases of building automation projects and allows users to easily manage complex systems. ETS6's features include advanced graphical interface, large device database, automatic device recognition and configuration, scenario generation and simulation, debugging and remote access. In addition, ETS6's integrated project management features enable large and complex projects to be organized and managed. ETS6 is considered as a reliable solution in the building automation industry and has become an industry standard for the design and management of KNX based systems. In this working model, all KNX devices were programmed with ETS6 and the system was monitored [26-29]. All KNX devices used in this study were programmed using ETS6 software. During the control processes, the Legrand 20-output module was configured through ETS by combining outputs and setting them to curtain and blind mode. This setting synchronizes the outputs, preventing voltage from being sent to both the upward and downward wires of the curtain simultaneously, thus protecting the motors from damage. The sensor used in the study required only the input of the desired constant lux value through ETS, thanks to its internal algorithm. Based on this value, the sensor automatically generated the addresses needed to control the DALI drivers and, throughout the operation, sent percentage-based signals to the DALI power supply to maintain the lighting at the defined level. During the programming of the DALI control module, only the first group on the module was activated, and the emergency lighting was disabled. This ensured that in case of power outages or energy interruptions, the lamps would not enter a fault state and would retain their previous state. Additionally, the feedback feature of the DALI control module was enabled, allowing the system to monitor whether the DALI devices reached the desired levels and enabling intervention when necessary. This setup and programming approach not only improves energy efficiency but also optimizes the reliability of the system

D. WORKING ENVIRONMENT SETUP

A room was selected for the model as shown in Figure 3. This room is equipped with windows to allow external light to enter and there are 8 electric lamps for the interior lighting of the room. The room has the dimensions of a standard room with a width of 4 meters, a length of 5 meters and a height of 3 meters. The walls are dark in color and the ceiling of the room is covered with white plasterboard. The floor is carpeted and the furniture is minimal so that the number of reflective surfaces is minimized. During the research, other light sources in the room were switched off and the amount of light intensity was analyzed for 7 days. This environment provides a controllable environment to ensure accurate and repeatable measurement of light intensity.

Figure. 3. Furniture setup in my automated room.

E. LIGHTING SCHEME

A Modern lighting schemes improve the comfort and quality of life of users by illuminating spaces with a combination of energy efficiency, intelligent control systems and aesthetic design. These arrangements often include the use of lamps equipped with LED technology, resulting in lower energy consumption and longer life. Control devices such as motion sensors and timers integrated with intelligent building automation systems enable automated lighting management and automatic adjustment of appropriate lighting levels at different times and for different activities. Dynamic lighting scenarios can change the lighting level according to the needs of users and thus save

energy.
Therefore, modern lighting schemes improve the quality of life by providing more efficient, comfortable and aesthetic lighting of spaces. In this model, 8 piece 700 lumen lamps were used and placed as shown in Figure 4. The amount of light was monitored and controlled by Legrand 048922 sensor

F. AUTOMATION ALGORITHM

In the algorithm created for the working scenario, it is first checked whether there is a presence in the room. If a presence in the room cannot be detected for 5 minutes, the lighting is not switched on. If a presence is detected in the room, the illumination value is measured by the sensor. Since this room is used as a reception, this illumination value is tried to be kept at 300lux value. If the measured value is lower than 300, the curtain automation is activated first and the desired value is tried to be achieved by opening 1% each time. If the desired value is not achieved when the curtain is fully opened, the dimmable lamp is increased by 1% and the desired value is tried to be achieved. If the illumination value is higher than the desired value, the dimmable lamp is first reduced by 1% and the value is tried to be captured. This algorithm is summarized in Figure 5. in commercial, industrial and educational buildings, it reaches 40% of the total daily energy consumption. these algorithms try to prevent this .in different sources, 30% savings in energy consumption and 10% savings in operating costs can be achieved with lighting control.

Figure. 4. Lamp and sensor placement in the working area.

G. CALCULATION LUX VALUE

The lighting level of a room is usually measured in units of ‘lux’ (lux). Lux refers to the light intensity on a surface and 1 lux represents 1 lumen of light per square meter of surface. Lumens represent the total amount of light emitted by a light source. The lumen value emitted by each light source in the room should be known. This value is usually indicated on the lamps. For example, a conventional 60 watt light bulb emits approximately 800 lumens of light. The lighting used in this study emits 700 lumens of light. The calculation in Equation 1 is used to calculate lux.

$$Lux\ Val = \frac{Total\ Lumen}{Area} \quad (1)$$

When an area of 20m2 is examined for this study, approximately 280 lux value is found from this calculation.

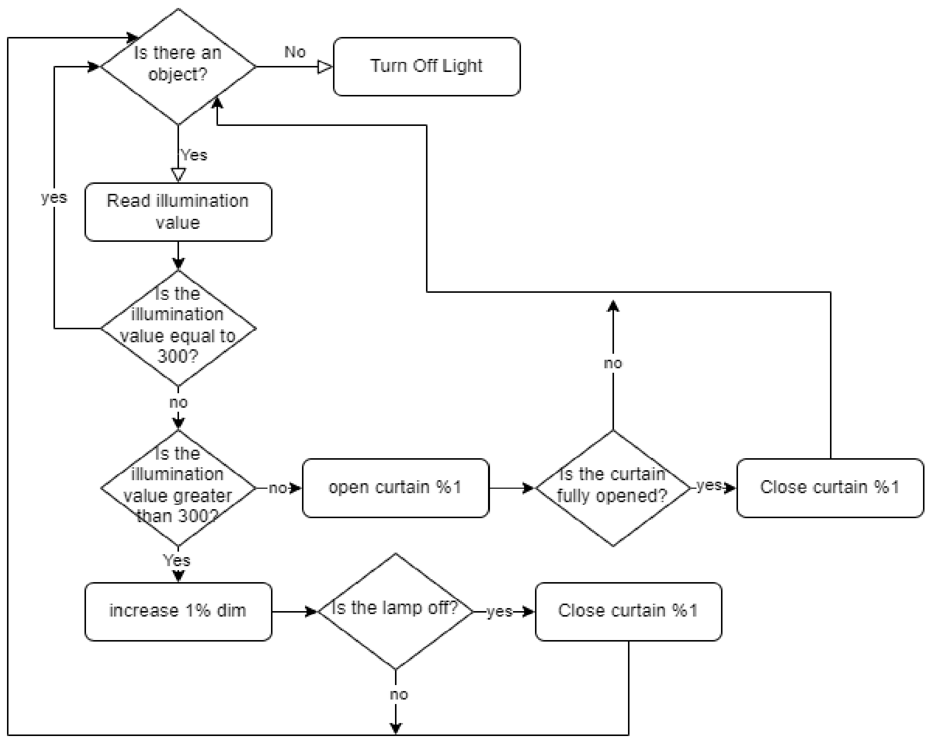

Figure. 5. Automation Algorithm.

H. MEASUREMENT DATA

In this test environment, the data were measured by sensors between 12 February 2024 and 17 February 2024 and recorded in 1 minute periods as shown in Figure 6. When the recorded 6-day data were analyzed, it was recorded that an average lux value above 300 was measured until 10:00 in the morning. At this point, the system is expected to reduce this value with curtain control. Later, when the sun started to approach the peak point, it was observed that the illumination value decreased to 300-400 lux band. The values, which continue in this way for a while, decrease as the sunset approaches and decrease to an average value of 100 lux. The illumination values were not in a certain distribution and followed a different behavior every day.

When the automation system works, it has managed to keep the illumination at a standard level of approximately 300 lux as shown in Figure 7, which increases the comfort of the employee by providing lighting suitable for the work he/she does all day long. When the energy consumed is examined, although the light was not manually switched on at some points, the automation tried to keep the lighting intensity constant by dimming a little, but when the 6-day working period was examined, the power graph in Figure 8 was revealed. When the total energy consumed during the total research (144 hour) process is divided by hours and examined, it is observed that in the system with manual switching on and off, an average of 10.98W power is consumed, while in the automation system, an average of 10.09W is consumed during the examination time, approximately 0.9W less energy is consumed for approximately 20m2 on average than the manual system. Unlike the simulation results, this situation was found to be approximately 8% more effective in real time test time. This difference in this model was created by a conscious consumer using the manual system. In addition, the fact that the model period was limited and was carried out at a time when the light could be used efficiently increased the margin of error in the simulation result and the working model result. The user in the manual system turned off the light every time he left the room and tried to prevent energy waste when the light intensity was slightly higher than it should be. Despite all these efforts, the user of the manual system could not catch the energy efficiency in automation. In this measured data, power consumption in the automation scenario was determined using the Legrand brand smart fuse on the panel. In the classical scenario, the system's on time was recorded and a theoretical calculation method was used.

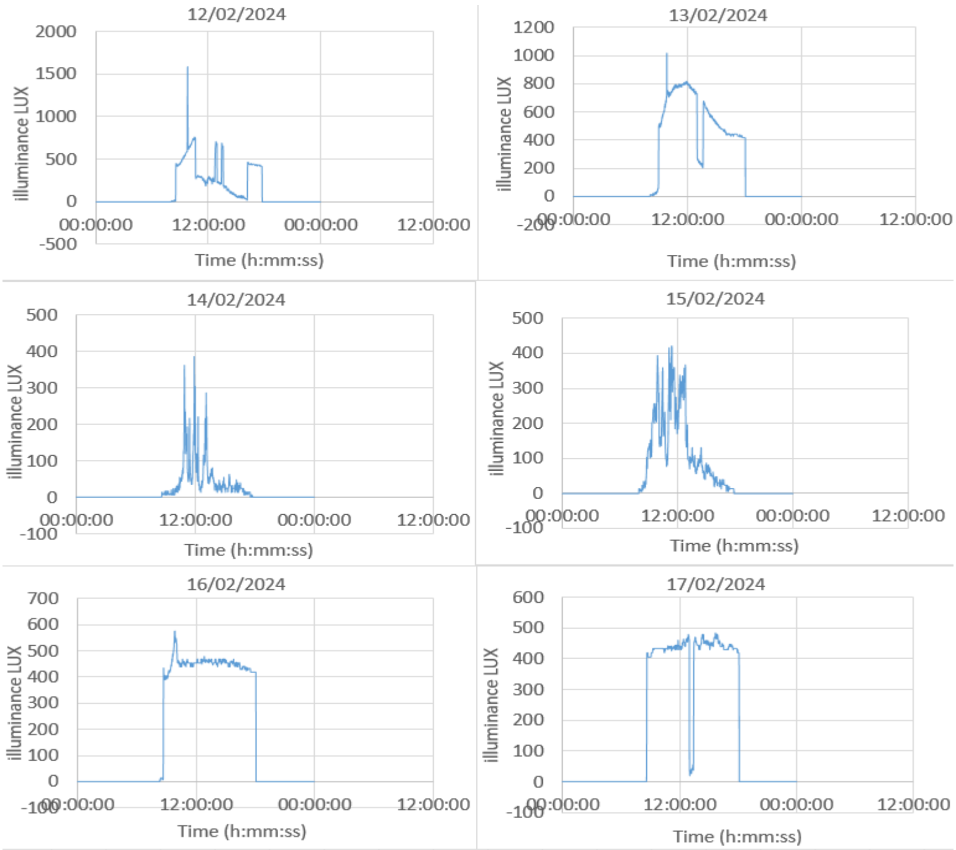

Figure. 6. 6-day light intensity data.

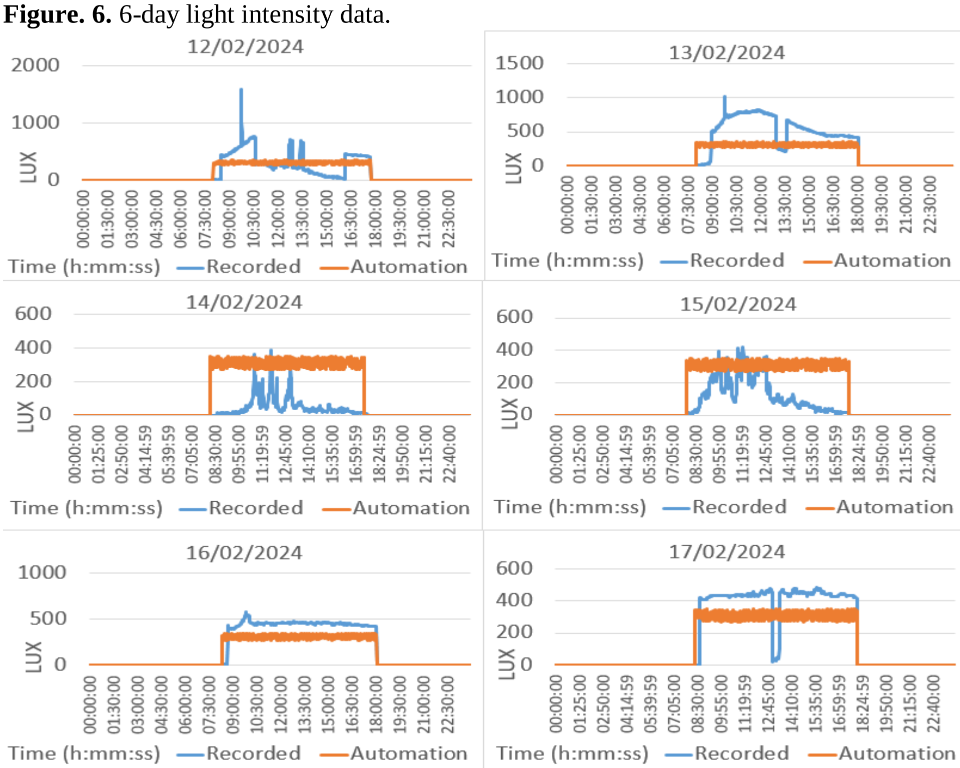

Figure. 7. Light intensity values obtained when the automation is running.

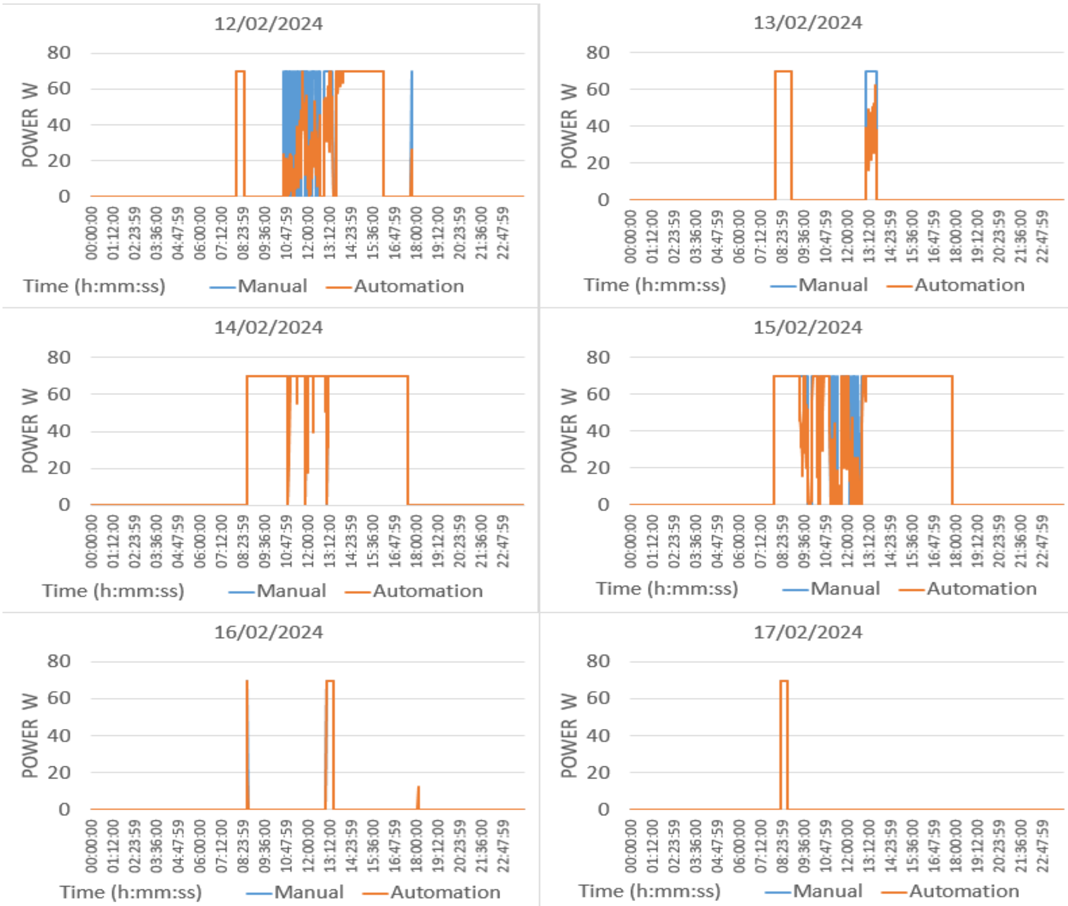

Figure. 8. Energy consumption.

III. DISCUSSION

Based on the data obtained from the research, as shown in Figure 6, it was observed that the light level in the room was particularly high during the morning hours. On some days, the lighting level exceeded 1000 lux, creating an uncomfortable working environment. The average lighting level during working hours was approximately 450 lux. While such fluctuations may not be critical in environments without automation systems, improper lighting levels can cause issues such as eye strain, headaches, and distraction, while low lighting reduces productivity, and excessive lighting causes eye strain and discomfort in the workplace. Over time, this negatively affects employees' motivation and performance and requires regulation. When the automation system was activated, as shown in Figure 7, the set lux level was consistently maintained, increasing employee comfort throughout the workday and maximizing work efficiency. However, detailed analyses revealed that the high adjustment frequency of the automation system caused oscillations in the lighting levels.

These oscillations could be minimized by reducing the sampling frequency.Energy consumption analysis shows that, over six days, when the system’s status (on or off) was considered, the average hourly energy consumption for the manually controlled system was calculated to be 10.98 W. On the other hand, the automation system consumed 10.09 W of energy over the same period, showing that the automation system consumed 0.9 W less energy than the manual system. In real-time tests, the automation system was found to be 8% more efficient than the manual system. The energy saving with 8 lamps of 8W each resulted in a total savings of 130W over 6 days, considering only the lighting. In the manual system, users tried to save energy by turning off the lights when leaving the room and intervening when light levels were high. However, these efforts could not prevent the manual system from reaching the high energy efficiency of the automation system. The limited test duration and the fact that the study was conducted during a period with abundant natural light increased the error margin between simulation and actual test results. Nevertheless, energy efficiency is critical for sustainability today. Automation systems optimize energy consumption, providing both economic savings and minimizing environmental impacts.In the manual system, the user attempted to prevent energy waste by turning off the lights when leaving the room and intervening when the light levels were high. However, these efforts could not bring the manual system to the same energy efficiency level as the automation system. In conclusion, this study demonstrates the superiority of automation systems in terms of energy efficiency and emphasizes the importance of their widespread adoption. Most automation systems used today generally focus on a single dimension. For example, in lighting automation, remote control or dimming operations are prioritized, while smart home systems offer remote control and scenario-based control options in the context of curtain control.

However, in active building automation systems, particularly in offices or public buildings, the integrated operation of lighting, curtain, and shutter systems is less common.The use of automation systems not only provides energy savings in various scenarios but also optimizes lighting levels in industrial environments, thereby enhancing worker safety and productivity. Moreover, by integrating machines and equipment, preventive maintenance can be carried out, reducing operating costs and ensuring uninterrupted production. In public institutions, these systems increase energy efficiency, reduce fossil fuel consumption, and lower carbon dioxide emissions. This way, energy savings also reduce environmental impacts and enable institutions to adopt a more environmentally friendly approach.Automation systems not only save energy but also optimize energy consumption over time and reduce maintenance needs. This leads to a significant decrease in overall operating costs. Moreover, reducing environmental impacts and achieving sustainability goals provides broader societal and economic benefits in the long run. Considering the initial investments, the cost-effectiveness of automation systems becomes clear when factors such as sustainability and energy efficiency are taken into account. An increase in employee comfort is also an important factor; well-managed aspects such as lighting, temperature, and air quality improve employee satisfaction and productivity. These improvements translate into fewer mistakes, higher productivity, and lower absenteeism rates, leading to further savings in operating costs.

IV. CONCLUSION

These Visual comfort is a critical factor for employee performance and overall satisfaction. Automation systems not only save energy but also optimize visual comfort. Lighting and curtain automation maintains the lighting balance of the space by enabling more efficient use of natural light. This ensures that the intensity of indoor illumination is kept at the desired levels and thus increases the comfort of employees. This dual benefit of automation systems shows how important it is to consider energy efficiency and visual comfort together. In the future, the wider use of such intelligent systems will provide significant gains in terms of both energy savings and visual comfort.

This study aims to maintain the ambient light level at an optimum level and ensure minimum energy consumption through the simultaneous use of different automation elements this study reveals that the average illumination level during working hours was approximately 450 lux, with some days exceeding 1000 lux, leading to discomfort in the workspace. Following the implementation of the automation system, the predefined lux level was consistently maintained, enhancing employee comfort and maximizing work efficiency. Working model show indicating a reduction of about 0.9 W. Real-time tests showed that the automation system was approximately 8% more efficient than the manual system. For a total of 6 days, the system saved 130W in lighting alone in a 20m2 room, this saving means that as a result of six days of automation, almost no costs are incurred on the seventh day compared to conventional use. Which corresponds to an annual value of 7200W per 20m2. Considering an entire 200m2 office, this system provides an annual saving of 72kW in an office.

Overall, the findings highlight the effectiveness of automation systems in reducing energy consumption and improving workplace comfort, underscoring their potential benefits. This study is expected to help increase the prevalence of such automation systems and optimize energy savings.

STATEMENT OF CONTRIBUTION RATE
Authors' contribution rates to the study are equal.

CONFLICTS OF INTEREST
They reported that there was no conflict of interest between the authors and their respective institutions.

RESEARCH AND PUBLICATION ETHICS
In the studies carried out within the scope of this article, the rules of research and publication ethics were followed.

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