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Indoor Lighting Conversion Approach for Sustainable Energy Efficiency Applications in Campus Buildings: Hitit University Engineering Faculty Study

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Highlights

- This paper focuses on strategies of increasing the energy efficiency of the existing building.
- The proposed energy-saving methods reduce electricity consumption by 68.2 %.
- The propounded strategy deduces the CO₂ emission significantly.

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Abstract

Global energy crises, limited energy resources and damage to nature in energy production have pushed humanity to use energy more efficiently and renewable energy sources. In this context, the importance of implementing energy efficiency and sustainable strategies in buildings that consumes high energy has increased. In this study, the effect of luminaires substitution with more efficient ones and electricity production by renewable energy sources on efficiency, sustainability and environment was examined on a sample education building. The calculations were made according to standards and equipment supplier data. As a result of this study, it has been found that the use of high-efficiency LED lighting instead of halogen or fluorescence luminaires in the engineering faculty building and laboratory of Hitit University, will reduce electricity consumption by 68.2%. In addition, it has been deduced that the solar energy system to be installed on the faculty's roof, will significantly reduce CO₂ emission, and has a payback period of 5.5 years. In terms of gas emissions, a roof-mounted solar energy system is 21, 45, and 32 times less hazardous to the environment than natural gas, lignite, and fuel oil, respectively.

1. INTRODUCTION

The rapid growth of the world population and the dependence on technology increased the need for energy worldwide. Most of the energy produced in the world is obtained from fossil fuels and this causes the climate crisis [1, 2]. For this reason, in recent years, it became increasingly important to use the currently available resources with higher efficiency and sustainability [3]. Energy efficiency can be described as the reduction of energy consumption per unit or product amount without compromising any of the comfort conditions or reducing the standard of living and quality of life. The greenhouse gases that emerge as a result of the production and use of energy also cause the disruption of the ecosystem of the earth on which we live. One of the most important sources of energy consumption is undoubtedly the buildings in cities. Buildings use substantial amounts of energy and generate large amounts of carbon emissions [4]. Buildings in cities can consume 75% of the total primary energy and accordingly produce 39% of carbon dioxide emissions. The World Green Building Council has published a vision for buildings to have 40% less carbon emission by 2030 and 100% net zero emission by 2050 [5]. Accordingly, higher education should improve energy efficiency methods and applications for sustainability. In this context, the results of the LED conversion and usage of renewable energy sources are discussed to reduce the damage to nature in the study for the university building.

The Energy Efficiency Law, with number 5627 was enacted in Turkey in 2007 [6]. The objective of this law is the efficient use of energy, prevention of waste and protection of the environment with the aim to increase the efficiency of energy consumption. In the Energy Efficiency Strategy Document (2012-2023)

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issued in 2011, the 6th strategic objective is to use energy effectively and efficiently in the public sector [7]. In this document, it is emphasized that "The annual energy consumption of buildings and facilities of public institutions will be reduced by twenty percent (20%) until 2023." The National Energy Efficiency Action Plan (2017-2023) that entered into force in 2018 was the first energy efficiency action plan. According to this action plan, the implementation of 55 measures in six different sectors is expected to save an equivalent of 23.9 million tons of petrol (energy) by 2023. This predicted value means a 14% decrease in the primary energy consumption of our country by 2023 [8]. In the National Energy Efficiency Action Plan 2017-2023, the Building and Services Sector section is required to define the Energy Saving Target for Public Buildings in the third action.

Considering the buildings in all university campuses in Turkey, the energy consumed in these buildings amounts to a substantial part of the total energy consumption. Concurrently, this consumption constitutes an important part of public resources. It, therefore, follows that any new university buildings to be built should be planned as energy-efficient buildings. In addition, significant energy savings can be achieved by improving existing buildings, especially those buildings that were not designed to today's energy performance standards and have never been renovated [9].

One of the most important energy efficiency applications is lighting. Lighting is very important in many areas such as homes and workplaces. It is well known that in densely populated places such as workplaces and schools, people work more efficiently in adequately lit and thermally comfortable workspaces, as this would prevent untimely employee fatigue. Moreover, adequate lighting has an important role in terms of the safety and health of employees. It is thought that the share of the electrical energy used to lighting the buildings in the total electrical energy consumed is high. Given that this is a significant portion, lighting has a serious potential for improving energy efficiency. One of the solutions for improving light quality and efficiency is the implementation of LED light technology [10].

There have been many studies in the literature on the energy efficiency of university buildings. In their study, Maistry and Annegarn determined energy saving points by analyzing the energy consumption patterns in universities. Their work concluded that an approximate 9% of the energy consumption can be saved by shutting down certain cooling facilities on certain days of the week [11]. In their study, Guan et al. developed a method to examine energy and water usage trends in university campus buildings in Norway. They analyzed the data for electricity, heating, and water consumption and made recommendations [12]. With the help of a simulation, Guo and Wei investigated different options to reduce consumption intensity and costs for a faculty building at the National Taiwan University. Their study concluded that by employing their method, better and more comprehensive solutions for energy saving could be provided for the buildings to be constructed in the future [13]. Irulegi et al proposed a different method for university campus buildings to reach an almost zero net energy consumption strategy. The study took place at the architecture faculty in Spain and was based on student comfort analysis, under real conditions. Different energy-saving measures were implemented, and the corresponding comfort conditions of the affected parties were determined through a questionnaire in real-time. Ultimately, their study identified a potential energy saving of up to 62% in addition to a two-month reduction in heating time [14]. Niemela et al. examined the energy efficiency and economic viability of a university campus in Finland [15]. Ascione et al. evaluated a university building in Italy in terms of energy efficiency and savings. Their work found that the most profitable energy performance improvement can be obtained by an air source heat pump installation and a PV system that will completely cover the building roof [16]. Coban et al. emphasized the importance of using solar PV systems in energy production in countries with electricity problems [17]. Yoshida et al. examined the strategies for reaching a sustainable campus at Osaka University in Japan. Their study concluded that the implementation of energy-saving technologies as well as the establishment of renewable energy technologies is necessary for a sustainable campus. In their work, the energy consumption could be reduced by approximately 22% with the strategies that were suggested [18]. Coban et al. examined the hybrid use of renewable energy sources in their study. As a result, they concluded that such systems are more stable [19]. Bellina et al. evaluated a university campus building in southern Italy. They found that approximately the energy efficiency can be improved by 33% and pollutant emissions can be reduced through the precaution packages they have offered in energy efficiency [20]. Ge et al. chose a university building in China and investigated indoor heating and cooling patterns and energy

consumption. They emphasized that their study will provide technical support for energy saving and retrofitting of the campus buildings in the region [21]. Shea et al. presented an energy-saving analysis of the cooling system in five different buildings on a university campus in the United States. They determined that 11 out of the 12 systems they examined were under extreme pressure. They achieved an average fan energy saving of approximately 33% with pressure correction. They also showed that 9 of the 12 systems served areas not used during the night and that approximately 35% of energy savings could be achieved by planning to shut down the cooling systems in these areas during the time they are being unused [22]. In addition, in the case studies that investigated the energy savings achieved by switching from fluorescent and halogen lamps to LED, it was found that the conversion led to a substantial decrease in the energy costs for the illumination. Booyesen et al. investigated the effect of the conversion from fluorescence light to LED in school buildings in South Africa and determined that annual electricity cost was reduced by 39% [23]. Similarly, Al Rashdi et al. determined that LED conversion can lead to a 43.8% decrease in annual lighting electricity consumption of the International Maritime College Oman (IMCO) building. Moreover, if LED luminaries include light control systems, the saving can reach up to 64.3% [24]. Duwal studied the effect of LED conversion from fluorescent lamps in a university building in the Netherlands. It was observed that the conversion brought about a 50% decrease in illumination costs [25]. Researchers conducted case studies for different applications to observe the led conversion effects. The analysed application areas can be listed as follows; mosque [26], road tunnel [27], street lighting [28], car park [29], sport facility [30], wastewater treatment facility [31], public garden [32], animal farm [33], commercial building [34], public building [35] and university buildings [36–40]. In these studies, the authors focused on the effect of led conversion on energy efficiency, electricity savings, conversion costs, feasibility, and comfort conditions. On the other hand, in these studies, fulfillment of the energy consumed by the led conversion with sustainable energy sources and therefore the effects on the environment was not discussed and this study fills this gap in the literature. This research is a case study and contributes to the existing knowledge by addressing the cost, feasibility, and positive outcomes of implementing the above-mentioned sustainability measures in university buildings moreover it provides suggestions based upon scientific results for investments. The innovative aspect of the article is the use of renewable energy sources and the effect of LED conversion on carbon emissions and electricity consumption values in addition to the costs of investment and payback periods of these measures.

2. MATERIAL AND METHOD

The province of Çorum is located within the central Black Sea region of Turkey at a latitude of 34 degrees 04 minutes 28 seconds east and a longitude of 39 degrees 54 minutes 20 seconds. Its average height above sea level is 801 m. The climate in the province of Çorum reflects its geographical position – within a transition zone between the Black Sea region and Central Anatolia. Hence, the summers are typically hot and dry, while the winters are cold and snowy. The annual average temperature of the provincial's center is 10.7°C. July and August are the hottest months. Hitit University Faculty of Engineering and laboratory buildings, shown in Figure 1, were selected as application areas for energy analysis.



Figure 1. Hitit University Engineering Faculty and Laboratory building view

Hitit University Engineering Faculty has an indoor area of approximately 7000 m² distributed over 3 floors, while the laboratory building is a single-floor building with an area of 850 m². The buildings were built in 1999 and 2011, respectively. Making use of the engineering faculty building, are a total of 1026 students and 108 staff. The information on the Faculty of Engineering building and laboratory building are given in Table 1.

Table 1. Buildings area table

	Ground Floor	1st Floor	2nd Floor	Lab. Building
	Area (m ²)			
Office	275	313	475	17
Classroom	0	862	864	0
Lab	819	114	0	487
Others	1,615	875	825	338
TOTAL	2,709	2,164	2,164	842

In the main building of the Faculty of Engineering, there are 19 staff offices, 16 laboratories of different sizes, 4 toilets, 1 canteen and 5 service rooms on the ground floor. On the 1st floor, there are 20 staff offices, 2 computer labs, 6 classrooms of different sizes, 1 library, 1 archive room and 4 toilets. On the 2nd floor, there are 25 staff offices of different sizes, 2 meeting rooms, 8 classrooms of different sizes, 1 archive room, 2 utility rooms and 4 toilets. In the laboratory building, there is 1 staff office, 13 laboratories of different sizes, 2 service offices and 2 toilets. In this work, the lighting intensities of the building parts shown in Table 1 were determined according to standard TS-EN 12464-1 [41]. Lighting calculations were made depending on the floor area and height of each room, according to the values taken from the standard. In addition, the analysis of the solar energy system planned to be installed on the building roof was also made. With the system to be installed on the roof area, the amount of electricity that can be produced and the cost of the system to be installed have been calculated.

The lighting calculations have been done with the following equation for each place:

$$N = \frac{E \times A}{\Phi \times UF \times LFF} \quad (1)$$

Here, N is the number of luminaires, E is the required level of illuminance, A is the area of the lighting place, Φ is the initial luminous flux of each luminary, UF is the utilization factor and LFF is the light loss factor. E is determined for each lighting place according to the mentioned standard. The room index is calculated with the following equation and UF is chosen from the utilization factors table according to the room index for each lighting place

$$RI = \frac{W \times L}{H_m (W + L)} \quad (2)$$

Here, RI , W , L , and H_m represent the room index, width of the room, length of the room, and the height of the luminaire above the working surface, respectively.

3. RESULTS AND DISCUSSION

Actions and solutions to improve energy efficiency are generally categorized as short, medium or long-term. Lighting improvement and analysis of electricity bills are short-term solutions that have been carried out. On the other hand, one of the long-term solutions is the implementation of renewable energy systems. In this study, an analysis of the monetary gains from implementing such a system is conducted. This long-term solution, together with the short-term solutions previously mentioned have been compared to the currently existing system.

3.1. Lighting Optimization

A person's ability to see and perceive the environment in a healthy way occurs through visual perception. The lighting in space has an immense influence on visual perception. It affects the field of vision and the ability to perceive the details of the work being done. Additionally, appropriate lighting increases the employee's perception of risk and reduces the likelihood of accidents, reducing health complaints. Energy saving in lighting should be done without reducing the quality of the lighting and by meeting the conditions of 'good lighting'. Since good lighting conditions can be provided with more efficient lighting elements, it is also possible to provide an equivalent lighting quality, with less energy consumption. The first criterion that must be met to ensure adequate lighting conditions is sufficient light intensity. While designing a lighting arrangement, care should be taken to distribute the light homogeneously in the workplace. Homogeneous light distribution is achieved by the order of the luminaires. In this study, calculations for the lighting design were made by considering the following parameters: the distance between the ceiling and the working plane, the room's dimensions, and wall and floor light reflection coefficients. The total electricity consumption and the lighting consumption for the faculty building and labs for the years 2016, 2017, and 2018 is given in Figure 2.

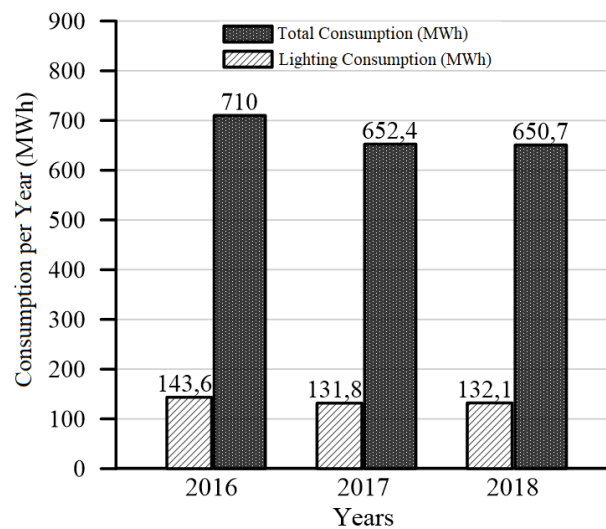


Figure 2. Electricity consumption by years

According to the values in Figure 2, the consumption rate is around 671 MWh annually. Consumption rates in the more recent years can be considered to be $\pm 10\%$ than this average value. It was found that the portion of electricity consumption for lighting systems for the faculty and laboratory buildings is approximately 20.2%. Accordingly, it can be concluded that the amount of electricity consumed by the lighting system is significant.

There are two types of luminaires within the buildings of interest: 4x18 parabolic fluorescence and 2x36 electronic ballasts. The distribution of the current luminaires in the buildings is given in Table 2 in detail. As seen in Table 2, there are in total 358 luminaires with 2x36 electronic ballast and 750 4x18 parabolic fluorescence luminaires within the two buildings. Taking into account the average daily consumption of the existing luminaires, the total electricity consumption has been calculated to be 131 MWh. It has been proposed to have the existing fixtures replaced with efficient LED (Light Emitting Diode) luminaires, the technical features of which are given in Table 3.

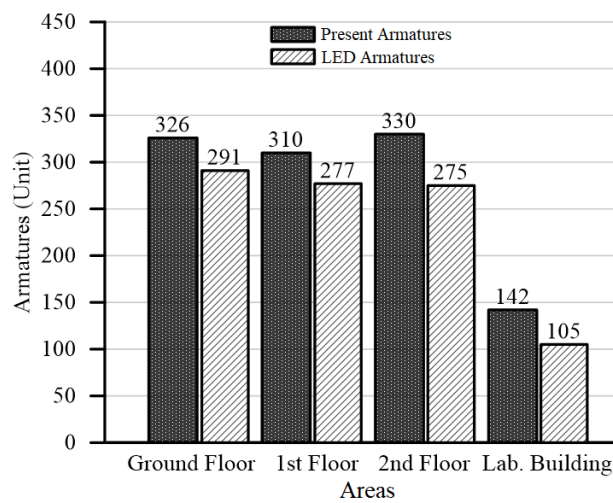
Table 2. Distribution of luminaires in the current situation

Luminaire	Ground Floor	1. Floor	2. Floor	Lab. Building	Total
2x36 Electronic ballast	138	86	134	0	358
4x18 Parabolic fluorescence	188	224	196	142	750

Table 3. Technical features of the LED [42]

Specifications	
Class	A+
Initial Input Power	36 W
Power consumption tolerance	+/-10%
Driver life	20,000 h
Panel Life	50,000 h
Input Voltage	200-240 V

To convert all the lighting sources to LED-type sources, the total luminous flux needed for each of the areas in the building has been calculated. Then the number of required luminaires was derived by dividing the total lumen by the luminous flux of the proposed LED luminaire. A numerical comparison of the existing luminaires with the proposed luminaires is given in Figure 3.

**Figure 3.** Comparison of the luminaires

It can be seen from Figure 3, that the number of luminaires will decrease with LED-type lighting sources. In the analysis, LED luminaires with the closest luminous flux value to the existing luminaires were preferred considering the costs. In buildings, static components such as beams and columns can cause insufficient lighting. In order to avoid this situation, LED luminaires are to be located within the spaces subject to the static components within each particular area. In order to obtain maximum illumination efficiency, luminous flux calculations were made for each unit separately. The comparison of the electricity consumed by the existing luminaires and LED luminaires is given in Figure 4.

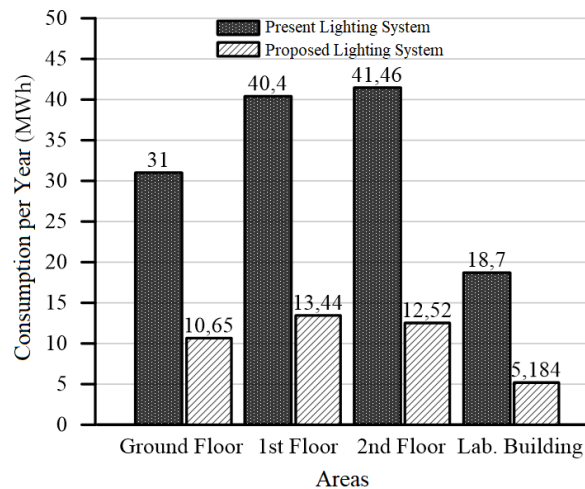
**Figure 4.** Comparison of the consumed electricity amount by existing luminaires and by the proposed LED luminaires

Table 4. Comparison of luminaires

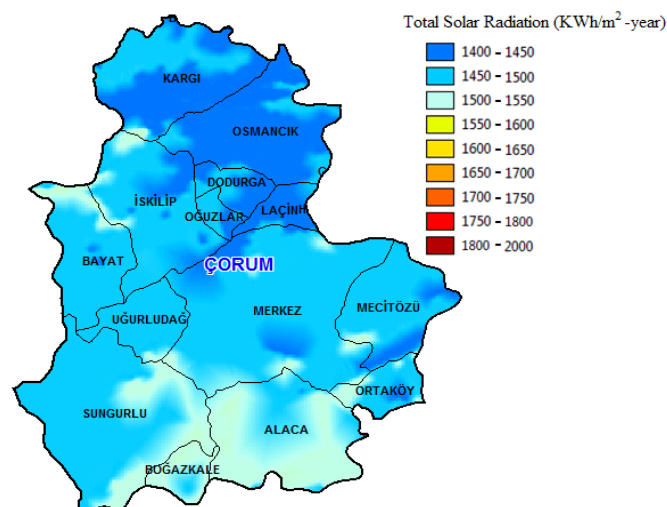
Luminaires	Number of Luminaires	Power Consumption per Unit [W]	Annual Consumption [kWh]	Annual Cost [\$]
Present	1108	88	131567.04	14472.37
LED	948	32	41799.36	4597.93
Difference			89767.68	9874.44

As shown in Figure 4 and Table 4, optimizing the lighting in the faculty and lab building decreases the electricity consumption used for lighting by approximately 68.2%. Taking into consideration that the unit price of electricity in Turkey is 0.11 \$ per kWh, the monetary gain to be obtained by lighting optimization is around \$ 9,874.44. If the cost to convert the existing luminaires to those of LED-type is assumed to be \$ 18.75 per luminaire, the total investment cost will be \$ 17,775. When the lighting system optimization cost and the current consumption cost are compared, the payback period of the system is calculated to be approximately 1.8 years. According to the technical specifications of the proposed LED conversion system, the driver life is approximately 11 years, and the panel life is approximately 27.7 years; comparatively, this makes the payback period quite low. In addition, considering that the electricity consumed is currently obtained from fossil sources, the reduction in electricity consumption translates to a reduction in carbon emission (by 68.2%). When the results obtained were examined, it was determined that they were compatible with the literature [23–25].

3.2. Renewable Energy Optimization

Renewable energy is an energy source that can be obtained from natural resources and can be renewed continuously. The most important feature of renewable energy is that it can renew itself and does not run out. Solar, wind, hydraulic, geothermal, biomass, and wave energies are all examples of renewable energy sources. However, the basis of all renewable energy sources is solar energy, because as sunlight and heat interact with the environment, some of the solar energy is transformed, through natural events, into other sources of renewable energy.

The Republic of Turkey has a good solar energy potential due to its geographical location. Turkey is between 36°-42° north latitudes and 26°-45° east longitudes. Although the sunshine duration varies throughout the year, the annual sunshine duration is approximately 2741.07 hours, and the total annual radiation intensity is 1527.46 kWh/m². The average daily sunshine duration is 7.5 hours and the daily total radiation intensity is known as 4.18 kWh / m². The solar energy potential map of the region where the system is planned to be established is given in Figure 5.

**Figure 5.** Solar energy potential map for Çorum province

For the region where Hitit University Faculty of Engineering is located, the lowest daily sunshine duration is 3.57 hours in January, while in the sunniest month of July, the sunshine duration is 10.67 hours. The average daily sunshine duration throughout the year has been found to be approximately 6.89 hours. The roof area of the Hitit University Engineering Faculty main building has been calculated as 3,040 m² in total. Considering the shading effect and unusable parts of the roof area, the maximum area that can be used for electricity generation from solar energy has been determined to be 1920 m². Solar panels will be placed on the module at an inclination of 32° in order to obtain maximum benefit from the solar radiation. The technical features of the panels that are planned to be placed on the roof of the building are given in Table 5.

Table 5. Solar panel features [43]

Solar Panel Specifications	
Cell Type	Polycrystalline
Number of Cells	60
Maximum Power (P_{max})	280W
Open Circuit Voltage (V_{oc})	38.64 V
Short Circuit Current (I_{sc})	9 A
Maximum Power Voltage (V_{mp})	32.99 V
Maximum Power Current (I_{mp})	8.49 A
Dimensions	1,652x997x35 mm
Weight	20 kg
Operation Cell Temperature	-40 to +85 °C

The faculty of engineering building exhibits a flat roof, which can accommodate a total of 1,129 roof-type solar panels. These installations would provide a power of approximately 316 kW. A representation of the solar panels that can be installed is given in Figure 6.



Figure 6. Hitit University Faculty of Engineering roof type solar energy system

The maximum amount of electricity that can be produced from the solar panels installed has been determined to be 797 MWh annually. It is expected that approximately 80% of this maximum amount will actually be produced. Therefore, it is thought that the annual electricity produced by solar panels will be 637 MWh. In the roof type solar energy system, in addition to the panels, inverters, dataloggers, solar cables, etc. will be required in the system. These components, together with their costs are given in Table 6.

Table 6. Rooftop solar system cost

System component	Unit	Cost per Unit (\$)	Total cost (\$)
Solar Panel	1,129	200	225,800

Inverter	13	6,250	81,250
Solar Cable (m)	10,000	2	20,000
Data logger	1	1,250	1,250
Other	1	40,000	40,000
Workmanship	1	20,000	20,000
TOTAL			388,300

For this roof-type solar energy system, the payback period was found to be 5.54 years. Since this system is expected to have a service life of 25 years, this payback period is considered to be reasonable. The amount of CO₂ emission that is produced from solar energy per GWh is compared to the CO₂ emission produced by other energy sources in Table 6.

Table 7. Comparison of CO₂ emission levels [44]

Type of Energy	CO ₂ emission (ton-CO ₂ /GWh)
Solar Energy	14.6625
Natural Gas	318.1125
Lignite	671.925
Coal	566.1
Fuel-Oil	467.2875

According to the figures presented in Table 7, a roof-type solar energy system is 21, 45, and 32 times less environmentally harmful, in terms of gas emission, than natural gas, lignite, and fuel oil, respectively.

4. CONCLUSION

In this study, two of the energy efficiency strategies that can be applied in the short and long term have been evaluated. As a case study, the university building on a campus in the Central Black Sea Region of Turkey was examined. As a short-term energy efficiency activity, a lighting optimization exercise was carried out for the university buildings (faculty and labs), while as a long-term efficiency activity, the installation of roof-type solar panels on the faculty building's roof was assessed.

The energy consumption of the concerned buildings was examined and analyzed in terms of total electricity consumption and electricity consumption used for lighting purposes. It was found that over a three-year period, the energy consumption rate was approximately the same. It was found that if LED lighting elements are used, the amount of electricity consumed for lighting can be reduced by 68.2%. The calculated reduction percentage of the electricity costs complies with the given related research. When the proposed lighting system investment was compared to the electricity consumption savings the payback period was found to be around 1.8 years. Since according to the technical specifications of the proposed LED conversion system the driver life is approximately 11 years and the panel life is approximately 27.7 years, depending on the building usage hours, it was concluded that the payback period is quite low.

On the other hand, as a long-term energy efficiency improvement action, a solar energy system that is planned to be installed on the roof of the university building was analyzed. It has been calculated that the total power capacity for the solar energy system to be installed can be as high as 316 kW. When the investment cost was taken into consideration, the payback period of the system was found to be approximately 5.54 years. The energy generated by the proposed solar energy system will decrease the current CO₂ emission to be generated by 21 times when compared to natural gas, 45 times when compared to lignite, and 31 times when compared to fuel oil.

The proposed method can create a more environmentally friendly and sustainable consumption habit by reducing the damage to nature and the carbon footprint by making the proposed transformation in the future, especially in old generation buildings with high energy consumption. Thus, our impact on the climate crisis can be reduced.

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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