IMPACT OF GREEN TECHNOLOGY IMPLEMENTATION IN UNIVERSITY INFRASTRUCTURE LIGHTING SYSTEMS

IMPACTO DE LA IMPLEMENTACIÓN DE TECNOLOGÍA VERDE EN SISTEMAS DE ILUMINACIÓN DE INFRAESTRUCTURA UNIVERSITARIA

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Abstract: *Energy efficiency was evaluated in the Building of the Faculty of Agricultural Sciences at the National University of Trujillo (EFCAUNT), Peru, which serves an average of 900 students daily across four undergraduate programs. The building houses classrooms, laboratories, administrative offices, and a specialized library, which operate for 14 hours during regular activities and up to 20 hours during research laboratories. In this context, green technology was implemented by replacing fluorescent lights with LED lights. The energy impact was measured with an electronic meter, recording first the consumption of the conventional fluorescent lights for 15 days,*

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followed by a 90-day period after their replacement with 16W T8 LED tubes. The initial consumption with fluorescent lights was 769,890 kWh/day, which was reduced to 537,610 kWh/day after their replacement, achieving a savings of 232,280 kWh/day. This result represents an estimated annual cost savings of S/. 24,883.58 (USD7,465.07) and a decrease of 49.483 kg of CO_2 emissions per day. Overall, the energy efficiency achieved was 30.2%, which demonstrates the positive impact of the transition to more sustainable lighting systems in terms of energy savings, cost reduction and a decrease in the institutional carbon footprint.

Keywords: Energy efficiency, energy consumption, T8 LED luminaires, carbon footprint, institutional sustainability, CO_2 emissions.

Resumen: *Se evaluó la eficiencia energética en el Edificio de la Facultad de Ciencias Agropecuarias de la Universidad Nacional de Trujillo (EFCAUNT), Perú, el cual atiende en promedio a 900 estudiantes diarios en cuatro programas de pregrado. El edificio dispone de aulas, laboratorios, oficinas administrativas y una biblioteca especializada, que funcionan 14 horas en actividades regulares y hasta 20 horas en los laboratorios de investigación. En este contexto, se implementó tecnología verde mediante la sustitución de luminarias fluorescentes por luminarias LED. El impacto energético fue medido con un medidor electrónico, registrando primero el consumo de las luminarias fluorescentes convencionales durante 15 días, seguido de un periodo de 90 días tras su reemplazo por tubos LED T8 de 16 W. El consumo con luces fluorescentes fue de 769.890 kWh/día, el cual se redujo a 537.610 kWh/día después de su reemplazo, logrando un ahorro de 232.280 kWh/día. Este resultado representó un ahorro económico anual estimado de S/. 24,883.58 (USD 7,465.07) y una disminución de 49.483 kg de emisiones de CO_2 por día. En conjunto, la eficiencia energética alcanzada fue del 30.2 %, lo que evidencia el impacto positivo de la transición hacia sistemas de iluminación más sostenibles en términos de ahorro energético, reducción de costos y disminución de la huella de carbono institucional.*

Palabras clave: Eficiencia energética, consumo energético, luminarias LED T8, huella de carbono, sostenibilidad institucional, emisiones de CO_2.

1. Introduction

Green technology is a broad term that includes innovations designed to be environmentally friendly from production to use [22,10]. It is a constantly evolving field whose main objective is to reduce the pressure on natural resources, especially in the context of increasing urbanization, which poses major sustainability challenges [28].

[3] Green technology, also referred to as sustainable, clean, or environmentally friendly aims to reduce, reuse, and recycle natural resources, contributing to environmental improvement. These technologies can harness renewable sources such as sunlight, rain, tides, wind, and plants [7].

At the international level, [23] it has been highlighted that there is a need to improve energy efficiency, for example in Chinese cities, as part of efforts to reduce carbon emissions. The authors emphasize that an effective strategy requires the promotion of innovative green technologies supported by strict environmental regulation. Similar studies analyzed thermoelectric technologies and applied a hybrid system with photovoltaic panels in remote rural settlements, improving energy supply efficiency and reducing environmental impact. [16]

In the Latin American context, the implementation of LED luminaires was evaluated at a mining concession in Cajamarca, Peru installing 54 luminaires of 17 W and 6 solar luminaires of 270 W, which allowed an approximate monthly saving of S/. 7,950.00 (USD2,385.23) [29]. Likewise, [26] a study was conducted at a university in Ghana, which identified energy-saving opportunities through audits and measurements of devices such as lighting systems, fans, and air conditioners. The analysis showed that luminaires accounted for 16% of total energy consumption (707.4 MWh/month) and that modernization with LED technology and more efficient systems could generate savings of approximately 163,400 kWh ± 5% per month, with significant economic and environmental benefits.

[37] At a Faculty of Engineering in Peru, greenhouse gas (GHG) emissions associated with the lighting system were analyzed. The study measured 1,509 luminaires with an average power of 30.56 W, operating between 6 and 8 hours daily, with an annual consumption of 122,143 kWh exclusively for lighting. This consumption generated emissions equivalent to 63.169 tons of CO_2 per year, with classrooms, laboratories, and libraries as the main sources (41.18%), followed by administrative offices (26.10%) and common areas (23.84%). This work proved the environmental impact of lighting systems in academic facilities.

[34] In the case of Peru, economic growth has been accompanied by an increase in CO_2 emissions. Although the country has high potential for renewable energy use, only 5% of electricity generation comes from these sources, due to deficiencies in the regulatory framework and public policies

[5].In this context, the significant environmental impact associated with electricity consumption were identified in the Building of the Faculty of Agricultural Sciences at the National University of Trujillo (EFCAUNT). This opened the opportunity to apply modern technologies with lower environmental impact, such as the implementation of LED luminaires and solar systems for outdoor areas, efficiently harnessing natural light. These measures aim to improve the quality of life and study conditions of the university community.

Energy saving is currently a priority issue, both for its environmental and economic implications. Therefore, the present study aimed to evaluate energy efficiency in the EFCAUNT module during 2025, incorporating green technologies, with the objectives of identifying initial energy consumption before implementation to establish a baseline; applying green technologies appropriate to the institutional context, prioritizing those that promote efficient energy use; and calculating the energy savings obtained in order to assess the real impact of the measures adopted in technical, economic, and environmental terms.

2. Materials and methods

A polyphase electric energy consumption meter, brand ELSTER, model Alpha A1800, with an operating range of 120 to 480 V, was used. The equipment was set up in a star connection structure for a three-phase system with neutral (Figure 1). The installation included three toroidal current transformers (CT), one for each phase (L1, L2, L3), connected to the meter terminals, allowing the recording of active, reactive, and apparent energy.

The toroidal transformers employed were CIRCUTOR TC5 (75/5A), whose transformation ratio ensures that the meter operates safely and within its nominal range. This current reduction protects the equipment against overloads, decreases electrical risks, and improves the accuracy of energy consumption records, a fundamental aspect for validating electrical demand [11].

The neutral was directly connected to the corresponding terminal, ensuring potential reference and imbalance detection [14]. In this way, the meters recorded energy behavior during equivalent periods before and after the technological implementation [11,17].

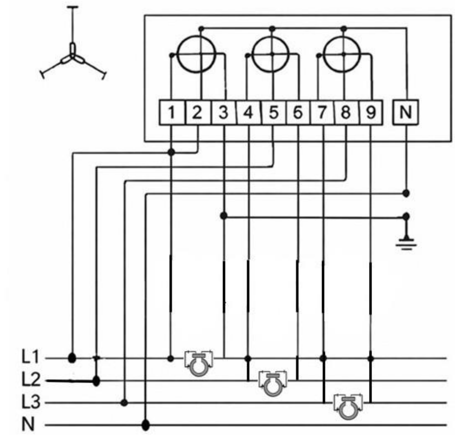

Figure 1. Star connection structure

As part of the initial diagnosis, a detailed inventory of the luminaires installed in the building was prepared to identify those to be replaced with LED lighting systems. The selected technology corresponded to Philips CorePro LEDtube 1200 mm 16W 865 T8 AP I luminaires (Figure 2), specifically designed for institutional applications. These lamps have a luminous efficacy of 112 lm/W and a nominal power of 16 W, making them a highly efficient alternative to conventional fluorescent tubes. Their average lifespan of 30,000 hours significantly reduces maintenance and replacement costs. In addition, they emit light at 6500 K (cool white), suitable for prolonged visual tasks in academic spaces, as it enhances concentration and detail perception.

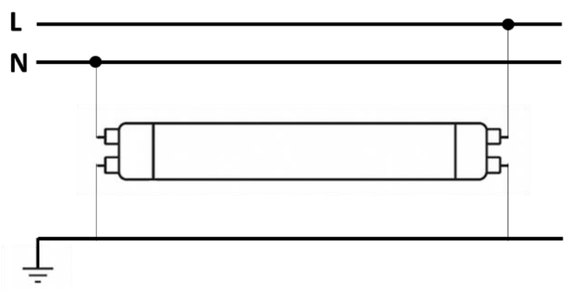

Figure 2. LED fluorescent CorePro LEDtube 1200mm 16W 865 T8 AP I

Finally, the energy consumption values obtained in the period prior to implementation were compared with those recorded after the incorporation of green technology. This evaluation showed the energy savings derived from the technological transition and established a baseline that will serve as a reference for future actions aimed at improving energy efficiency in the academic environment.

3. Results and discussions

In the EFCAUNT module, four types of luminaires were identified: 957 linear fluorescent tubes T5 of 28 W, 13 LED panels of 18 W, one LED bulb type A60 of 16 W, and one circular luminaire type F36C of 36 W. According to technical information, the T5 fluorescent tubes of 28 W generate a luminous flux of 2800 lumens, with an efficacy close to 100 lm/W. Their color temperature ranges between 2700 and 6500 K, allowing adaptation to both warm and cool environments, and they have an approximate lifespan of 20,000 hours [20,30].

The 18 W LED panels normally provide 1600 lumens, with an efficacy of 90 lm/W and a beam angle of 120°, favoring uniform light distribution in offices and corridors. Their lifespan reaches 40,000 hours, making them an efficient alternative to traditional fluorescent lighting [25,12].

The 16 W LED bulb type A60 emits between 1400 and 1450 lumens, with an efficacy of 87–90 lm/W and a beam angle of 150°. Its color temperature ranges between 2700 K and 6500 K, making it versatile for different environments. Its lifespan is between 10,000 and 15,000 hours, and it is commonly used as a replacement for incandescent bulbs in small spaces [31].

The circular luminaire type F36C of 36 W reaches a luminous flux between 3200 and 4100 lumens, with an efficacy of 110 lm/W. Its color temperature ranges from 4000 to 8000 K, making it suitable for general lighting in large spaces. With an approximate lifespan of 50,000 hours, it is a durable and efficient option [40,25].

Figure 3 shows the percentage distribution of the luminaire inventory in the EFCAUNT module before the implementation of green technology. It can be observed that the T5 fluorescent tubes of 28 W (orange color) represent 98.0% of the total. In smaller proportions are the square LED panel luminaires of 18 W (1.3%, blue color), the LED bulbs type A60 of 16 W (0.1%, green color), and the circular luminaires type F36C of 36 W (0.1%, purple color). This shows the predominance of fluorescent luminaires, which justified the need for a replacement strategy through a new technological proposal with technical, economic, and environmental benefits.

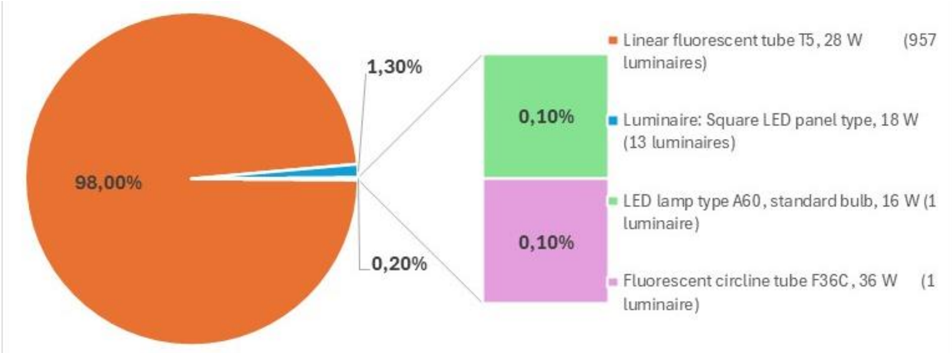

Figure 3. Distribution, power and types of luminaires in the EFCAUNT module before the implementation of LED systems

The distribution shown in Figure 3 constituted the baseline for the analysis of energy consumption and the evaluation of the technical feasibility of a transition to LED technologies.

[39] The implementation of LED systems in institutional buildings can reduce energy consumption by up to 30%, depending on the type of luminaire and the usage pattern. In addition, [35] it is reported that the substitution of fluorescent luminaires with LED not only generates significant savings in operating and maintenance costs, but also improves lighting quality.

The presence of LED panels and A60 bulbs indicates that lighting in the module is still at an early stage, while the coexistence of older technologies, such as the circular F36C tube of 36 W, reinforces the need to optimize energy efficiency and reduce operating costs associated with lighting. In this regard, [6] the appropriate selection of luminaires and photometric parameters can have a direct impact on the energy efficiency of lighting projects in industrial and academic environments.

On the other hand, Figure 4 shows the record of daily electricity consumption in the EFCAUNT module during a period of 15 working days prior to the implementation of green technologies. A growing trend in energy consumption can be observed, especially in the recorded values, indicating a higher electrical load in the corresponding area. The total daily consumption reached peaks close to 50 kWh/day, reflecting the need for corrective measures to improve efficiency and rationalize energy use.

This graph supports the initial findings on the lighting system, allowing the quantification of energy consumption associated with the use of conventional fluorescent luminaires. The upward trend in daily consumption reinforces the need for a technical intervention aimed at optimizing energy efficiency in the EFCAUNT module, especially in areas of higher electrical demand [6].

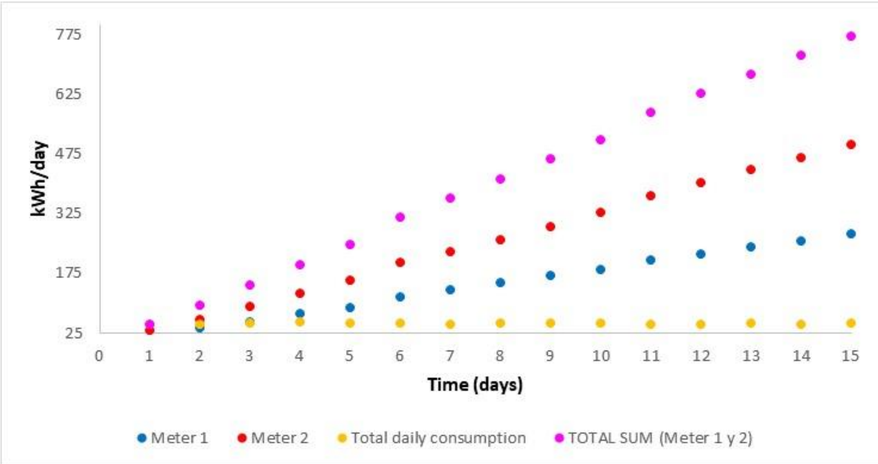

Figure 4. Record of cumulative and daily electricity consumption before the implementation of green technology in the EFCAUNT module

Figure 5 shows the behavior of daily electricity consumption in the EFCAUNT module during a 90-day period of academic activity, following the implementation of green technology through the installation of 362 LED luminaires. In this stage, conventional fluorescent luminaires were replaced with linear LED T8 tubes of 16 W, with G13 sockets, an approximate luminous flux of 1600 lumens, a color temperature of 6500 K, and an estimated lifespan of 15,000 hours.

This substitution aimed to improve the energy efficiency of the lighting system, ensuring greater durability and better use of light in academic and industrial environments, thus providing evidence of the positive impact of the transition toward more sustainable technologies.

In this case, the implementation of 16 W LED T8 tubes represents a significant improvement compared to conventional fluorescent luminaires of higher power, while maintaining the required lighting levels in terms of both energy efficiency and operational durability. LED tubes do not require electromagnetic ballasts, have superior luminous efficacy (120–150 lm/W), and a lifespan that can exceed 40,000 hours, which helps reduce maintenance and replacement costs. According to studies from the University of Michigan

[41], the direct replacement of T8 fluorescent tubes with LED T8 can generate energy savings between 35% and 50%, depending on usage patterns and product quality. In addition, by eliminating flicker and improving color rendering (CRI > 80), lighting quality is optimized in classrooms (300–500 lux), offices (300–500 lux), and laboratories (500–750 lux), ensuring adequate conditions for concentration and visual safety [19,18,38].

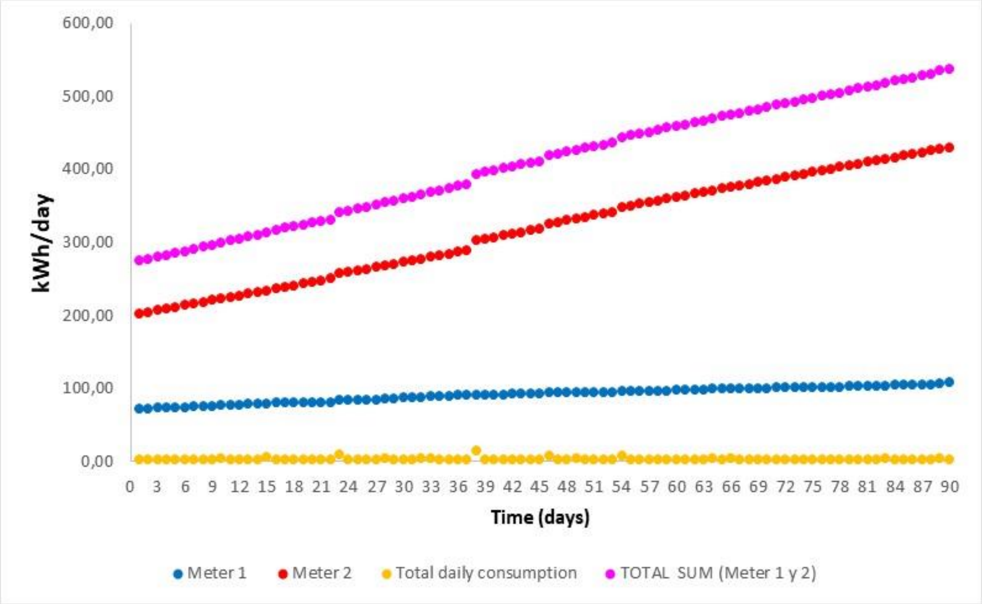

Figure 5. Record of cumulative and daily electricity consumption after the implementation of green technology in the EFCAUNT module

The substitution of 28 W T5 fluorescent tubes with 16 W LED T8 tubes constitutes a substantial improvement in terms of energy efficiency. This change implies a direct reduction in electrical consumption of approximately 43% per luminaire, without compromising lighting levels, thanks to their high luminous efficacy (112 lm/W). Likewise, by eliminating or reducing dependence on electronic ballasts, electrical losses are minimized. According to Philips Lighting (2023), this type of LED tube can generate cumulative savings of up to 50% in energy consumption and 60% in maintenance costs, due to its longer lifespan and lower replacement frequency.

Figure 6 presents the results of the calculation of carbon dioxide (CO_2) emissions associated with the energy consumption of luminaires before and after the implementation of green technology in the EFCAUNT module. In this process, actual electricity consumption readings recorded by the meters were considered, applying a standard emission factor to convert kilowatt-hours (kWh) consumed into kilograms of CO_2 generated. As observed, energy consumption prior to the intervention was 769.890 kWh, generating 164.011 kg of CO_2, while after the installation of 16 W LED T8 luminaires, consumption decreased to 537.610 kWh, with emissions of 114.528 kg of CO_2. This difference represents a reduction of 30.17% in emissions, showing the positive impact of the technological transition not only in terms of energy efficiency but also in mitigating the environmental footprint of the lighting system.

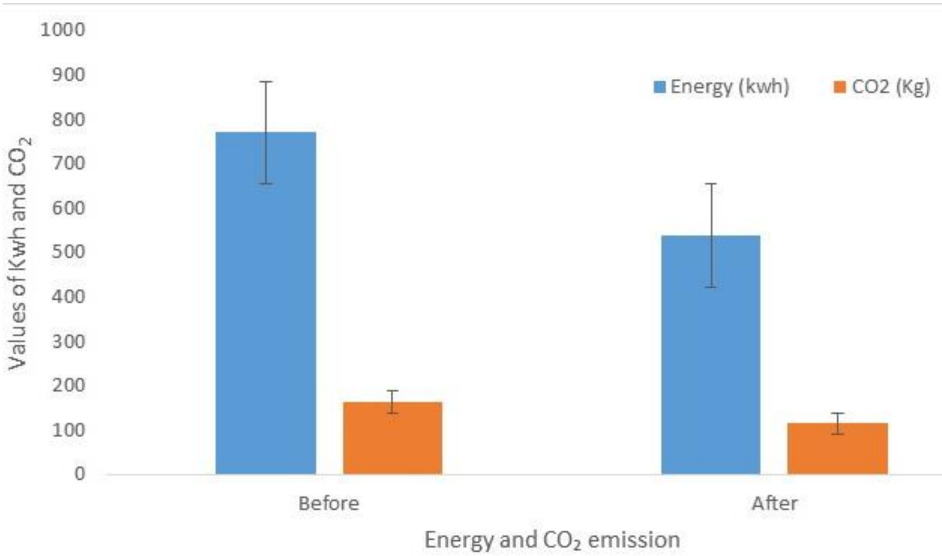

Figure 6. Mass of CO_2 emitted by the daily energy consumption of the luminaires in the EFCAUNT module

Figure 6 displays the indirect quantification of the environmental impact of the technological intervention carried out in the EFCAUNT module, showing a reduction of 49.483 kg of CO_2, equivalent to 30.17% compared to the previous scenario. This result is consistent with studies performed in university environments to evaluate the effect of replacing fluorescent luminaires with LED systems. [37] A Faculty of Engineering in Lima, Peru, reported that electricity consumption associated with lighting represented a significant source of indirect GHG emissions (Greenhouse Gases, such as

CO_2, CH_4, and N_2O) corresponding to Scope 2 (indirect emissions associated with the consumption of purchased electricity used by an institution), and that the transition to LED reduced the institutional carbon footprint by more than 28%.

Similarly, [36] the substitution of fluorescent luminaires with LED in academic spaces at the UPC (Barcelona) generated an energy reduction greater than 35%, together with improvements in lighting quality and system lifespan. [24] Researchers in other institution also concluded that replacing fluorescent lamps with LED lamps of equivalent luminous flux can reduce CO_2 emissions by between 30% and 50%, depending on the type of luminaire, usage pattern, and energy source. These values validate the results obtained in the present implementation, which justifies the technical and environmental validity of the intervention.

Figure 7 shows the behavior of daily electricity consumption of luminaires before and after the implementation of green technologies in the EFCAUNT module. In the initial stage (blue bars), corresponding to 15 days, an average consumption close to 11–12 kWh/day was observed, associated with the use of 28 W T5 fluorescent luminaires. After the technological intervention (orange bars), to replace them with 16 W LED T8 tubes, energy consumption decreased steadily, and stabilized at values close to 6–7 kWh/day over 90 days. This represents an approximate reduction of 35–40% in daily energy demand.

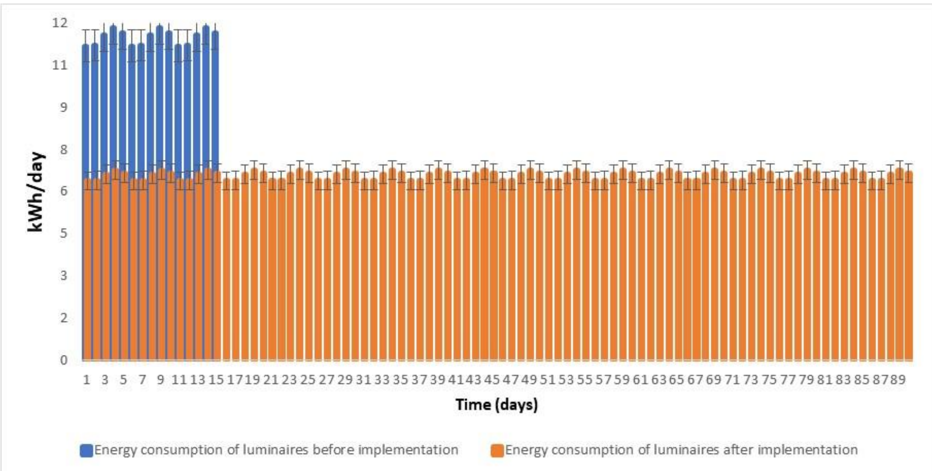

Figure 7. Comparison of daily energy consumption before and after the implementation of green technology in the EFCAUNT module

It is worth noting that this improvement was achieved only with the partial replacement of 362 LED luminaires, so the potential impact on energy savings and emission reductions would be even greater if all conventional luminaires (972) present in the EFCAUNT module were replaced. In conclusion, the figure clearly presents the impact of the technological transition on the energy demand of the lighting system, reinforcing the results obtained in CO_2 measurements and consolidating the environmental and operational benefits of the intervention.

This behavior is consistent with LED lamp studies [9], in which the effect of LED lamp installation in public buildings in Peru was analyzed, concluding that energy savings offset the investment within a period of 2 to 3 years, with a reduction of up to 50% in installed power. Furthermore, it was reported that the transition from conventional lamps to LED [2] in the public lighting of the city of Cusco (Peru) generated a 38% improvement in energy efficiency, in addition to a decrease in CO_2 emissions.

Moreover, [6] energy efficiency does not depend solely on the type of luminaire, but also on the photometric curve, understood as the graphical representation of the distribution of luminous intensity in space and its adaptation to the physical environment. In warehouse lighting projects, the use of optimized photometric curves can improve light distribution and reduce electricity consumption without increasing installed power. This technical approach reinforces the importance of considering not only the type of lamp but also its optical design and contextual application, which is replicable in academic spaces such as the one evaluated in this study.

The calculated energy efficiency applied to the measured total consumption values (769.890 kWh before and 537.610 kWh after) allowed an energy saving of 30.17%, a significant improvement in the performance of the lighting system after the introduction of 16 W LED T8 tubes. This value confirms the effectiveness of the operation and falls within the range reported by similar studies in university contexts. Supporting this, [35] a university in Ecuador reported a 32% improvement in energy efficiency after replacing fluorescent luminaires with LED, complying with UNE-EN 12464-1 standards through DIALux simulations. Another university in Mexico [21], designed a home automation lighting system that also achieved energy efficiency above 35% by integrating motion sensors and programmed schedules. Finally, [8] energy audits in universities can identify improvement opportunities that translate into efficiencies of up to 40%, especially in lighting systems with high occupancy. These studies reinforce the validity of the results obtained in the current study, which fall within regional and institutional trends towards energy sustainability. Moreover, the use of a transparent methodology based on real measurements strengthens the technical analysis and facilitates its replicability in other academic environments.

The economic analysis derived from the energy savings obtained after the implementation of 16 W LED T8 tubes replacing 28 W T5 fluorescent luminaires showed a saving of 232.280 kWh, equivalent to a 30.2% reduction in electricity consumption. This saving represents a daily monetary benefit of S/. 68.17 (USD 20.45), projected to S/. 2,045.23 (USD 613.57) monthly and S/. 24,883.58 (USD 7,465.07) annually, considering an average price of S/. 0.2935 (USD 0.088) per kWh. These results confirm the financial viability of the intervention and are similar to those from UPC (Barcelona) [36], where it was demonstrated that replacing fluorescent luminaires with LED in academic spaces generated savings above 35%, with investment recovery in less than three years. Similarly, [1], in Chimbote, Peru, switching public lighting to LED luminaires reduced monthly consumption by 218.93 kWh and energy costs by S/. 146.18 (USD 43.85), with an IRR of 20% and an NPV of S/. 5,478.13 (USD 1,643.44), confirming project profitability. , At UNAP-Peru, [13] optimizing the lighting system with LED technology in urban avenues also generated sustainable economic benefits, with improvements in lighting quality and emission reductions. These findings indicate that the economic savings obtained in the present implementation follow a trend that supports the vision of the circular economy and the need to move towards sustainability.

The Internal Rate of Return (IRR) of the investment made in replacing 28 W T5 fluorescent luminaires with 16 W LED T8 tubes was 87%, proving that the investment is not only recoverable but highly profitable in the short term. This result far exceeds the reference threshold of 10–15% considered acceptable in public or institutional projects and is well above the values reported in similar studies. [32] Regarding energy efficiency in municipal lighting systems, a 28.6% IRR is reported, with a positive NPV and a three-year payback period. [33] In an educational institution, it was reported that the implementation of LED luminaires with photovoltaic supply reached an IRR of 35.4%, validating investments based on technical and environmental criteria. [8] In university energy audits, LED lighting projects can reach IRRs above 40% when combined with lighting control strategies and rational energy use. Although positive, these values are considerably lower than the 87% achieved in the present investigation, indicating optimal conditions of energy savings, low investment cost, and high operational efficiency, derived from an adequate selection of luminaires and proper technical implementation.

Figure 8 shows the economic impact of the application regarding energy consumption after the implementation of 16 W LED T8 luminaires, evaluated over a three-year horizon. In the first year, an initial expenditure of S/. 23,275.00 (USD 6,982.50) was recorded, corresponding to the investment in the acquisition and installation of luminaires. From the second year onward, a positive cash flow was observed, with annual revenues of S/. 24,883.58 (USD 7,465.07) derived from accumulated energy savings. This outcome continued in the third year, achieving investment recovery and generating financial surpluses.

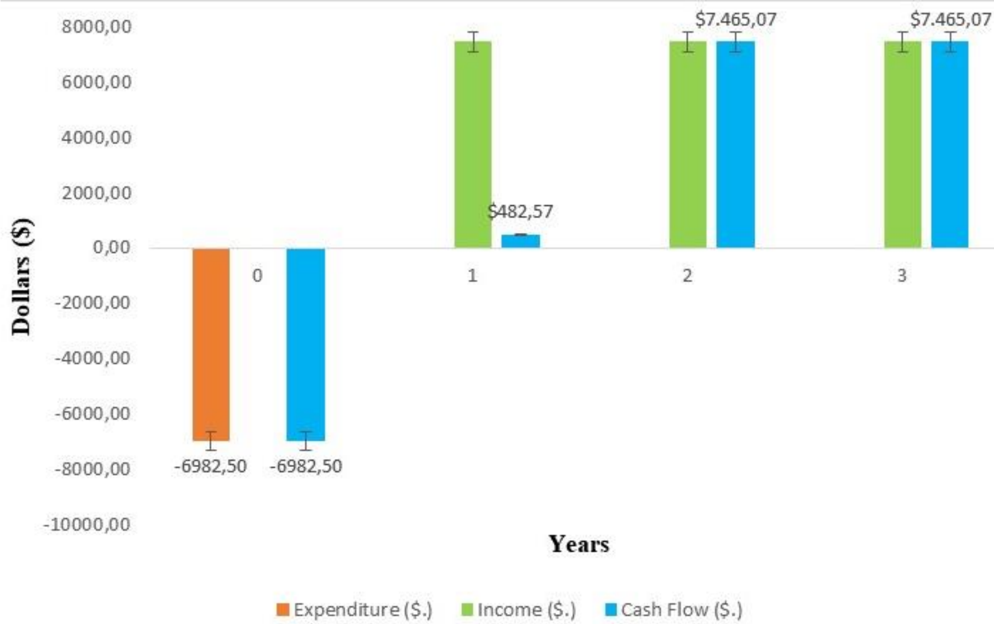

Figure 8. Cumulative cash flow from energy savings with 16W T8 LED luminaires

On the other hand, a favorable return on investment (ROI) is visible from the first year. The initial expenditure of S/. 23,275 (USD 6,982.50) for the acquisition and installation of 362 LED T8 luminaires of 16 W is offset by accumulated energy savings that generate annual revenues of S/. 24,883.58 (USD 7,465.07), allowing a positive cash flow from the second year onward. This behavior confirms that energy efficiency projects in lighting can be profitable in the short term, especially when obsolete technologies are replaced with LED systems of high luminous efficacy (120–150 lm/W) and long lifespan (up to 40,000 hours).

[32] The cost analysis in municipal lighting systems has demonstrated that the use of LED lamps significantly reduces operating expenses and CO_2 emissions. Likewise, the High-Efficiency Lighting Guide of CAF [4] highlights that the implementation of LED technologies in public buildings can recover the investment in less than three years, depending on usage patterns and electricity tariffs. In this study, the accumulated cash flow by the third year exceeds S/. 49,000 (USD 14,700), reinforcing the financial sustainability of the implementation and its potential replicability in other academic modules.

An ROI analysis in LED lighting projects shows that investment can be recovered in less than three years, thanks to energy savings and reduced maintenance costs [27]. This type of intervention is particularly relevant in academic environments, where the intensive use of lighting increases the environmental and financial impact of the technologies employed.

In line with the findings of various studies, it has been shown that the transition to LED lighting systems in educational institutions does not only improve energy efficiency but also contributes significantly to the reduction of GHG emissions and sustained economic savings. LED lamps can reduce CO_2 emissions by up to 80% compared to fluorescent technologies, as they do not require polluting materials such as mercury and do not generate high thermal losses [15].

4. Conclusions

The technological intervention carried out in the EFCAUNT module, based on the replacement of fluorescent luminaires with 16 W LED T8 tubes, proved to be an effective strategy to improve energy efficiency, reduce environmental impact, and generate sustainable economic benefits. The results showed a significant decrease in daily electricity consumption, a cumulative reduction in CO_2 emissions, and a positive cash flow from the first year, with investment recovery in less than twelve months.

The potential of LED technologies to optimize energy performance without compromising the required lighting levels in classrooms, offices, and laboratories (300–750 lux) is highlighted. Likewise, the proper selection of luminaires and photometric curves allowed efficient light distribution, reinforcing the importance of optical design in institutional lighting projects.

Taken together, the technical and financial evidence obtained supports the replicability of this implementation in other academic spaces, as part of a comprehensive strategy for sustainability and responsible energy management.

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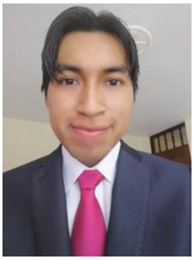

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