Diaz, Mauricio Chamorro; Mira, Miguel Viveros; Quispe, Enrique C. et al.

Article

A methodology to analyze significant energy uses and energy consumption for improving energy performance in higher education buildings

Provided in Cooperation with:
International Journal of Energy Economics and Policy (IJEEP)

Reference: Diaz, Mauricio Chamorro/Mira, Miguel Viveros et. al. (2023). A methodology to analyze significant energy uses and energy consumption for improving energy performance in higher education buildings. In: International Journal of Energy Economics and Policy 13 (6), S. 636 - 649.
https://www.econjournals.com/index.php/ijeep/article/download/14974/7606/35071.
doi:10.32479/ijeep.14974.

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2023, 13(6), 636-649.

A Methodology to Analyze Significant Energy Uses and Energy Consumption for Improving Energy Performance in Higher Education Buildings

Mauricio Chamorro Diaz[1], Miguel Viveros Mira[1], Enrique C. Quispe[1]*, Rosaura Castrillón[1], Ana Lasso[2], Juan R. Vidal[1]

[1]GIEN Research Group, Faculty of Engineering, Universidad Autónoma de Occidente, Colombia, [2]PAI+ Research Group, Faculty of Engineering, Universidad Autónoma de Occidente, Colombia. *Email: ecquispe@uao.edu.co

Received: 28 July 2023 **Accepted:** 25 October 2023 **DOI:** https://doi.org/10.32479/ijeep.14974

ABSTRACT

This paper introduces a methodology to conduct an energy assessment at a Higher Education Institution (HEI) based on the international standard ISO 50001. This methodology was applied at the Universidad Autónoma de Occidente (UAO) in Cali, Colombia, to develop energy consumption baselines for each building and the air conditioning system of the main building based on the establishment of relevant variables affecting the energy consumption of each Significant Energy Uses (SEUs). The energy assessment allows us to determine energy performance improvement opportunities. This study case identified that energy consumption could be reduced by 14.2% by applying actions on the campus lighting, office equipment, and air conditioning system. This study provides guidance and guidelines for conducting an energy assessment at a university campus, with restrictions on measuring energy consumption. It provides insights for other universities implementing an Energy Management System and the government for conducting public energy policies.

Keywords: ISO 50001 Energy Review, Significant Energy Use, Energy Performance, Higher Education Buildings, Energy Management System
JEL Classifications: Q40, Q41, Q47, Q48

1. INTRODUCTION

The buildings sector accounts for approximately 30% of global energy consumption with a value of 135 EJ and 27% of CO_2 emissions related to the operation of buildings with a value of about 10 Gt CO_2 (Global Alliance for Buildings and Construction, 2021). The main energy uses in buildings are subsystems such as cooling or heating systems (45%) and appliances (30%) (IEA, 2022), lightning systems, automation systems, office, and laboratory equipment such as computers, televisions, printers, video beams, and others (Shan et al., 2019). In addition, energy consumption in this sector is expected to increase by more than 40% in the next 20 years (Mariano-Hernández et al., 2021).

Implementing energy management systems (EnMS) has proven to be effective in increasing the energy performance of organizations (El Majaty et al., 2022; Fichera et al., 2020; González et al., 2012; Müller et al., 2013). It does not imply changing to new or more efficient technologies but controlling energy procedures through the EnMS. For example, concerning cooling or heating systems to achieve greater energy efficiency, it is more cost-effective and sustainable to perform energy management on this equipment than replace it with more efficient modern technologies because, if these new technologies are operated inadequately, it can result in excessive energy consumption (Aguilar et al., 2019). Therefore, integrating building management systems (BMS) will reduce greenhouse gas (GHG) emissions, a key factor in achieving

United Nations Sustainable Development Goals. It offers opportunities to build an environmentally sustainable and high-impact educational culture focused on successfully transforming into an environmentally friendly society (Fontalvo et al., 2021).

ISO 50001 (International Standards Organization (ISO), 2019) provides the requirements for an EnMS. It has been successfully applied to increase the energy performance of industrial and commercial organizations, becoming an important reference for developing an EnMS in buildings. This standard establishes guidelines for planning, implementing, monitoring, and controlling an organization's energy performance through adopting an EnMS (Fichera et al., 2020). The implementation of the EnMS, under ISO 50001 requirements, contributes to reducing energy consumption and thus achieving commitments to reduce carbon footprint in organizations both at the national and international levels (Castrillón-Mendoza et al., 2020), being an element to strengthen the path towards energy sustainability.

Higher Education Institutions (HEI) are composed of specific groups of buildings like laboratories, offices, classrooms, and cafeterias with significant energy consumption, which makes them an excellent test bed to characterize and understand the energy consumption of a group of mixed buildings (Ocampo Batlle et al., 2020). In addition, they serve as educators; rising energy costs have become a major impediment to their growth, as these constitute their largest budget (Sai Sachin G et al., 2018). Hence, HEIs worldwide have committed to energy conservation (Lo, 2013).

HEIs are responsible for guiding initiatives to promote sustainable development. EnMS must be implemented in university buildings since improving the energy performance of higher education buildings encourages initiatives that promote energy savings (Desideri et al., 2012). Implementing BMS and strategies to improve energy efficiency in buildings is a topic discussed previously. There are case studies in which BMS has been applied to buildings since 1976, and reports indicate that up to 2016, 10,5% of these cases have been reported in universities worldwide, mainly in North America, Europe, and Asia (Lee and Cheng, 2016).

In China, a sustainable campus project was developed, which included an energy management system as an initial step to implement and maintain a sustainable campus (Tan et al., 2014). Also, in Europe, the Educa-RUE project was developed, which aimed to improve the energy performance of buildings with a special emphasis on education buildings. It achieved the development of actions to promote sustainable energy use, the definition of an environmentally friendly energy management model, a commitment of local authorities to comply with European legislation, raising awareness of communities and public institutions, and increasing the adoption of environmentally friendly behavior (Desideri et al., 2012).

An energy management system for buildings was developed in Japan at Osaka City University to monitor and measure energy consumption, using current transformers to measure electricity consumption at each distribution box. Webcams monitor the lightning in each room, the air conditioning status, and gas consumption at the meter by recognizing characters and sending this data over the network to a computer for control and analysis (Yuan et al., 2015a) In Brazil, at the Federal University of Itajubá (UNIFEI), a methodology was developed to establish baselines and energy performance indicators based on ISO 50001 standard to identify potential energy consumption savings and establish energy management strategies implemented at the university campus (Ocampo Batlle et al., 2020).

A BEMS for a smart building is proposed in Italy at the University of Genoa, which consists of two modules. The first one is an optimization tool to efficiently manage the heating, ventilation, and air conditioning (HVAC) system to ensure the thermal comfort of occupants; the second one consists of a simulation tool based on an equivalent electrical circuit to evaluate the transient thermal behavior of the building (Bianco et al., 2020). At Universidad Autónoma de Occidente (UAO) in Colombia, a sustainable campus program has been developed to reduce its CO_2 emissions while improving the energy performance of the campus (UAO, 2016). In 2014, Universidad Autónoma de Occidente installed solar photovoltaic panels and updated the system to 400 kW. Between 2015 and 2021, UAO reduced CO_2 emissions for energy consumption of 461 tons CO_{2eq} (Universidad Autonoma de Occidente, 2021).

It is also important to consider the impact that government energy policies can have. Regarding this aspect, it is found that governments have established policies that promote energy efficiency improvement in buildings; for example, Colombian laws regulate and promote the use and consumption of energy, using non-conventional renewable energy sources, and evaluating its energy performance (Congreso de la República de Colombia, 2021). Similarly, the European Commission estimates that implementing energy efficiency policies can lead to savings of 25% in energy demand, and energy efficiency also encompasses the variables of affordability, energy security, and environmental sustainability, which requires the implementation of policies by governments (Fontalvo et al., 2021).

When implementing an EnMS in higher education buildings, there are five main considerations: economic feasibility, environmental impact, institutional characteristics, impact due to occupancy, and technical practicality (Gul and Patidar, 2015). Consequently, efforts are focused on meeting energy efficiency requirements in buildings, ensuring improved energy performance of building subsystems, thus contributing to a sustainable environment (Mariano-Hernández et al., 2021).

This paper presents a methodology for conducting an energy assessment under ISO 50001 in a HEI in Cali, Colombia. First, energy use and consumption are analyzed based on measurements; then, significant energy uses, and responsible personnel are identified, relevant variables and energy performance are determined, and finally, opportunities for improvement are determined. The above is to design and implement an EnMS, attached to institutional policies, which also provides insight into the energy performance of this, to implement corrective actions that lead to an energy performance improvement, contributing to energy transition and sustainability of the country.

2. METHODOLOGY

According to ISO 50001, the energy review is the first step of the energy planning stage for implementing an EnMS in an organization. In this work, a methodology is developed to perform the energy review in buildings on a university campus, and then it is applied to the campus at Universidad Autónoma de Occidente (UAO). The methodology follows the next steps: analysis of energy use and consumption, determining energy performance for each Significant Energy Use (SEU), identification of energy performance opportunities, and estimation of future energy use and consumption. As seen in Figure 1, the data needed to initiate the energy review are current energy types, past and present energy uses, and consumptions.

The procedures at each stage of the methodology are detailed below:

2.1. Data Acquisition

Institutions having energy metering systems will have access to consumption information either by area or by equipment. Those institutions with no metering system or the metering system need to cover sufficient areas to determine areas of higher consumption can perform a census of loads. This tool consists of making an inventory of equipment, in which the information on the installed power capacity of each one is obtained through the plate data. In case of not being able to access this information, on-site measurement of energy consumption can be performed (Castrillón Mendoza and González Hinestroza, 2018), and surveys and image analysis can also be performed to determine the hourly use of loads (Diaz-Acevedo et al., 2019; Yuan et al., 2015).

2.2. Energy use and Consumption Analysis

The analysis of energy use and consumption data aims to identify energy sources used (electricity, liquid and solid fuels, steam, heat, compressed air, etc.), to determine past and current energy use and consumption (Mohamed et al., 2022), and to establish the SEUs, i.e., those that represent substantial energy consumption and offer considerable potential for energy performance improvement (Fuchs et al., 2020).

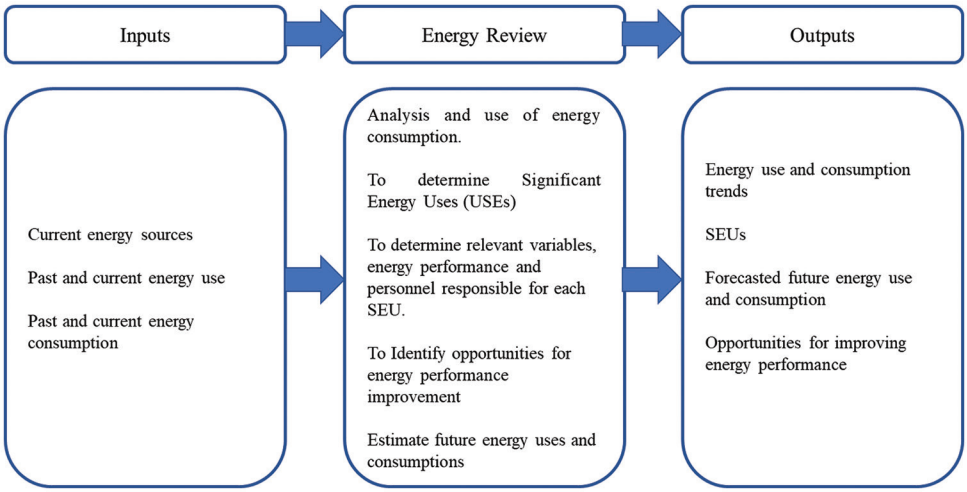
For data analysis, some tools used are bar and trend graphs, control charts, tables, and energy matrix. Because each energy source's measurement unit is different, a consistent unit must be defined to analyze its consumption. The conversion factor must be verified in official sources of suppliers since each country's energy properties vary; for example, the Watt-hour (Wh) or Joule (J) can be used as a unit of measurement (Subramanyam et al., 2015). The energy matrix should be made with energy consumption data for at least 1 year, as the contribution of each energy source can vary from month to month due to the activities carried out by HEIs or the climate factor.

Based on this analysis, the ESUs are identified, which are those representing substantial energy consumption and offer considerable potential for energy performance improvement (Fuchs et al., 2020), thereby identifying where to conduct energy performance improvement efforts (NTC-ISO 50001: 2019, Sistemas de Gestión de La Energía, Requisitos Con Orientación Para Su Uso., 2019).

To analyze consumption in the past and present, a simple but useful tool is the trending graph, which shows the behavior of energy consumption over time, allowing comparisons to be made when implementing corrective actions and predicting behavior (Nepal and Paija, 2019). The following considerations for its construction are: defining the time scale and data from at least 2 years. This information allows comparisons because consumption in higher education buildings varies according to the academic activities conducted and climatic conditions, which have a greater impact in the case of countries with seasons.

The energy review scope can be determined by identifying each area's consumption. To graphically observe the energy distribution in the institution, a Sankey diagram is used to visualize the amount of energy delivered to certain areas or processes, identifying those with the highest consumption. Within the areas defined in the scope of the energy review, the equipment with the highest consumption is specified using the Pareto diagram, which is a bar graph representing 20% of the equipment that consumes 80% of the energy, these being SEUs in each area.

Figure 1: Energy review



2.3. Determining Energy Performance for Each Significant Energy Use (SEU)

If energy performance is to be established, it is necessary to determine the relevant variables for each SEU. For this purpose, simultaneous measurements of energy consumption and variables that affect consumption, such as indoor and outdoor temperature, occupancy, and number of services, must be collected. With the data collected, the probabilistic value (P-value) is used; this is the lowest significance level at which the observed value of the test statistic is significant (Walpole et al., 2012). Ideally, the P-value should be <0.05 to consider the variable meaningful. If no variable achieves this value, a multivariate analysis can be performed.

In addition, it is necessary to identify the people who influence or affect the consumption of SEUs. This analysis makes it possible to determine factors that affect the energy performance related to its operation. To identify the personnel who influence the control of the consumption of the SEUs, an interview was conducted with the person who manages the maintenance and operation personnel of the institution to know the personnel in charge of the maintenance and operation of this equipment. To determine their impact, the information collected is organized in a table describing the location of the SEU, the operator in charge of controlling the area or process, the person in charge of the area, and the SEU variables to be controlled.

2.3.1. Establishing the current energy efficiency

ISO 50001 describes energy performance as measurable results related to energy efficiency, use, and consumption (NTC-ISO 50001: 2019, Sistemas de Gestión de La Energía, Requisitos Con Orientación Para Su Uso., 2019). With the analyses and data collection performed up to this point, the energy performance state of each component can be established. To determine the current state of energy efficiency, a table was created to compile information on the loads with the highest usage and consumption, where the values of their nominal efficiency are given, to identify opportunities for improvement in the energy efficiency of the equipment.

2.3.2. Establish current energy use

In terms of energy use, a format was developed to determine how end loads are used. Uses refer to the main activities for which the loads are used. Then common loads can be grouped for an area. In the observation column, behaviors that may affect the consumption of the area or process are written, such as times of use, typical operation, failures encountered, or no-load uses.

2.3.3. Establishing energy consumption

A format was developed to establish the consumption characteristics of HEIs according to the term (holidays, classes) and their area. The service provided by the area and its consumption are described.

2.4. Identify Opportunities for Energy Performance Improvement

A table was made to organize the opportunities for improvement by analyzing the uses of loads. With the observations previously obtained, information can be provided on any misuse of a load in an area, so strategies can be proposed to improve energy performance, such as changing the hourly use of certain equipment, setting standards, training personnel in charge, and scheduling maintenance, among others. Each proposal will depend on the load and the personnel in charge of that load; the consumption must be quantified after applying the energy strategy to provide feedback to determine whether the measures implemented improve energy performance and obtain economic benefits.

2.5. Estimating Future Energy uses and Consumptions

Three scenarios were established to estimate future uses and consumptions, considering technological changes to more efficient equipment and systems and the recommendations found from identifying opportunities for improving energy performance. Even so, it is noted that technological change can be used as a tool to improve energy efficiency and reduce energy consumption (Leal Filho et al., 2019) and contributes to reducing emissions to the environment (Amin et al., 2023).

The energy consumption of buildings is mainly influenced by six factors: (1) climate, (2) building façade, (3) building services and energy systems, (4) building operation and maintenance, (5) occupant activities and behavior, and (6) air quality provided inside the building (Yoshino et al., 2017) It is necessary to investigate all six factors together to understand building energy consumption data. A detailed comparative analysis of building energy data concerning the six factors mentioned above would provide essential guidance for identifying opportunities for energy savings (Yoshino et al., 2017).

This paper considers four of these six factors: Climate, building services and energy systems, operation and maintenance, activities, and occupant behavior because there is no reliable measurement to assess air quality and no updated inventory of the building façade.

2.5.1. Identify technological change options

Possible technological changes are established based on improving the efficiency of the equipment through appropriate predictive and preventive maintenance of the main building's refrigeration system, as well as maintaining an automated lightning system, where the staff in charge of the building's lightning turns the luminaires on and off according to the established usage schedules. In addition, the amount of equipment and luminaires in the main building and classroom buildings are estimated to know the efficiency of each equipment and, if necessary, recommend a change to more efficient technologies.

2.5.2. Opportunities for improvement during assessment

The energy review established three possible scenarios: negative, positive, and neutral for computer equipment and the lightning system. For computer equipment, a positive scenario consists of switching off all computer equipment used by staff for half an hour, e.g., at lunchtime when staff have lunch simultaneously. A neutral scenario is 50% of the computer equipment switched off for half an hour, and a negative scenario is only 10% of the computer equipment, as noted in Chapter 4.3.2.

2.5.3. Opportunities to improve chiller performance

Based on necessary measurements of the main building's air-conditioning system and surveys of maintenance personnel,

opportunities for improvement were identified for this system, which are related to hourly use and maintenance. Therefore, energy and economic savings could be made by switching off the equipment half an hour earlier and continuous maintenance to improve efficiency.

3. CASE STUDY

The Universidad Autónoma de Occidente (UAO), founded in 1970, has its Valle de Lili campus, located at Calle 25 #115-85 Km 2 Vía Cali-Jamundí, with a total area of 111816 m^2. It is at longitude 3.3538852133967345, latitude -76.52192889263506, and 1018 meters above sea level.

The campus has seven buildings in operation, as shown in Figure 2. Four classroom buildings (CB 1-4), with four floors, offices, and mainly classrooms for undergraduate and postgraduate classes, a university wellness building, where offices and cafeterias are located, a gym building with lightning towards the football fields, and lots. Finally, the campus has a multipurpose main building with four floors and two basements. On each floor are the faculties, administrative offices, and library. In basements are the computer rooms for classes, laboratories, and television studios, where the main administrative processes of the University are developed. On the other hand, the campus has its own Wastewater Treatment Plant (WWTP) and Drinking Water Treatment Plant (DWTP). The following energy sources are used to operate the campus: electricity, solar photovoltaic, natural gas, fuel, and diesel oil.

Inside the campus, electrical energy is distributed through 3 substations that feed different sectors of the campus. Substation one, with a capacity of 500 kVA, provides loads of the main building; substation two has a power of 1000 kVA, which feeds loads of the common areas of the campus, the four classroom buildings, the university wellness building, and the Physical Conditioning and Health Centre (CAFS), and substation three with a capacity of 800 kVA, feeds the air conditioning system of the main building except for its handlers. Regarding photovoltaic solar energy, there are eight solar systems on the roofs of parking lots, classrooms, the main building, and the university wellness building. The solar generation is connected to the nearest distribution boards; the total installed capacity is 404 kWp. Natural gas is mainly used to generate electricity with a 956 kVA emergency power plant; also, natural gas is used in laboratories and restaurants; however, each restaurant acquires its service independently. Finally, gasoline and diesel oil are used for lawnmowers and to mobilize tractors for gardening.

The UAO campus has an electrical energy measurement system that monitors consumption. This system has 19 SCHNEIDER meters with telemetry systems that collect information on active, reactive, and apparent power and energy with a 15-min periodicity; the data is reported and stored in the Power Monitor-CGE software. The meters are in some distribution boards that feed different loads of the campus areas. The areas measured are shown in Table 1 except for the internal border meter, the main circuits refer to the total output of the substation, so they measure all the consumption of this; in the case of substation 2, this has two outputs. There are distribution boards that do not have metering; however, all consumption is measured by the meters of the main circuits of each substation. The electricity network service provider has power metering for each solar system and one meter for the total electrical energy consumption at the university.

The average consumption of the buildings evaluated is 1,32 GWh/year for the main building and 93,31 MWh/year for CB 1. In Tables 2 and 3, the characteristics of the buildings can be observed. A characterization of the different areas of each building was made to identify their use, as this influences their consumption.

The energy assessment focuses on the building representing the highest energy consumption, which is the main building and one

Table 1: Areas monitored by the measurement system

Substation 1	Substation 2	Substation 3
Main circuit	Main circuit 1	Main circuit
Basement 1 south	Main circuit 2	
Basement 1 north	CB 1	
Basement 2 north	CB 2	
	CB 3	
	CB 4	
	HVAC CB 1	
	HVAC CB 2	
	HVAC CB 3	
	HVAC CB 4	
	WWTP	
	University wellness building	
	University wellness building, 3rd floor	

HVAC: Heating, ventilation, and air conditioning, CB: Classroom building, WWTP: Wastewater treatment plant

Table 2: Identification of the areas of classroom building 1

Building	Department	Areas number
CB 1	Classrooms	28
	Halls	4
	Office of international relations	1
	Men's and women's bathrooms	8
	Language institute	1
	ELC language institute	1
	Language teacher's lounge	1
	General services warehouse	1

CB: Classroom building

Figure 2: Aerial View Campus Valle de Lili-UAO

of the classrooms, as their consumption varies according to their hourly use.

4. RESULTS AND DISCUSSION

4.1. Energy Matrix

The university's energy matrix comprises four energy sources: Solar photovoltaic energy, electrical energy, natural gas, fuel, and Diesel Oil. The main use of natural gas is in the emergency generation plant, according to Figure 3. The main use of natural gas is in the emergency generation plant so that, in the end, this energy is converted into electricity, which is why the analyses focus on the consumption of this energy source. Gasoline and Diesel Oil consumption occurs in lawnmowers and tractors used in gardening work.

4.2. Analysis of Past and Current Energy Consumption

Figure 4 shows the load profile of the Valle de Lili campus from 2017 to 2022, in which the total consumption per month for each year is illustrated. In 2020, due to the pandemic, this consumption decreased. Even so, when comparing 2022 with 2019, they follow a similar pattern. The red lines indicate the beginning of each academic term, and the black lines indicate the end of each academic period. In intermediate periods classes are given, but only some subjects are offered, and the employees are given holidays. Classes usually start in the last week of January and end in the 1st week of June, and in the second semester, they begin in the last week of July and end in the last week of November. It can be seen then that the months of highest consumption are at the beginning or end of the semester, and those of lowest consumption are June and December, without considering the years 2020 and 2021, since in those years, the campus was not fully operational due to COVID-19 pandemic.

Figure 5 shows the distribution of electrical energy within the campus in an academic term; data is presented in percentages. 49.6% of the energy is used for the operation of the main building, 49.1% of the energy feeds the other buildings and areas of the campus, and lastly, 1.3% of the energy is consumed in other areas that are not discretized or could be energy losses. Inside the main building, the air conditioning system is the most energy consumer, with 20.5% of the power of the whole campus, followed by the area cataloged as "other sub 1," which is the most consumed inside the main building. This area has distribution boards that are not discretized in the measurement. These boards feed the loads of the south side of basement two, where television studios and laboratories having high consumption equipment are located.

Among buildings with the highest energy consumption on campus are the classroom buildings, which consume 28.6% of the total energy of the campus, and between these buildings and the main building, they account for 78.2% of total energy consumption. It is noted energy consumption of classroom buildings 1 and 2 is lower than the energy consumption of classroom buildings 3 and 4. This is due to the hourly use of classroom building 4, whereas it has been found that classroom building 3 operates inefficiently, even though it has a similar hourly load to classroom buildings 1 and 2.

In the other section of substation 2, loads such as WWTP, CAFS, and air conditioning of floors 2 and 3 of the university wellness building are fed. Based on this analysis, the main building and the classroom buildings are of main interest for the energy review.

4.2.1. Analysis of past and current consumption of equipment in the main building

For the main building, Figure 6 shows the daily energy consumption of it without considering the air-conditioning system. These data

Table 3: Identification of the main building areas

Building	Department	Areas number
Main building	Human management psychology	1
	Academic registration	1
	Administrative and financial vice rectorate	3
	Marketing division and admissions department	1
	Men's and women's bathrooms	20
	Faculties	5
	Cazcoli hall	1
	Principal office	1
	Principal assistant	1
	Multimedia office printing services	1
	Labs	44
	Multimedia warehouse	1
	Systems room	6
	Young researchers room	1
	BVC hall	1
	Stage design warehouse	1
	Library	1
	Onda UAO coordination area	1
	Graduate studies management unit	1
	Cessa	1
	Contact centre	1
	Central institutional archives	1
	User services department	1
	Administrative direction labs	1
	Financial support for students	1
	Synapsis	1
	Project rooms	4
	Simulation rooms	4
	90 min newscast	1
	Conceptual design room	1
	Warehouse 4	1

UAO: Universidad autónoma de occidente

Figure 3: Energy matrix campus UAO

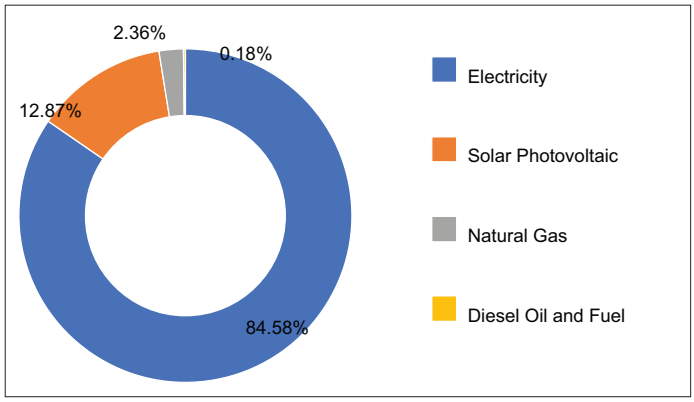


Figure 4: Campus Valle de Lili Compsuntion Since 2018-2022

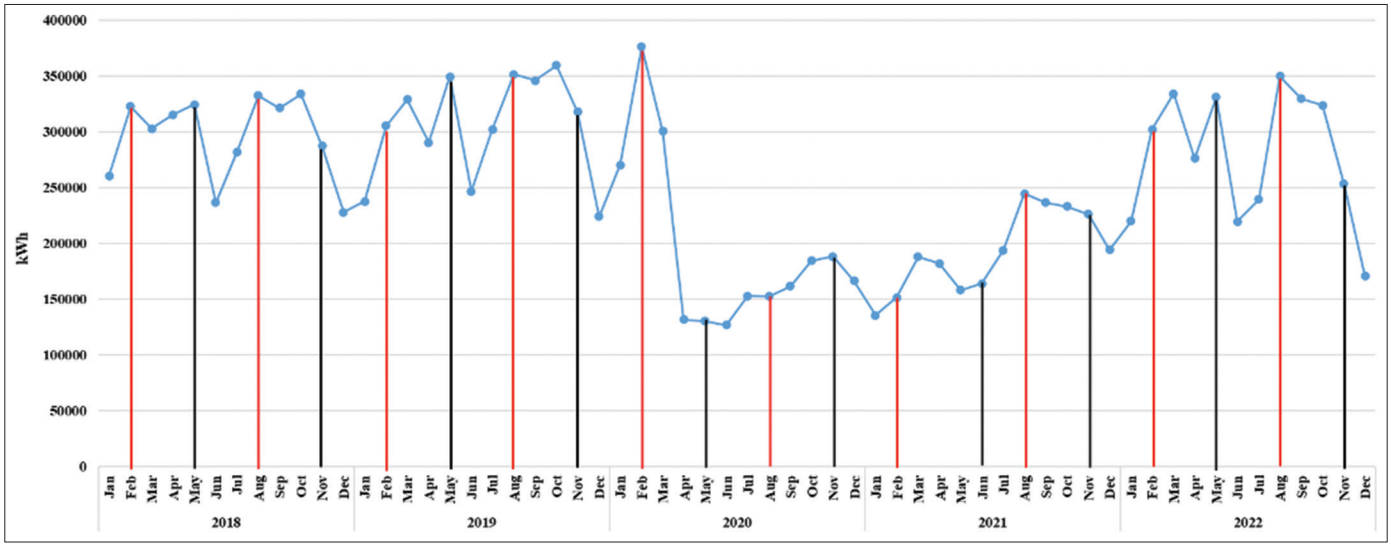
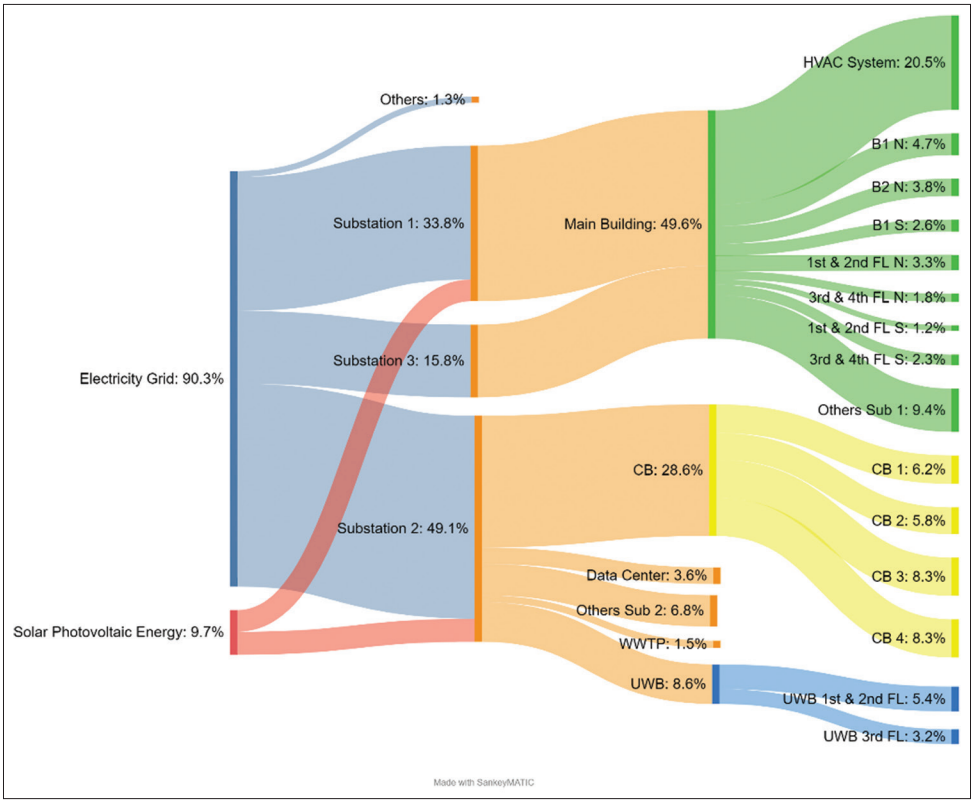


Figure 5: Sankey diagram



are presented for months in which sufficient data is available for analysis. This information is for grid-supplied electricity and does not consider energy consumption from solar photovoltaic generation. The graph shows that the main building consumes an average of 4 MWh during the months of the academic term. It also shows that consumption in the main building at weekends could be lower since the administrative offices work from Monday to Friday.

During academic months, weekday consumption averages 4 MWh, Saturday 2,5 MWh, and Sunday 1,3 MWh. In January, weekday consumption averages 2,9 MWh, Saturday 1,8 MWh, and Sunday 3,3 MWh. For June and July, weekday consumption averaged 4 MWh, Saturday 2 MWh, and Sunday 1.1 MWh.

Figure 7 shows differences in the main building energy consumption. January energy consumption (Figure 7a) is lower than in June (Figure 7c), despite both being academic holidays. Figure 7b shows the energy demand in the main building during May, an academic term. It can be concluded that the consumption profile has the same behavior regardless of the periods.

Figure 6: Energy consumption per day in main building

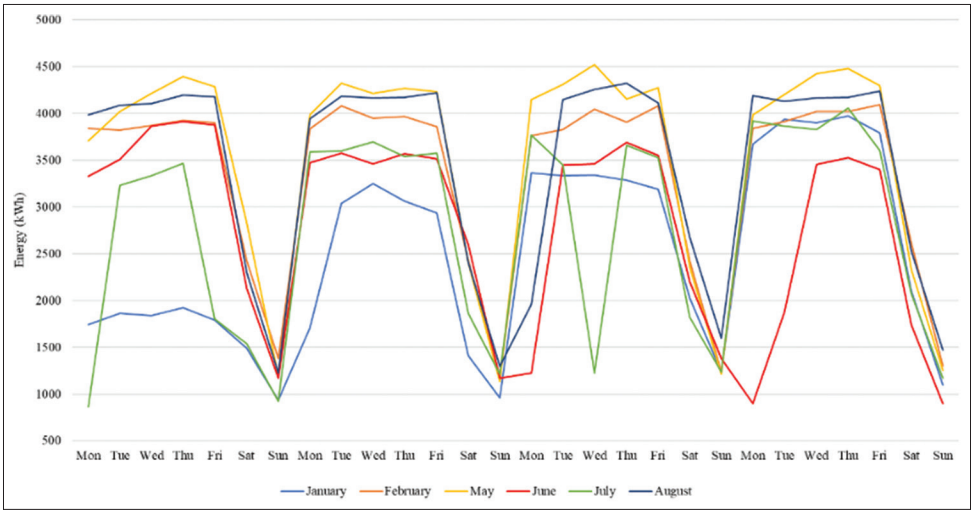
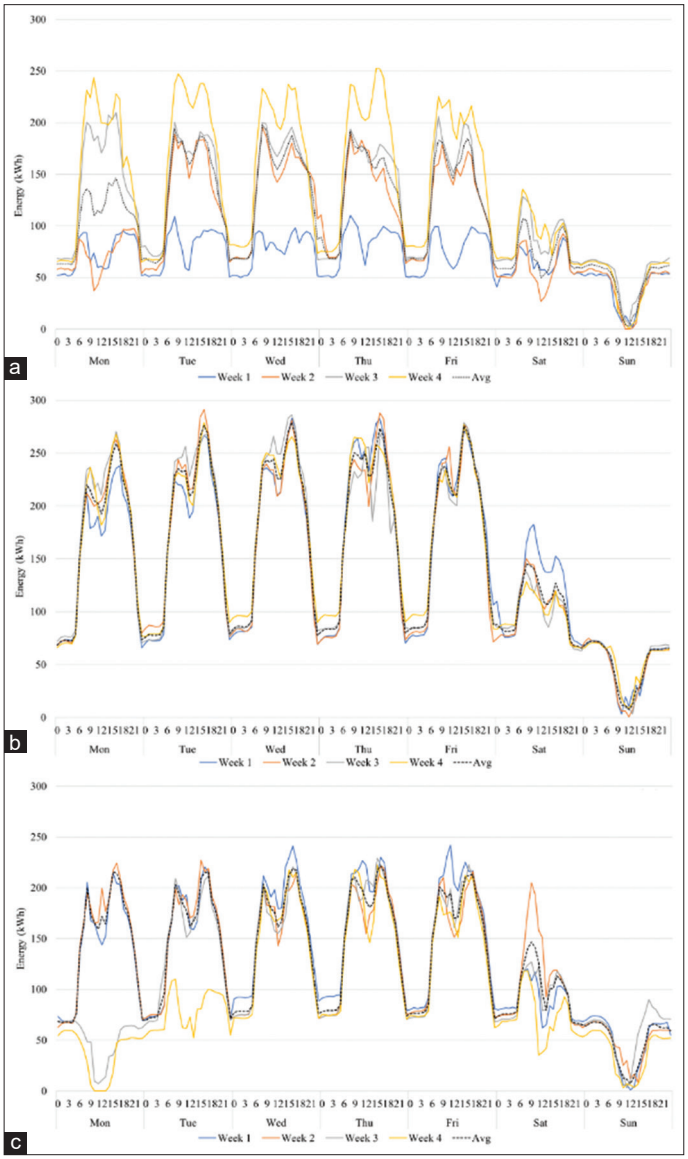


Figure 7: Energy demand in the main building by month: (a) January, (b) May, (c) June



Energy consumption increases from 6:00 AM and decreases at noon (12:00 PM to 2:00 PM). Between 3:00 PM and 4:00 PM, the highest consumption of the day occurs on weekdays. Saturday has the highest consumption between 8:00 AM and 9:00 AM, where consumption decreases at noon. Energy consumption on Saturdays is reduced by 40% compared to weekdays. On Sunday, energy consumption is reduced by an average of 66% compared to weekdays, and energy consumption from the grid decreases due to solar photovoltaic power generation. Consumption drops to zero or close to zero on holidays. In periods when consumption decreases in the middle of the day, it is due to the generation of solar photovoltaic energy in the buildings.

4.2.2. Analysis of past and current consumption of the main building air-conditioning system

Figure 8 shows the daily energy consumption of loads of the main building's air-conditioning system: Chiller 1, Chiller 2, condensing-evaporating pumps, and chilled water distribution pump, during months in which sufficient data is available. In the academic months, the average weekly consumption is 2,3 MWh, on Saturday 1,3 MWh, and on Sunday 31,2 kWh. For January, the average weekly consumption is 1547,1 kWh, on Saturday 235,3 kWh, and on Sunday 28,1 kWh.

Figure 9a shows that during the 1st week of January, the energy consumption of the air conditioning system is less than half of the consumption commonly presented. After this week, the consumption is almost constant from 6:00 AM to 6:00 PM. During the last week of January, when classes start, the consumption per day increases since the operation of this system extends its schedule until 8:00 PM.

Figure 9b presents the consumption profile of the days in February. This month's hourly consumption is like January after its 1st week. The difference is that the February schedule is from 6:00 AM to 8:00 PM from Monday to Friday and from 7:00 AM to 4:00 PM on Saturdays. The average hourly consumption during operating hours is 157 kWh from Monday to Friday and 132 kWh on Saturdays. There is little potential for savings from this substation, as the consumption gap is low when the system operates.

4.2.3. Analysis of current and past consumption classroom buildings

Figure 10 illustrates the daily consumption of the four classroom buildings (CB) for several weeks. Figure 10a shows the consumption in the months of the academic period (February, May, and August). It is observed that consumption is higher for classroom buildings 3 and 4 compared to classrooms 1 and 2. Figure 10b shows the consumption in the holiday period in the middle of the year (June and July). The consumption decreases mainly in classroom building 4. In the other classroom buildings, the consumption decreases to a minor extent.

Figure 11 presents the hourly consumption of the four classroom buildings for several weeks; the colors have the same interpretation as in Figure 10. Figure 11a shows the consumption pattern in the months of the academic period (February, May, and August). Classroom building 4 has the highest consumption during class hours, and classroom building 3 has the highest consumption during non-class hours. Figure 11b shows the consumption pattern in the mid-year holidays (June and July). Classroom building 3 has the highest consumption between 8:00 AM and 5:00 PM when the solar panels generate energy and the energy consumption from the grid decreases. Each classroom building has a solar panel system with the same installed capacity.

4.2.4. Analysis of current consumption per building and consumption gaps

Table 4 provides the average daily energy consumption of each building on the university campus by period. The building with the highest consumption is the main building, as it is the building that offers the largest number of services. This table allows us to observe the reduction in energy consumption during the academic and holiday

Figure 8: Energy consumption per day in substation 3

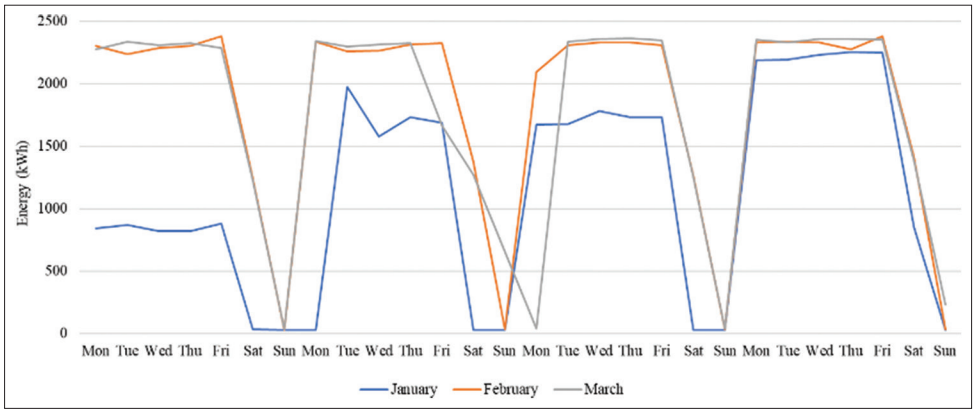


Figure 9: (a) Energy demand January (or non-academic period) in sub 3 (b) Energy demand February (or academic period) in sub 3

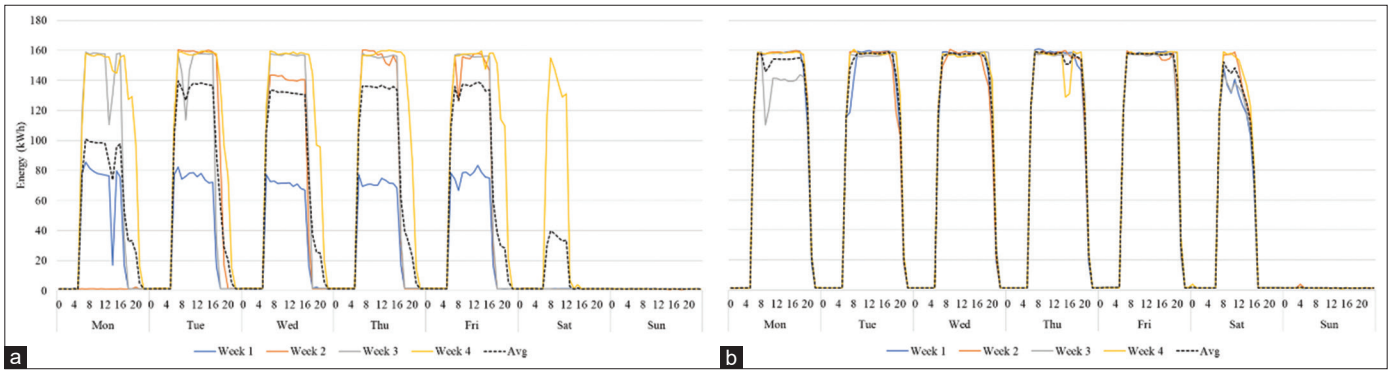
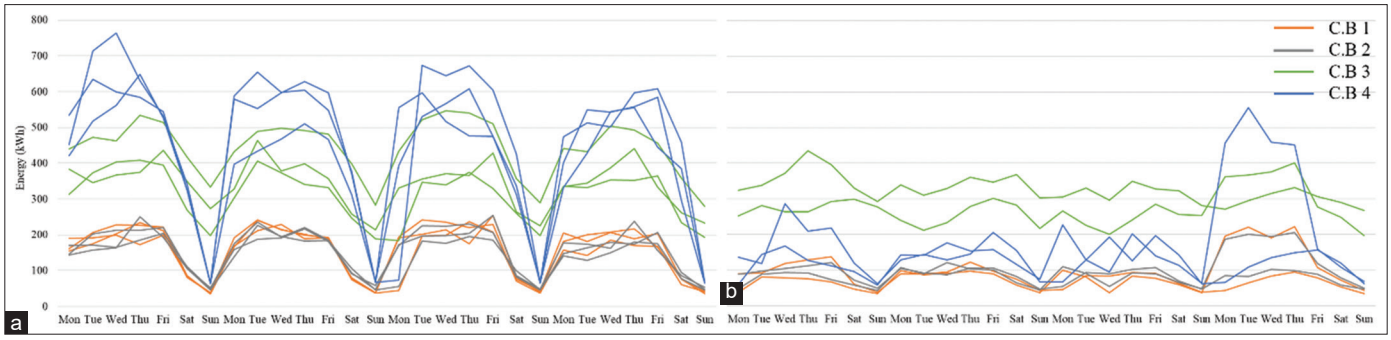


Figure 10: (a) Energy consumption per day in academic term (b) Energy consumption per day in non-academy term



periods, where there is a difference in consumption since the campus offers far fewer services during the holiday period. Therefore, this gives us a base value of energy consumption in each period that has a difference in the hourly usage behavior of the buildings.

Table 4: Average monthly consumption of each building per day

Building	Academic term (kWh/day)	Holiday term (kWh/day)
Main building	3449.8	3024.2
CB1	159.7	74.9
CB2	157.5	83.3
CB3	378.8	292.6
CB4	419.7	133.3
Wellness university building	1049.2	877.8

CB: Classroom building

Table 5 shows consumption gaps in each building for the academic and holiday periods. This table shows that the consumption gaps for the main building can be between 1 kWh and 529 kWh per day during the holiday period. During the academic period, the gaps are between 8 and 481 kWh, which indicates that energy consumption can be reduced to minimize the consumption gap. In the case of classroom building 1, the consumption gap on weekdays during holidays is 2 to 70 kWh, and 1 to 62 kWh, for weekdays during the academic period, indicating that the main building has a higher saving potential than the classroom building. It should also be noted that the minimum consumption of the main building on holiday is 9 kWh, and for classroom building 1 is 2 kWh.

4.3. Identification of SEU

Measurements were collected over time in the main and classroom buildings to identify the SEU. For the main building, Figure 12a

Table 5: Daily consumption gaps in university areas

Consumption energy gaps	Academic term (kWh)		Holiday term (kWh)	
	Weekdays	Weekends	Weekdays	Weekends
CB 1	1–62	1–15	2–70	1–17
CB 2	2–68	2–18	1–55	1–18
CB 3	1–206	3–152	39–171	15–85
CB 4	1–221	1–162	1–160	1–40
Main building	9–481	3–407	1–529	42–737
Main building air conditioning system	1–99	3–104	0	0

CB: Classroom building

Figure 11: (a) Energy demand in academic terms for classroom buildings (b) Energy demand in non-academic terms for classroom buildings (CB)

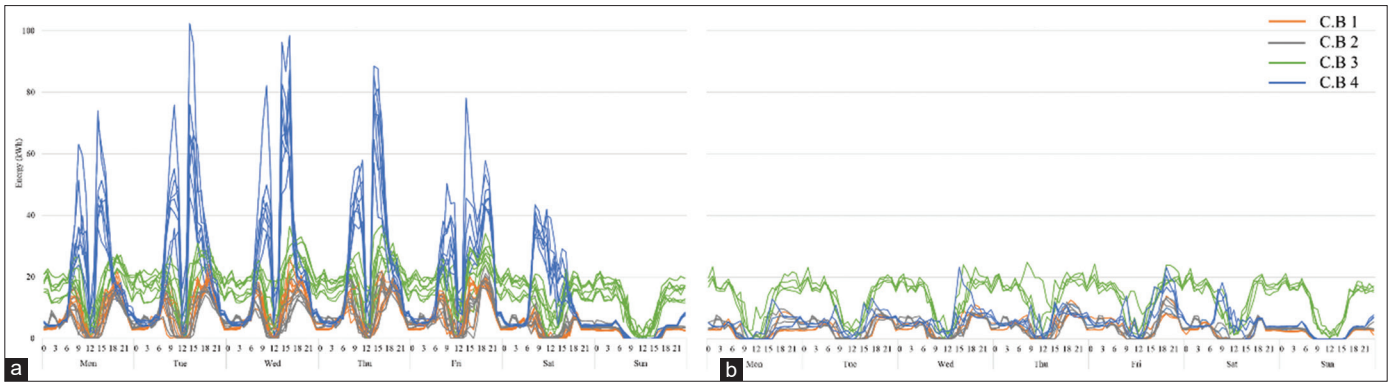
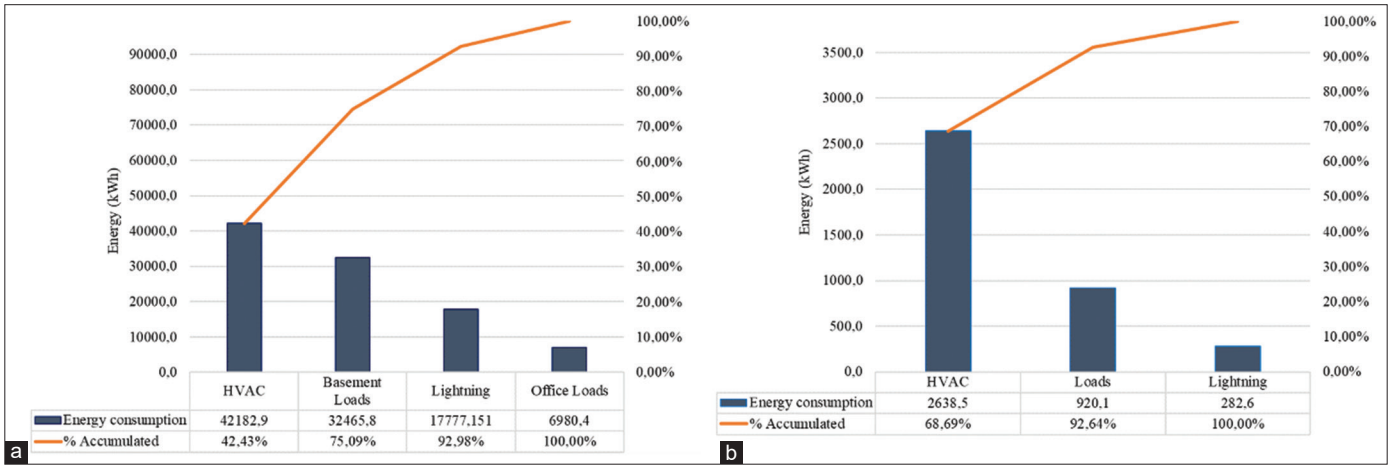


Figure 12: Pareto diagram (a) main building (b) classroom building



shows that the air-conditioning system and the basement equipment are the biggest energy consumers. The basement equipment includes computers, motors, 3D printers, the television studio, and equipment for different laboratories. The air-conditioning system consists of two chillers of 250 tons of refrigeration, water pumps, and air handlers. Figure 12b shows that the air conditioning system has the highest consumption for the classroom buildings, followed by the building loads, including the consumption of computers and projectors.

4.3.1. Identify relevant variables, responsible personnel, and energy performance for each SEU

Figure 13 shows an Ishikawa diagram showing the relevant variables that affect the energy consumption of each SEU, which, as can be seen, impacts the energy performance of the university campus.

Figures 14a and 14b show correlations between temperature and energy consumption of Chillers 1 and 2 of the air-conditioning system of the main building, according to the value of the coefficient of determination R2, the degree days (temperature difference between outside and inside) is not relevant in the consumption of this equipment. The correlation between hours of use and energy consumption for classroom building 1 is shown in Figure 14c, where the coefficients of determination indicate that the relationship between consumption and hours of use impacts energy consumption. Figure 14d presents the correlation between consumption and the number of students enrolled, where it is observed that the number of occupants affects the consumption of classroom building 1.

Table 6 shows the energy performance for each SEU of the campus UAO, divided by location and SEU. It shows that the equipment consuming the most is the air conditioning system in the main building, between the air handlers and the water-cooling systems, with an energy efficiency of only 40% and consumption of 51916,6 kWh/month. The remaining energy-intensive systems have an efficiency of approximately 70%, with the lightning in the main building having the highest consumption with 17,777 kWh/month. Table 6 also shows which area of the university is responsible for each system, which is responsible for the proper management of the use

Figure 13: Identification of relevant variables for each SEU on the campus UAO

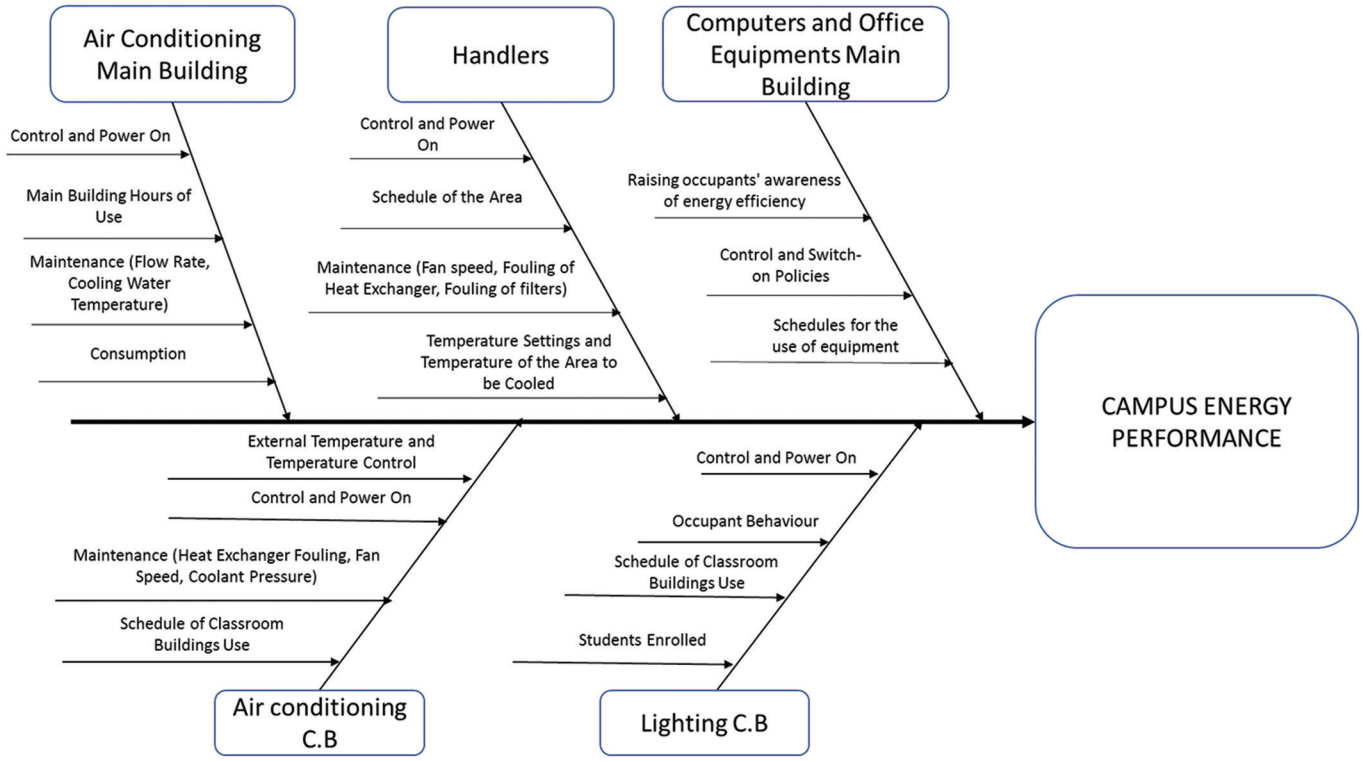


Table 6: Energy performance of significant energy uses (within the scope of the energy review)

SEU	Location	Responsible	Consumption (kWh/month)	Technology efficiency (%)	Schedule (h)
Air conditioning main building	Main building	Technical infrastructure coordination	42,182.9	40	13
Handlers	Main building	Protection and control	9733.7	30	13
Air conditioning CB 1	CB 1	Centre for welfare services solutions	10,554	70	11
Lightning main building	Main building	Protection and control	17,777.2	70	18
Lightning CB 1	CB 1	Protection and control, university community	1130.526	70	18

CB: Classroom building, SEU: Significant energy uses

of these systems following the recommendations made in the energy review.

4.3.2. Opportunities to improve energy performance at the campus UAO

This section presents estimations made to determine the savings in energy consumption that can be obtained from the analysis of the data resulting from the energy review.

Table 7 shows the proposed energy savings for the lightning system of the UAO campus, with three scenarios. A positive scenario assumes the lights are turned off 8 h daily, saving 1351 kWh/month. The second scenario is a neutral scenario, where the campus lights are turned off for 4 h, saving 676 kWh/month in consumption. Finally, a negative scenario, where the lightning is turned off for 1 h more, results in a very low saving of 169 kWh/month. Despite a very low energy saving, it is observed that energy saving is possible with the lightning system operating for 18 h/day.

Table 8 shows estimated energy savings under three scenarios. A positive one where 100% of the computers are switched off for half an hour, assuming that the HEI staff is on lunch break, saving 5276 kWh/month. Under this assumption, the reality is that the disparity in the lunch break of staff and occupants would not allow reaching this saving. In a neutral scenario, switching off 50% of the computers for half an hour daily would save 2639 kWh/month. This scenario is more achievable, and it is feasible if a culture of energy efficiency is adopted. More conservatively, in a negative scenario, if 10% of the computers were turned off for half an hour, with an estimated saving of 528 kWh/month.

Table 9 shows the energy saving proposals for the air conditioning system in the main building, as this is the equipment with the highest consumption in the whole campus UAO. The first recommendation is to achieve maximum equipment efficiency through adequate preventive and predictive maintenance, which could result in annual energy savings of 31938 kWh, which would be 7%. In addition, if the equipment is turned off half an hour before the currently scheduled time, 27000 kWh could be saved annually, representing a saving of 4%. If both recommendations are implemented, the total saving is 11%.

Table 10 shows savings opportunities for the SEU of the campus UAO, according to the neutral base scenario for lightning and computers and posing both proposals for the air conditioning system of the main building, a saving of 9718 kWh/month can be achieved, considering these recommendations, it can be saved USD 1396/month.

UPME emissions factor for Colombia is 0,126 ton CO_2eq/MWh (RESOLUCION No. 000320 de 2022 "Por La Cual Se Actualiza El Factor de Emisión Del Sistema Interconectado Nacional Del Año 2021 Para Inventarios de Emisiones de Gases de Efecto Invernadero (GEI) y Proyectos de Mitigación de GEI.," 2022). According to this factor, potential energy savings will reduce CO_2 emissions in 1,23 ton CO_2eq emissions, complying with national policies that seek to promote low-carbon development in the country, such as law 2169 of 2021 (LEY 2169 DE 2021, 2021), which establishes minimum targets and measures to achieve a neutral carbon footprint and to mitigate climate change.

Figure 14: (a) Energy consumption versus degree days Chiller 1. (b) energy consumption versus degree days Chiller 2. (c) time of use versus energy consumption CB 1. (d) Occupants' population versus energy consumption CB1

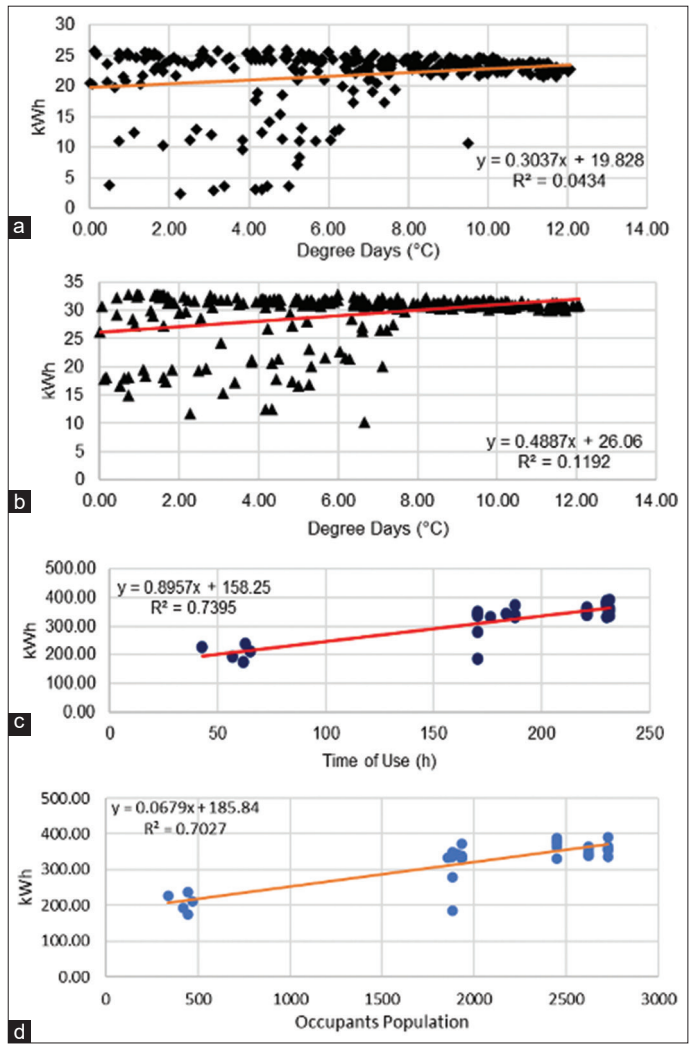


Table 7: Energy saving proposal for the lightning system

Recommendations	Scenarios		
	Positive	Neutral	Negative
Time (h)	8	4	1
Saving (kWh/day)	56.30	28.15	7.04
Saving (kWh/month)	1351	675	169

Table 8: Energy saving proposal for computer use

Recommendations	Scenarios		
	Positive	Neutral	Negative
Time (h)	0,5	0,5	0,5
Percentage computers on	100	50	10
Saving (kWh/day)	220	110	22
Saving (kWh/month)	5276	2639	528

Table 9: Proposals for energy savings in the air-conditioning system of the main building

Recommendations	Current scenario Monthly energy consumption (kWh)	Proposed scenario Monthly energy consumption (kWh)	Potential monthly energy savings (kWh)	Annual energy saving potential (kWh)	Cost savings (USD)
Efficient use of both chiller	34039	31377,84	2661,051	31938	4587
Turn the chiller off 30 min before the scheduled time	55390	53140,91	2250,00	27000	3878
Proposals 1 and 2	55390	48985,86	6405,05	76860	11,039

Table 10: Savings opportunities based on the neutral scenario for computers and lightning

Loads	Current consumption (kWh/month)	Consumption with the proposal (kWh/month)	Potential energy savings (kWh/month)	Potential financial savings (USD/month)
Air conditioning	55391	48985	6405	920
Computers	10552	7914	2638	379
Lightning	2533	1857	675	97

5. CONCLUSION

This paper presents a methodology for conducting an energy review under ISO 50001 in an HEI in Cali, Colombia. First, the use and consumption of energy are analyzed based on measurement. Then, significant energy uses, and their personnel were identified, relevant variables and energy performance were determined and opportunities for improvement were established. From this, it was determined that the air conditioning system could have an energy saving of 11%, representing a saving of 58938 kWh per year.

It was also found that the lighting system can save 675 kWh per month, and computers can save 2638 kWh per month, which with a monthly saving of the air conditioning system of 6405 kWh/month gives a total of 9718 kWh/month with a saving of USD 1412/month., which represents energy savings of 14.2%. Based on potential energy savings, CO_2 reduction emissions were estimated to have a 1.23 ton CO_{2eq} emissions saving for consciousness about energy performance in the HEI.

To design and implement an EnMS, coupled with the institution's policies and offers a vision of its energy performance, to adopt corrective actions that lead to an improvement in energy performance, contributing to the energy transition and sustainability of the country. It also contributes to the sustainable campus program being developed at the HEI. Thus, this methodology can be taken to create new energy policies for HEI and the building sector in the country.

Following the energy review, awareness campaigns should be conducted to communicate the EnMS. Also, training for staff interacting with the SEUs about the importance of implementing and maintaining an EnMS at the campus, considering the benefits to the environment and society.

REFERENCES

Aguilar, J., Garcès-Jimènez, A., Gallego-Salvador, N., Gutièrrez de Mesa, J.A., Gomez-Pulido, J.M., Garcìa-Tejedor, À.J. (2019), Autonomic management architecture for multi-HVAC systems in smart buildings. IEEE Access, 7, 123402-123415.

Amin, N., Shabbir, M.S., Song, H., Farrukh, M.U., Iqbal, S., Abbass, K. (2023), A step towards environmental mitigation: Do green technological innovation and institutional quality make a difference? Technological Forecasting and Social Change, 190, 122413.

Bianco, G., Bracco, S., Delfino, F., Gambelli, L., Robba, M., Rossi, M. (2020), A building energy management system based on an equivalent electric circuit model. Energies, 13(7), 13071689.

Castrillón Mendoza, R.D.P., González Hinestroza, A.J. (2018), Metodología Para la Planificación Energética a Partir de la Norma ISO 50001. Colombia: Autónoma de Occidente.

Castrillón-Mendoza, R., Rey-Hernández, J.M., Rey-Martínez, F.J. (2020), Industrial decarbonization by a new energy-baseline methodology. Case study. Sustainability, 12(5), 12051960.

Congreso de la República de Colombia. (2021), LEY 2099. Available from: https://www.funcionpublica.gov.co/eva/gestornormativo/norma_pdf.php?i=166326

Desideri, U., Leonardi, D., Arcioni, L., Sdringola, P. (2012), European project Educa-RUE: An example of energy efficiency paths in educational buildings. Applied Energy, 97, 384-395.

Diaz-Acevedo, J.A., Grisales-Noreña, L.F., Escobar, A. (2019), A method for estimating electricity consumption patterns of buildings to implement energy management systems. Journal of Building Engineering, 25, 100774.

El Majaty, S., Touzani, A., Kasseh, Y. (2022), Results and perspectives of the application of an energy management system based on ISO 50001 in administrative buildings-case of Morocco. Materials Today Proceedings, 74, 3233-3237.

Fichera, A., Volpe, R., Cutore, E. (2020), Energy performance measurement, monitoring and control for buildings of public organizations: Standardized practises compliant with the ISO 50001 and ISO 50006. Developments in the Built Environment, 4, 100024.

Fontalvo, L.A., Martínez-Marín, S., Jiménez-Barros, M., Parra-Negrete, K., Cortabarria-Castañeda, L., Ovallos-Gazabon, D. (2021), Modeling energy-efficient policies in educational buildings-a literature review. Procedia Computer Science, 198, 608-613.

Fuchs, H., Aghajanzadeh, A., Therkelsen, P. (2020), Identification of drivers, benefits, and challenges of ISO 50001 through case study content analysis. Energy Policy, 142, 111443.

Global Alliance for Buildings and Construction. (2021), 2021 Global Status Report for Buildings and Construction towards a Zero-emissions, Efficient and Resilient Buildings and Construction Sector. Available from: https://www.globalabc.org

González, A.J., Castrillón, R., Quispe, E.C. (2012), Energy Efficiency

Improvement in the Cement Industry through Energy Management. In: 2012 IEEE-IAS/PCA 54th Cement Industry Technical Conference.

Gul, M.S., Patidar, S. (2015), Understanding the energy consumption and occupancy of a multi-purpose academic building. Energy and Buildings, 87, 155-165.

IEA. (2022), World Energy Outlook 2022. Available from: https://www.iea.org/t&c

Instituto Colombiano de Normas Técnicas y Certificación (ICONTEC). (2019), NTC-ISO 50001:2019, Sistemas de gestión de la energía. Requisitos con orientación para su uso. Editada por el ICONTEC, Bogotá, D.C., Colombia.

International Standards Organization (ISO). (2019), ISO 50001-Energy Management System Standard. Geneva: International Standards Organization.

Leal Filho, W., Salvia, A.L., Paço, A.D., Anholon, R., Gonçalves Quelhas, O.L., Rampasso, I.S., Ng, A., Balogun, A.L., Kondev, B., Brandli, L.L. (2019), A comparative study of approaches towards energy efficiency and renewable energy use at higher education institutions. Journal of Cleaner Production, 237, 117728.

Lee, D., Cheng, C.C. (2016), Energy savings by energy management systems: A review. Renewable and Sustainable Energy Reviews, 56, 760-777.

LEY 2169 DE 2021. (2021), Pub. L. No. 2169. Available from: https://acmineria.com.co/sitio/wp-content/uploads/2022/01/ley-n0002169-de-2021-1.pdf

Lo, K. (2013), Energy conservation in China's higher education institutions. Energy Policy, 56, 703-710.

Mariano-Hernández, D., Hernández-Callejo, L., Zorita-Lamadrid, A., Duque-Pérez, O., Santos García, F. (2021), A review of strategies for building energy management system: Model predictive control, demand side management, optimization, and fault detect and diagnosis. Journal of Building Engineering, 33, 101692.

Mohamed, O., Fakhoury, S., Aldalou, G., Almasri, G. (2022), Energy auditing and conservation for educational buildings: A case study on Princess Sumaya University for Technology. Process Integration and Optimization for Sustainability, 6, 901-920.

Müller, E., Poller, R., Hopf, H., Krones, M. (2013), Enabling energy management for planning energy-efficient factories. Procedia CIRP, 7, 622-627.

Nepal, R., Paija, N. (2019), A multivariate time series analysis of energy consumption, real output and pollutant emissions in a developing economy: New evidence from Nepal. Economic Modelling, 77, 164-173.

Ocampo Batlle, E.A., Escobar Palacio, J.C., Silva Lora, E.E., Martínez Reyes, A.M., Melian Moreno, M., Morejón, M.B. (2020), A methodology to estimate baseline energy use and quantify savings in electrical energy consumption in higher education institution buildings: Case study, Federal University of Itajubá (UNIFEI). Journal of Cleaner Production, 244, 118551.

Resolucion No. 000320 de 2022 "Por la cual se actualiza el factor de emisión del Sistema Interconectado Nacional del año 2021 para inventarios de emisiones de Gases de Efecto Invernadero (GEI) y proyectos de mitigación de GEI.," Pub. L. No. 000320 de 2022. (2022), Available from: https://www1.upme.gov.co/normatividad/320_2022.pdf

Sai Sachin, G., Surya, P., Gunalan, K. (2018), Smart Institutions using Energy Management System. In: 4th International Conference on Electrical Energy Systems (ICEES).

Shan, S., Cao, B., Wu, Z. (2019), Forecasting the short-term electricity consumption of building using a novel ensemble model. IEEE Access, 7, 88093-88106.

Subramanyam, V., Paramshivan, D., Kumar, A., Mondal, M.A.H. (2015), Using Sankey diagrams to map energy flow from primary fuel to end use. Energy Conversion and Management, 91, 342-352.

Tan, H., Chen, S., Shi, Q., Wang, L. (2014), Development of green campus in China. Journal of Cleaner Production, 64, 646-653.

UAO. (2016), Programa: "Campus Sostenible-Fase II." Available from: https://campussostenible.org/wp-content/uploads/2017/04/anexo-4-programa-campus-sostenible-fase-ll.pdf

Universidad Autonoma de Occidente. (2021), Reporte de Sostenibilidad 2021. Available from: https://campussostenible.org/wp-content/uploads/2022/10/reporte-sostenibilidad2021.pdf

Walpole, R.E., Myers, R.H., Myers, S.L., Ye, K. (2012), Probabilidad y Estadística Para Ingeniería y Ciencias. 9th ed. London: Pearson Education, Inc.

Yoshino, H., Hong, T., Nord, N. (2017), IEA EBC annex 53: Total energy use in buildings-analysis and evaluation methods. Energy and Buildings, 152, 124-136.

Yuan, J., Farnham, C., Emura, K. (2015), Development and application of a simple BEMS to measure energy consumption of buildings. Energy and Buildings, 109, 1-11.