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Evaluation of LED-based Outdoor Lighting Solution for University Campus Enhancement

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Abstract— Nowadays, power demand is on the rise primarily driven by the ongoing development of nations, services, and daily operations. Consequently, there is a growing emphasis on reducing electricity usage to lower bills and move towards a more sustainable society with minimal energy generation emissions. To achieve this reduction in electric consumption, accurate data and intelligent systems are essential, as well as promoting energy efficiency programs focused on decreasing power demand while maintaining services and customer requirements. Under this framework, this study aims to decrease electricity consumption in a university environment by implementing LED-based high efficiency lighting solution on the campus of Albacete, which is part of the University of Castilla La Mancha (Spain). Results and power demand data are also included in the paper to compare both power demand profiles before and after the lighting transition, in terms of cost and energy saving estimations.

Index Terms — Energy efficiency, LED lighting, smart lighting, energy consumption.

I. INTRODUCTION

The increase in public services, the improvement in daily life, the development of society and modernization are some of the factors for which we find increases in the demand for electricity [1]. In addition, Internet connectivity and domotization in public centers are, in turn, increasing the demand for electricity [2], reflected in $C0_2$ emissions [3]. Current climatic conditions do not help to reduce energy demand, as it has been proven that global warming can lead to a growth in electrical energy demand [4]. This has not only affected public buildings and facilities, but has also affected domestic consumption, having increased by 2% annually in the last 10 years [5]. In Spain, electricity consumption has increased by 4.2% per year, being this value higher compared to some European Union countries [6]. In countries such as Japan, in the period from 2001 to 2015, electrical energy consumption increased by a total of 44,884 million kWh [7], at a rate of approximately 3,000 million kWh per year.

One solution targeted at reducing energy consumption in both residential and public settings has been the LED lighting revolution, owing to its advantages such as reduced power consumption and enhanced efficiency [8][9]. LED technology achieves an efficiency of up to 330 lm/W, depending on the color and the streetlight [10], leaving behind the efficiency of old lighting systems such as sodium vapor, with lower efficiencies. Indeed, LED lighting systems are currently around 70% more efficient than traditional lighting systems [11], which are still used in public places, such as in the case study of this work. In addition, LED technology not only has a higher efficiency, but also a longer lifetime, thus achieving a lower cost over the lifetime of the streetlight. Thanks to LED implementation, countries such as the United States have achieved annual primary energy savings of about 30 TWh/year, being equivalent to a saving of 3 billion dollars per year; and a reduction of 30 billion tons of CO_2 [10]. The energy used for street lighting is approximated to account for roughly 30% of a country's overall electricity usage [12]. Therefore, installing LEDs and intelligent systems is a good solution to reduce the power demand of this end-use.

In Spain, the LED lighting implementation is promoted with the aim of reducing energy consumption. Additionally, regulations such as RD 1890/2008 establish various aspects such as [13]: (i) improving energy efficiency and savings, as well as reducing greenhouse gas emissions; and (ii) limiting nighttime light glare or light pollution and reducing intrusive or bothersome light. Furthermore, Spanish law promotes the adoption of more efficient lighting technologies as urgent measures for growth, competitiveness, and efficiency, including LED lighting [14]. There are several studies addressing the implementation of LED lighting. A study conducted in the city of Fuengirola (Spain) [15] proposed a methodology for implementing LED lighting for outdoor illumination over a 2-km-long urban stretch, obtaining electrical parameters and conducting economic analysis to estimate the investment. The authors tested different scenarios with a variety of streetlight power demand: 180 W, 190 W, 200 W, and 210 W respectively. To conduct the economic study, data were collected by including the cost of the projectors, the cost of removing the old lighting system, and the cost of implementing the new streetlights. Auxiliary costs, such as material cost, were also considered. In the initial energy study, it was found that the total energy demanded by the old streetlights would be significantly reduced by applying any of the proposed scenarios, with a significant decreasing consumption: 54,690 kWh/year for the case of the 210 W LED streetlight; and 68,000 kWh/year for the case of the 180 W LED streetlight. Regarding the economic study, it was found that the investment payback period was approximately between 3.30 and 6.20 years, depending on the type of streetlight finally selected and on the cost of replacing them. Other studies leverage the implementation of LED technology in conjunction with an intelligent lighting system to further minimize costs. A study conducted by the National University of Singapore explored this initiative from the perspective of implementing the intelligent lighting system, as the building already had LED lighting [16]. This study aimed to reduce consumption by 60% thanks to the intelligence system, leveraging the efficiency of LED technology. While it is evident that LED technology can play a crucial role in reducing energy consumption, there is a lack of studies conducted in public entities, such as university campuses, that provide real-time energy consumption data to compare power demand profiles before and after the lighting transition. Furthermore, few studies offer detailed insights into the investment required for implementing such solutions. With this aim, this paper discusses and evaluates a solution based on implementing LED-based high efficiency lighting solution on a university environment to decrease electricity consumption and increase energy efficiency. Results and power demand data are also included in the paper to compare both power demand profiles before and after the lighting transition, proposing some future initiatives to increase the efficiency of the campus. The rest of the paper is structured as follows: Section II discusses materials and methods; the case study is described in Section III; results are presented in Section IV and, finally, Section V gives the conclusions.

II. MATERIALS AND METHODS

To carry out a proper economic study, it is firstly necessary to conduct a suitable energy analysis, focused on consumption patterns at the lighting supply point. This preliminary analysis includes operating hour data, as well as maximum and minimum power demand values throughout the year 2023. To access the data from the lighting supply point, a commercial platform is currently available for the case study, where these consumption data are available in a variety of formats. In this case, the exported generation data follows an hourly format, allowing for the visualization of daily electricity consumption patterns. Once the consumption data is exported, it can be imported into the software used for the energy study, in this case MATLAB [17]. This software is a well-known numerical computing environment. Within this framework, the generation data vector is treated as a matrix to obtain daily, monthly, and yearly cumulative energy.

Monthly cumulative consumption is obtained by the following expression,

$$E_{Cm} = \sum_{i=1}^{h} E_{Ch} \ , \qquad (1)$$

being E_{ch} the energy demanded in a specific hour, and h each of the hours available in the month. Therefore, the annual electrical energy consumed is then determined as,

$$E_{Cy} = \sum_{i=1}^{n} E_{Cm} \qquad (2)$$

being E_{cm} the accumulated electrical energy of a specific month, and n the number of months in the year.

For the economic analysis of the implementation of the two scenarios described in Section III, information regarding the new LED streetlights to be installed is available. More specifically, each LED streetlight has a power rating of 62 W, representing a significant reduction compared to the existing streetlights, with 185 W, and resulting in considerably higher expenses. Additionally, it is known that the daily usage of the streetlights amounts to a total of 8 hours per day, and that the monthly usage period spans 30 days.

The estimation of the total installed power for each scenario is determined by,

$$P_{inst} = N \cdot P_{lum} \qquad (3)$$

where N is the number of streetlights and P_{lum} is the power of each streetlight, either for existing ones (185 W) or for new ones (62 W). With this parameter, energy savings can be calculated, and with the average monthly energy price, energy savings can be determined. In this economic study, it is calculated how much the University of Castilla La Mancha would have saved if the LED lighting system was implemented in each of the scenarios. Therefore, to carry out the amortization of the installation accurately, it is then necessary to calculate how much the university paid for the energy consumed per month.

The cost of monthly energy consumption is governed by **(4)**:

$$C_{kWh} = Cost\ Active\ Energy\ / \ Active\ Energy \qquad (4)$$

where the cost of active energy corresponds to the cost of active energy consumed by the supply point, being available from the University's billing data; and the active energy is the monthly active energy consumed by that supply point, available from the billing data and the data acquisition platform.

III. CASE OF STUDY

This work analyzes the energy usage in the outdoor lighting of a university campus. The electricity demand is analyzed through real data from an educational public institution, providing a comparison between data before and after the lighting transition, as discussed previously in Section I. This study focuses on the Albacete University Campus, belonging to the University of Castilla La Mancha, Spain. The University of Castilla-La Mancha is in the South of Spain. It includes four campuses spread across various cities in Castilla-La Mancha, such as Albacete, Ciudad Real, Cuenca, Toledo, as well as two satellite campus at Almadén and Talavera de la Reina. Albacete University Campus consists of a total of 14 buildings, see Fig. 1, including faculties, research institutes, and a sports centre. This analysis was focused on the outdoor lighting consumption of all the buildings on the Albacete university campus (Spain). In addition, it is also analyzed the LED streetlight implementation on the main roads of the campus or all the streetlights of the entire campus, moving away from conventional streetlights such as those manufactured from mercury vapor and metal halides. The public lighting consumption studied in this work belongs to the following centers:

1. Edificio Paraninfo / José Prat
2. Edificio Simón Abril
3. Edificio Melchor de Macanaz
4. Edificio Polivalente
5. Instituto de Energías Renovables
6. I3A – Instituto de Investigación Informática
7. Edificio Manuel Alonso Peña
8. IDR – Instituto de Desarrollo Regional
9. Edificio Infante Don Juan Manuel
10. Edificio Benjamín Palencia
11. Pabellón polideportivo
12. Apartamentos Campus

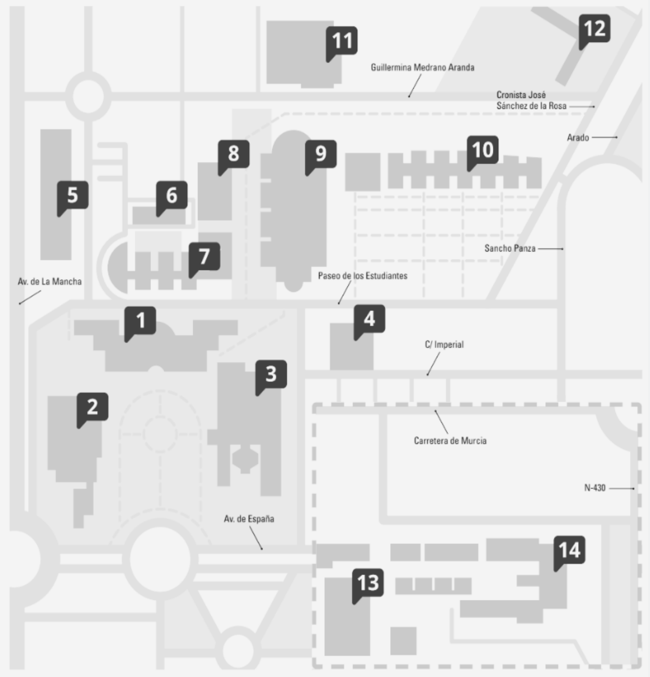

Figure 1. University Campus of Albacete (Spain).
Source: http://www.uclm.es

The university campus lighting system has approximately 300 streetlights. Therefore, the following replacing scenarios were considered: (i) 300 streetlights with LED streetlights; and (ii) 135 streetlights with LED streetlights.

IV. RESULTS

Following the data processing presented in Section III, the hourly consumption of the supply point for the campus street lighting system is depicted in Fig. 2. In addition, the behavior of the annual hourly consumption is provided in Fig. 3. Note that the operating hours for street lighting span from nighttime until early morning, and part of the afternoon until nighttime. Consequently, the solar trajectory throughout the year causes these lighting hours to vary as the months progress. The results of operating hours of the public lighting obtained for each of the months of the year 2023 are the following:

- January: 15 hours/day.
- February: 13 hours/day.
- March: 12 hours/day.
- April: 11 hours/day.
- May: 10 hours/day.
- June: 9 hours/day.
- July: 9 hours/day.
- August: 10 hours/day.
- September: 12 hours/day.
- October: 13 hours/day.
- November: 14 hours/day.
- December: 14 hours/day.

By using eq. (4), the monthly cost of active energy is estimated, as can be seen in Fig. 4. Once the data on the cost of active the energy at the supply point under study and the hours of use of the electrical system per month are known, the accumulated monthly active energy at the supply point for 2023 is calculated, as observed in Fig. 5.

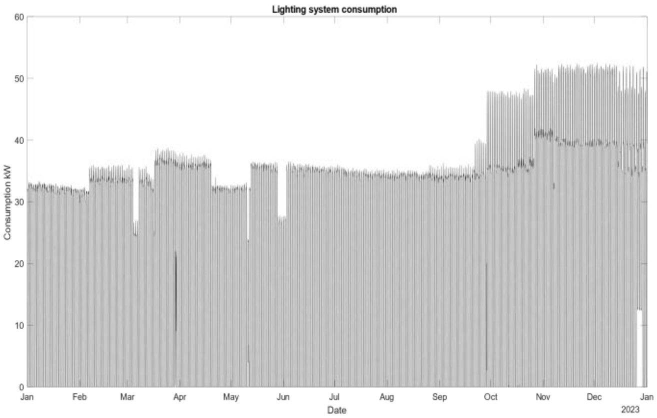

Figure 2. Hourly lighting system consumption of Albacete's campus in 2023.

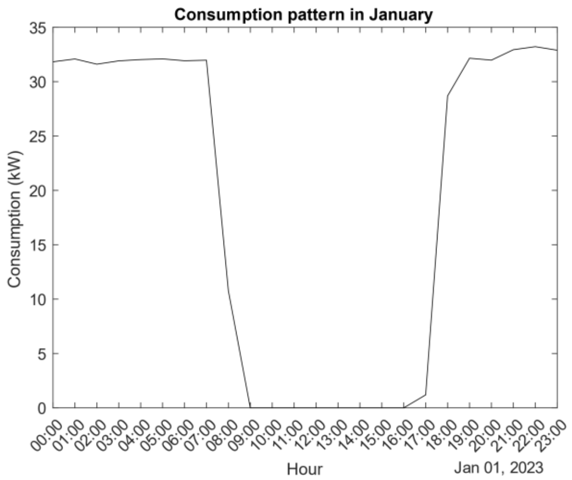

Figure 3. Distribution of electrical consumption on 01/01/2023.

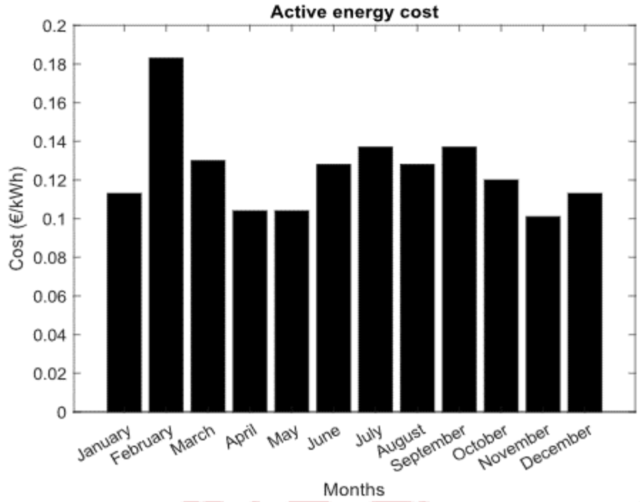

Figure 4. Cost of active energy consumed by the supply point in 2023.

This accumulated active energy is key for conducting the economic study to determine the monthly savings, annual accumulated savings, and ultimately the payback of the installation. In Fig. 5, it is observed how consumption during the warmer months is lower than during the colder months. This is because during the warmer months, it can be found more hours of solar radiation mainly due to: (i) the sun reaches its highest point in the sky during the year on June 21, which is known as the summer solstice. This day, which heralds the arrival of summer in the northern hemisphere (including Spain), is notable for having the most daylight hours of the year. (ii) the time of day when the sun is at its highest point in the sky is known as solar transit. This solar transit happens at midday in the summer, giving that day's sunshine its highest intensity.

In Table 1, all monthly and cumulative consumption values are summarized. Once the monthly active energy values are known, the economic study of the lighting change is then conducted. The total installed power of the public lighting supply point is 66 kW, a value not exceeded by the lighting of the university campus, since, applying equation 3, the current installed power amounts to 55.5 kW for the case of the 300 streetlights and 24.975 kW for the case of the 135 streetlights.

Based on eq. (3), it is obtained that, in the scenario of 135 LED streetlights, the new total installed power would be 8.76 kW, and in the scenario of changing the 300 streetlights to LED, the new total installed power is 18.6 kW. By reducing the installed power of the lighting, the total contracted power at the supply point is reduced, decreasing by 16 kW in the case of changing the 135 streetlights and by 36.9 kW in the case of changing the 300 streetlights. This reduction in contracted power represents a monthly savings in fixed costs, as shown in Table 2. Additionally, the current streetlights require annual maintenance, which amounts to €5625. Therefore, this savings contributes to a quick recovery of the investment.

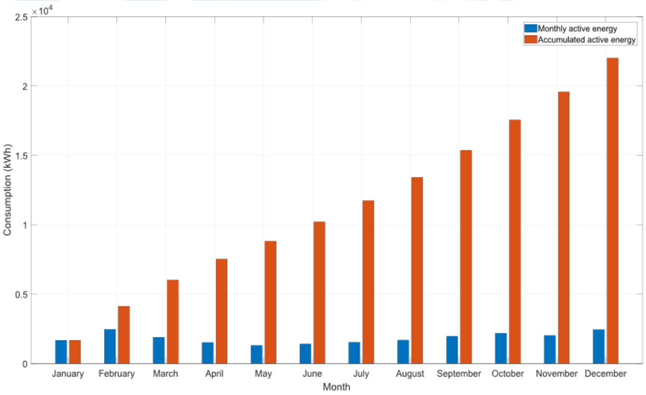

Figure 5. Accumulated month energy consumed by the supply point in 2023.

Table 1. Monthly and cumulative consumption at the supply point in 2023.

Month	Active energy (kWh)	Accumulated (kWh)
January	1665.50	1665.50
February	2454.11	4119.61
March	1891.77	6011.38
April	1504.26	7515,64
May	1294.50	8809.69
June	1397.58	10207.30
July	1524.46	11731.70
August	1677.88	13409.60
September	1957.48	15367.10
October	2179.46	17546.50
November	2017.69	19564.2
December	2435.45	21999.7

To determine the number of years needed to recover the investment, it is necessary to determine the monthly consumption, see Table 2. Therefore, the consumption savings for each month can be determined for the two scenarios. With the cost of energy for each month in the year 2023, see Fig. 4, the monthly savings in each of the two scenarios are obtained. Once this information is known, it is necessary to determine the investment for each scenario. The cost per streetlight, including all management, labor, and purchase expenses, is €280 per streetlight. Therefore, for the first scenario, the total investment cost is €37,800, and for the second scenario, the total investment cost is €84,000. It has been found that for scenario 1, the payback period of the investment due to energy savings and implementation conditions is equal to 2.57 years. For scenario 2, the payback period is very similar, being 3.29 years. The significant reductions in both energy consumption and accumulated costs, approximately 33% as can be seen in Fig. 6 , stand out as noteworthy findings and justify the need for further research in this area.

Table 2. Economic study of the two scenarios analyzed for the economic conditions of 2023.

Scenario	**Installed Power (kW)**	**Power savings (kW)**	**Monthly consumptions (kWh)**	**Montlhy savings (€)**	**Savings from contrated power (€/month)**	**Savings for maintenance (€/year)**	**Payback (years)**
1. Change of 135 streetlights	8.37	16.6	January - 3892.05	January - 875.17	40	5625	2.57
			February - 3046.68	February - 1109.93			
			March - 3113.64	March - 806.07			
			April - 2762.10	April - 569.79			
			May - 2594.70	May - 533.07			
			June - 2259.90	June - 575.53			
			July - 2335.23	July - 638.26			
			August - 2594.70	August - 659.9			
			September - 3013.20	September - 820.23			
			October - 3373.11	October - 803.8			
			November - 2762.10	November - 555.52			
			December - 2854.17	December - 642.78			
2. Change of 300 streetlights	18.6	36.9	January – 8649.00	January - 1944.84	70	5625	3.29
			February – 6770.40	February - 2466.52			
			March – 6919.2	March - 1791.28			
			April – 6138,00	April - 1266.21			
			May – 5766,00	May - 1184.61			
			June – 5022,00	June - 1278.95			
			July – 5189,40	July - 418.37			
			August – 5766,00	August - 1466.46			
			September – 6696,00	September - 1822.75			
			October – 7495,80	October - 1786.22			
			November – 6138,00	November - 1234.5			
			December – 6342,60	December - 1428.41			

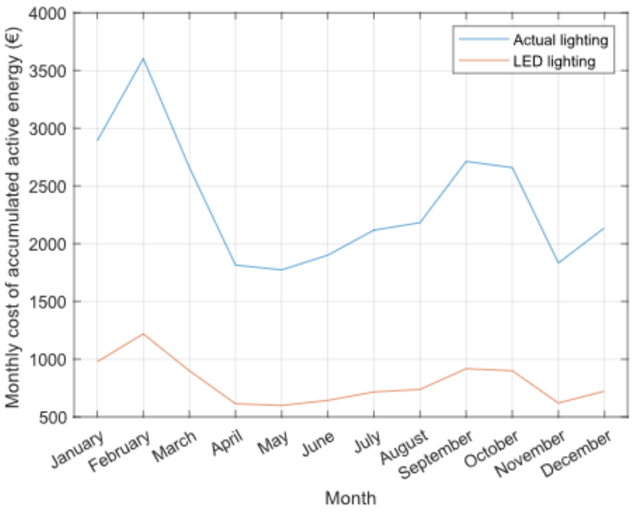

Figure 6. Differences in the monthly accumulated energy cost for the current lighting versus the cost of the LED lighting system. Replacing all streetlights scenarios.

V. CONCLUSIONS

In this work, it has been demonstrated that the implementation of LED lighting emerges as an effective tool to reduce energy consumption without compromising the development of daily activities in public environments, while also contributing to the elimination of pollution associated with non-renewable energy sources. It has been observed that, for both analyzed scenarios, the payback period is relatively short, indicating that the adoption of LED lighting brings short-term economic benefits and translates into a financially viable option in the long term compared to conventional lighting systems, such as the one currently deployed on the Albacete University Campus.

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