

## Analysis of Electric Power Consumption and Proposals for Energy Sustainability for the University of Unicomfacauca (Colombia)

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**Abstract**— The negative effect caused by the degradation of nature and its ecosystems by the production of unbridled energy, drives in recent years the reduction of environmental impacts generated by high energy consumption through policies and proposals focused on the generation of rational energy. Although there are international laws and conventions in favor of energy sustainability, backed by international standards for energy management, such as ISO 50001, there is a lack of disclosure of cases of research studies focused on different entities that produce goods and services in countries developing. This paper presents the analysis of the electricity consumption of the University of Unicomfacauca in Popayán-Colombia, which leads to the generation of proposals for savings, energy efficiency and generation of photovoltaic energy for self-consumption; the first phase of the study consists in carrying out the energy inventory of the equipment and facilities; the second phase consists of the diagnosis, load inventory, macro consumption analysis and definition of energy saving and efficiency measures; the third phase involves the implementation of the proposed measures taking into account the cost benefit; the fourth phase, monitoring and evaluation of the measures implemented is carried out. The results show the model for the total monthly and annual electricity consumption, the energy analysis of the electrical system of the specified substations in maximum active power and apparent power, the load index and the electric power consumption; Likewise, the energy analysis of the lighting system and the viability of generating photovoltaic energy for self-consumption.

**Keywords**— energy consumption; energy efficiency; energy saving; ISO 50001; renewable energy; photovoltaic energy; electrical network analyzers; electrical substations; energy management.

### I. INTRODUCTION

Colombia is a country that enjoys a relatively rich energy matrix in both fossil fuels and renewable resources. Currently, the exploitation and production of 5290 Peta Joules (PJ) (E. Primary) according to the Colombian energy balance of 2017, it is broadly constituted in 93% of primary resources of fossil origin, approximately 4% of hydropower and 3% of biomass and waste [1], [2]. In the 2018 management report of the Energy Mining Planning Unit - UPME, Colombia exports approximately 69%, mainly in the form of mineral coal (approximately 94% of the produced representing 62% of energy exports) and oil (approximately 66% of the produced, representing 36% of energy exports), and uses 31% (1580 PJ demand E. Primary) of which, about 78% corresponds to fossil resources and 22% to renewable resources [3].

The economic development of Colombia demanded 1,219,827 Tera Joules (TJ) of final energy of which consumption of the energy belongs to the sectors the transportation (40.2%), industrial (28.9%) and residential (16.5%) sectors according to the latest Colombian energy

balance of 2018 [4]. The activity tertiary sector has a consumption close to 5%; although it is low, it presents significant opportunities to improve energy efficiency in segments such as commercial, public entities, educational institutions, hospitals and public lighting. For the Ministry of Mines and Energy -MME in the document Plan of action indicative of energy efficiency (2016 - 2021), this tertiary sector formed by the commercial, public and services subsectors, boosts the Colombian economy, as well as others in the world, showing in the last decades a greater participation so that at present, it constitutes about 60% of the Colombian Gross Domestic Product (GDP) and according to the most recent characterization study carried out by the Mining Planning Unit Energy of the year 2018, the primary energy sources used in this tertiary sector are electricity (9146 Gigawatt hours per year (GWh/year), natural gas (414 million m<sup>3</sup>/year) and Liquefied Petroleum Gas (LPG) (52 million kg/year), where the main uses of electricity are: lighting (31%), air conditioning (22.8%) and refrigeration (13.9%), the driving force (12.4%) and office equipment (8.8%) [5], [6].

According to this energy consumption data, different challenges and opportunities were found for proposals and studies in the economic sectors for Colombia country. These chances are oriented to the use of renewable energies and energy efficiency as a priority need for the transition of the current energy system, therefore, carry out research projects and studies in this area, generates significant contributions to the economy and culture for the energy consumption of Colombia. In consideration of this analysis, the tertiary sector, specifically in the education subsector, generates the favourable scenario for development responsibility and social impact projects. The implementation of renewable energy and energy sustainability projects, provides to primary education, secondary education, further education and higher education for being a leader in research and development for energy consumption and energy-saving campus plans.

The institution of higher education Unicomfauca, located geographically in the municipality of Popayán of the department of Cauca in Colombia, aware of its influential and vanguard role in the process of transforming the current energy system in the region from the academy, concerned about the energy consumption of its facilities and the feasibility of generating electricity through renewable energy for self-consumption, generates the right space to develop a project in the area of renewable energy and energy sustainability. It is noteworthy that the location of Unicomfauca in the historic colonial sector of the city of Popayán, has generated that its physical, architectural and technological infrastructure does not meet the current requirements focused on energy efficiency, energy-saving and limits the implementation of energy systems based on renewable sources; which establishes some parameters, requirements and challenges for the development of projects in this area of knowledge.

The purpose of this paper is to examine the electrical energy consumption of the Unicomfauca facilities, aimed at optimization, controlled and rational demand for electric energy that leads to the implementation of efficiency and energy-saving techniques, in accordance with the international standard ISO 50001, in order to propose an energy system based on photovoltaic energy for self-consumption in the University's electronics and automation laboratories.

## II. MATERIALS AND METHOD

Colombia has made a great effort by the state and the private sector over a long period of time for the structuring of the electrical system, it went from being a centralized, monopolistic and vertical integration system in the distribution, transmission and generation services, to a system with a fundamental change in the monopoly, allowing the participation of the private sector, the introduction of competition to the electricity sector and the separation of services and businesses of energy generation, distribution and transmission, leaving a role of regulator and supervisor to the state.

### A. Legal Context and Normative

The Colombian electricity system establishes a scheme that involves the entities that produce, transport and sell the

energy, as well as those who coordinate these activities; likewise, it includes the entities that establish the general policies and standards to deliver good quality products and services at a reasonable price and finally to the entities that ensure that all related actors comply with existing standards. Table I describes the general structure of the current electricity system discriminated by the responsible entities and the role of each of them in the Colombian electricity system.

TABLE I  
ORGANIZATION OF THE COLOMBIAN ELECTRICITY SECTOR

Entity	Function
Presidency of the republic Ministry of mines and energy (Minminas)	Direction
Ministry of mines and energy (Minminas) National planning department (DPN) Ministry of finance and public Credit	Sectorial politics
Congress of the republic	Legislation
Energy mining planning unit (UPME) Transmission advisory Committee (CAPT)	Planning
Energy and gas regulation commission (CREG)	Regulation
National dispatch center (CND) National operations council (CON) Administration of the commercial Exchange system (ASIC) Marketing advisory committee (CAC)	Operation and marketing
Superintendence of public services	Control and surveillance

Table II presents the legal context of renewable energy, energy efficiency and the electricity sector in Colombia.

TABLE II  
MAIN LAWS OF RENEWABLE ENERGIES AND ENERGY EFFICIENCY IN  
COLOMBIA

Politics	Description
Law 142 -143 of 1994	It establishes the regime and general guidelines for the provision of the domiciliary public service of electric energy and regime for the generation, interconnection, transmission, distribution and commercialization of electricity in the national territory [7],[8].
Law 629 of 2000 Law 697 of 2001 Law 788 of 2002	It establishes the approval and adherence to the Kyoto protocol of the united nations in convention on climate change, making renewable energy a strategic option for Colombia, it promotes the Rational and Efficient Use of Energy (URE) as a matter of National convenience [9]-[11].
Law 1215 of 2008 Law 1665 of 2013 Law 1715 of 2014	It establishes an income tax exemption on income derived from the sale of electric energy generated from agricultural waste, wind sources and biomass; the statute of the International Renewable Energy Agency (IRENA) is approved, which promotes the sustainable use of renewable energies and the development and use of unconventional energy sources is promoted [12]-[15].

### B. Energy Efficiency and Sustainability

As established in the indicative action plan for energy efficiency 2016 - 2021, A Reality and Opportunity for

Colombia [5]. Energy efficiency is considered a mechanism to ensure energy supply, since it is based on the adoption of new technologies and good consumption habits, in order to optimize the management and use of available energy resources, this increases national productivity and competitiveness as the main strategy to mitigate environmental impacts in the energy chain.

C. International Standard ISO 50001

The objective of ISO 50001 is to enable organizations to implement systems and processes necessary to improve the energy performance of the facilities, with the explicit intention of reducing greenhouse gas emissions and operating energy costs. Like all ISO management system standards, ISO 50001 is designed to be applied by any organization, whatever its size or activity, whether in the public or private sector, regardless of geographic location, this standard sets objectives to improve energy efficiency, this means that any organization, regardless of its current energy management domain, can apply ISO 50001 to establish a baseline and then improve it at a pace appropriate to its context and capabilities (Fig. 1) as stated in the Organization document International Standardization [16].

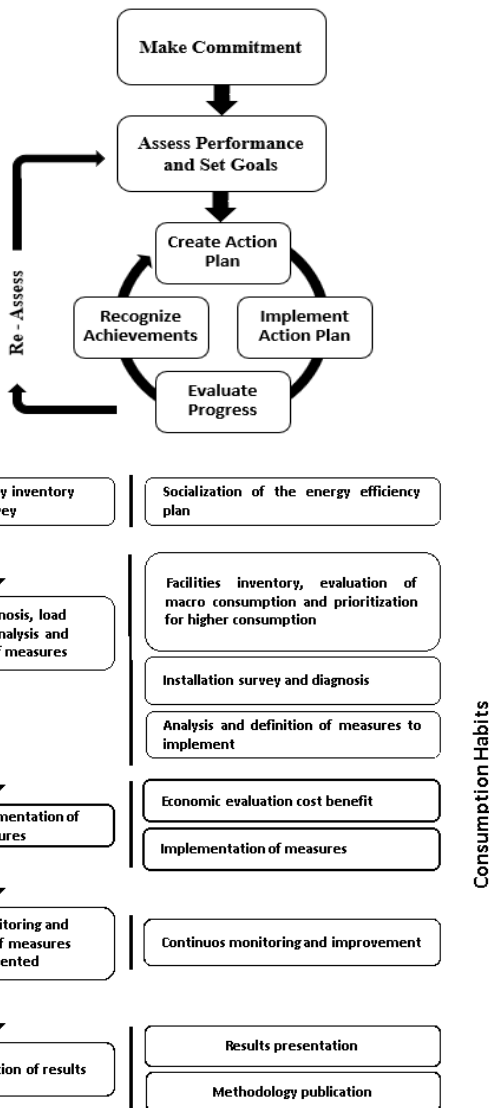


Fig. 1 Guide for the implementation of an energy efficiency plan

D. Geographical, Climatological and Meteorological References of Project Location

Colombia is located in the northwest corner of South America, is located between the magnificent Amazon rainforest, Panama, and the Pacific and Atlantic oceans are also crossed by the high Andes mountain range, which originates from a wide variety of climates and ecosystems. For its part, the department of Cauca, due to its location between the Central and Western mountain ranges, presents a variety of thermal floors that generate a variety of atmospheric and geographical conditions establishing a diversity of climates. While the municipality of Popayán, capital of the department of Cauca (Table III), is located to the southwest of Colombia and has an average temperature of 18 ° C to 19 ° C throughout the year and maximum temperatures in July, August, and September in hours noon [17].

TABLE III  
MOST RELEVANT GEOGRAPHICAL, WEATHER AND METEOROLOGICAL CHARACTERISTICS [18]

Characteristic	Department of Cauca	Municipality of Popayán
Location	North: between 00°58'54'' and 03°19'04'' north latitude. West: between 75°47'36'' and 77°57'05''.	North: 2 ° 27 ' West: 76 ° 37'18 " longitude.
Weather	It has warm weather; 19.24% of the area of the department, has a temperate climate 33.34%, a cold, 14.3%, freezing climate, 29.62%, and moorland 3.42%.	Enjoys the thermal floors and because of this its climate is warm and humid.
Global solar radiation	The average global horizontal solar irradiation received on the surface ranges from a maximum of between 3.5 and 4.0 kWh / m2 per day.	The sun shines about 4 hours a day in the rainy months; in the dry, the sunstroke is 1 less than 6 hours a day/day. The surface ranges from a maximum between 3.0 and 3.5 kWh / m2 per day.

Unicomfauca has as its principal domicile the city of Popayán, in the historic sector, on Calle 4 # 8-30 with coordinates 2 ° 26'34.8 "to the North and 76 ° 36'27.9" to the West, place, where management and administrative functions are centralized and higher education services, are provided at the undergraduate, postgraduate, continuing education and marketing levels. This headquarters is made up of four blocks distributed in block A (five floors), block B (five levels), block C (four levels) and block D (six levels). Table IV specifies the built area of Unicomfauca is 208588 m<sup>2</sup>, including external wellness spaces called Olympic Village and Pisoje recreational centre with an area of 198200 m<sup>2</sup>, this place is not located in the main headquarters of the historical town centre, therefore, these spaces will not be included in the project study, obtaining; as

a result, a study area of 10388 m<sup>2</sup> corresponding to the headquarters described above.

TABLE IV  
BUILT AREA OF UNICOMFACAUCA

Space	Area (m <sup>2</sup> )
Parking lot	1839
Circulation areas	1521
Administrative services	866
General services	206
Classrooms and teaching spaces	2900
Internal wellness services	417
External wellness spaces - Olympic sports villa	99500
External wellness spaces - PISOJÉ recreation center	98700
Sanitary services	519
Libraries	520
Systems	456
Workshops	40
Study rooms	200
Laboratories	705
Internal auditorium	199
Total	208588 m <sup>2</sup>

### III. RESULTS AND DISCUSSION

For Unicomfauca headquarters in Popayán, an analysis of the electrical energy consumption is carried out in a period between January 2015 and August 2019, based on the registration of billing periods by the Western Energy Company - CEO, company that provides the service of supply and sale of electricity; the annual monthly consumption, historical consumption, the general total consumption is determined month by month during the period of study time and the general annual total consumption, the consumption period cycle, the start and end of each calendar month are specified.

#### A. Total Electrical Energy Consumption Month by Month

In the period of study and analysis of the consumption of electrical energy, the general total consumption is determined month by month, by accumulating the monthly consumption of active energy and reactive energy; Unicomfauca, presents a monthly peak annual average in the months of May with an active energy of 24556 kWh and reactive energy of 4906 kVarh, June with an active energy of 25374 Kwh and reactive energy of 4800 kVarh, November with an active energy of 25311 Kwh and reactive energy of 4805 kVarh and December with an active energy of 25284 kWh and reactive energy of 4991 kVarh, Table V shows the behaviour of the accumulated active energy consumption and reactive energy of all months in the 2015-2019 time period (except the year of 2019 which is studied until August) and in Fig. 2, it is observed in detail the total annual consumption of monthly electrical energy, specifying active energy and reactive energy, it highlights the peaks in May, June, November and December generated by the activities of the end of the semester academic periods, where machines, equipment and tools are used, accompanied by extended hours in the areas such as laboratories, auditoriums and common areas, in addition to the development of dissemination events of entrepreneurship and research activities; furthermore, in the months of January, February,

July and August, there is a decrease in consumption generated by the holiday period. The consumptions present in these months are caused by the institution's maintenance activities, continuing academic education activities, academic levelling activities and the administrative and directive operation.

TABLE V  
AVERAGE ANNUAL ELECTRICITY CONSUMPTION (2015 – 2019)

Total Annual Electrical Energy Consumption (2015 – 2019)				
Month	Active Energy (kWh)	Reactive Energy (kVarh)	Average Active Energy (kWh)	Average Reactive Energy (kVarh)
January	77529	16914	15506	3383
February	67968	13196	13594	2639
March	110911	20039	22182	4008
April	119054	24014	23811	4803
May	122781	24530	24556	4906
June	126871	23998	25374	4800
July	91252	17549	18250	3510
August	84636	20354	16927	4071
September	92301	18850	23075	4713
October	99500	18838	24875	4710
November	101243	19221	25311	4805
December	101136	19963	25284	4991

The reactive energy shows a fluctuating behavior due to the different periods of use of industrial machines, ovens, motors, air conditioners and old electrical installations among others; the variations presented in the historical behavior of consumption, in the months of April and October of 2018, are generated by the availability of four new laboratories called: Manufacturing processes, Electromechanics, ICT Audiovisuals, and Quality, which were equipped with equipment and specialized industrial machinery, in addition to the activities carried out for their conditioning.

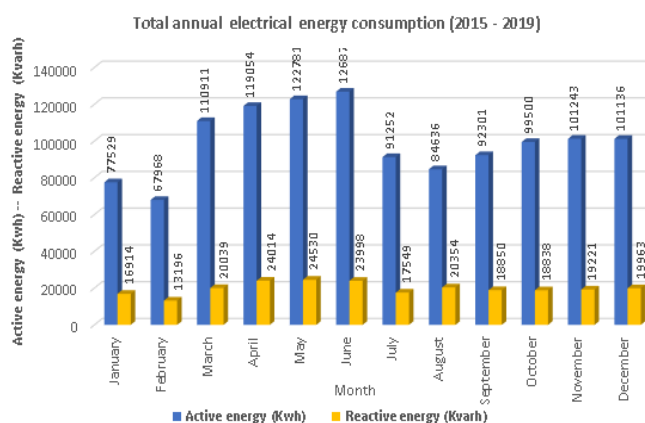


Fig. 2 Total energy consumption month by month (2015 – 2019)

#### B. General Annual Electrical Energy Consumption

The historical study and analysis of electrical energy consumption, shows an annual increase, taking as a reference the year of preliminary study, a percentage increase of electrical energy consumption between the years of 2014 - 2015 of 0.58%, between the years of 2015 - 2016

of 2.05%, between the years 2016 - 2017 of 3.53% and for the years 2017 - 2018 of 4.03% until the month of August, the increase in electrical energy consumption in the years 2018-2019 are referred to a population increase of students of Unicomfauca and the behavior described above in the general total consumption section month by month.

The aspect of costs related to the consumption of electric energy, the Western Energy Company- CEO, governed by the Commission for Energy and Gas Regulation –CREG, establishes a rate of fluctuating service provision costs, according to the energy situation of the country, specifically in the department, the ownership of the assets, the class of the service and the level of tension, Fig 3 shows the mathematical relationship to determine the rate of payment of electricity, considering the factors of generation, transmission, distribution, marketing margin, recognized losses and restrictions.

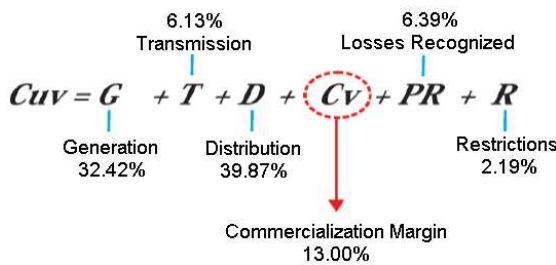


Fig. 3 Mathematical relationship to determine the rate of payment of electricity [19]

Therefore, the average unit costs of providing the service (Cuv = \$ / kWh) for the period of analysis and study are: for the year 2015 it has an annual average of Cuv of \$ 375.33 / kWh, the year 2016 it has an annual average of Cuv of \$ 378.08 / kWh, the year 2017 has an annual average of Cuv of \$ 382.08 / kWh, the year 2018 has an annual average of Cuv of \$ 351.16 / kWh and for the year 2019 it has an average Cuv of \$ 373.56 / kWh until August. In total billing costs, 2016 stands out due to the high annual average Cuv, generating a monetary cost of € 29015.96, it is specified that the annual total to pay only involves the consumption of active and reactive energy, factors in which it can be effected through measures to save electrical energy, the cost of street lighting is provided to complement the study information.

Table VI and Fig. 4 show the behavior of electricity consumption in the 2015-2019 study period.

TABLE VI  
ANNUAL ELECTRICITY ENERGY CONSUMPTION COSTS

Annual Electrical Energy Consumption (2015 – 2019)				
Year	Active Energy (kWh)	Reactive Energy (kVarh)	Street Lighting (€)	Total (€)
2015	250008	50808	581	28228.6
2016	251468	52092	567.9	28174.9
2017	256647	54195	581.2	29015.9
2018	265709	48767	547.9	27565
2019	171349	31604	366.6	18437.2

### C. Energy Analysis of the Power System

The technical analysis of the Unicomfauca energy system is carried out through a study of the two 300 kVA

and 150 kVA substations to determine the active power and the apparent power with electrical network analyzers; subsequently, the apparent power demanded by each substation is determined through a load study to establish the power required by each of them; to determine the load profiles registered by the Western Energy Company - CEO, are installed electrical network analyzers simultaneously, in each of the substations to establish the electrical parameters of line overload and operation.

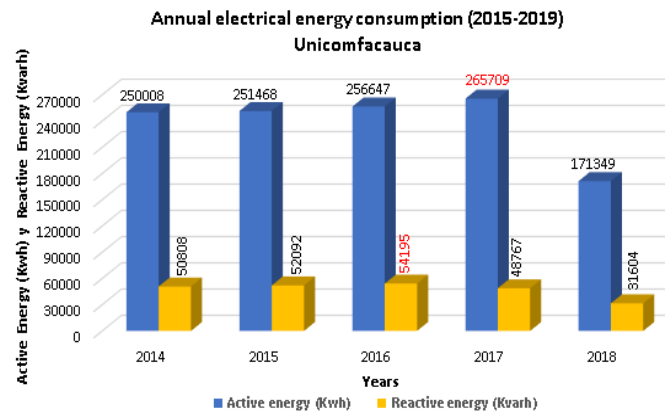


Fig. 4 Annual electrical energy consumption (2015 – 2019)

The graphs generated by the electrical network analyzers allow the identification of peaks, valleys and the average of the maximum active power (Fig. 5) and the maximum apparent power (Fig. 6) of each of the supply lines of the three phase power system of the substations in 24 hours, stipulated by the hours of operation on the day and night workday during a period between June 15 and 25, 2018.

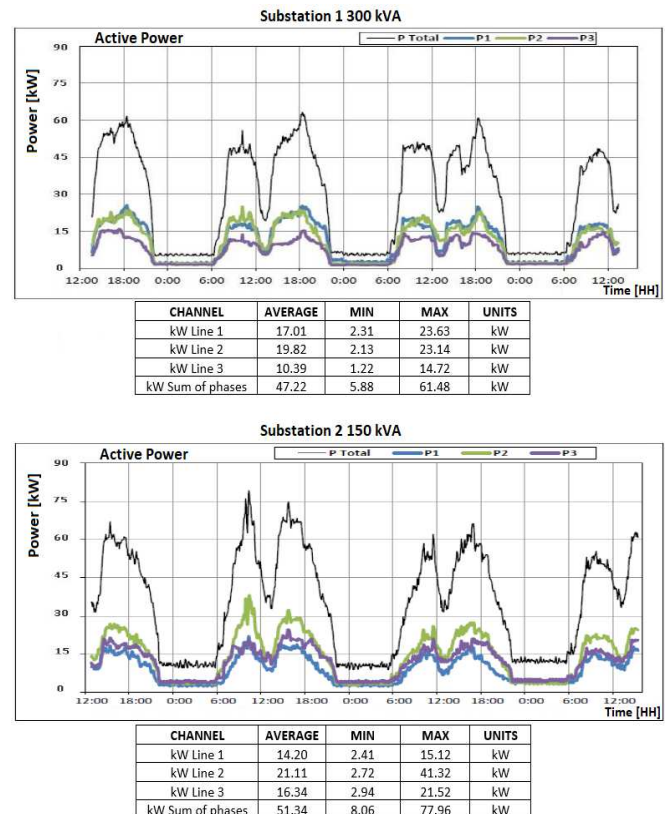


Fig. 5 Maximum active power in substation 1 (300 kVA) and substation 2 (150 kVA)



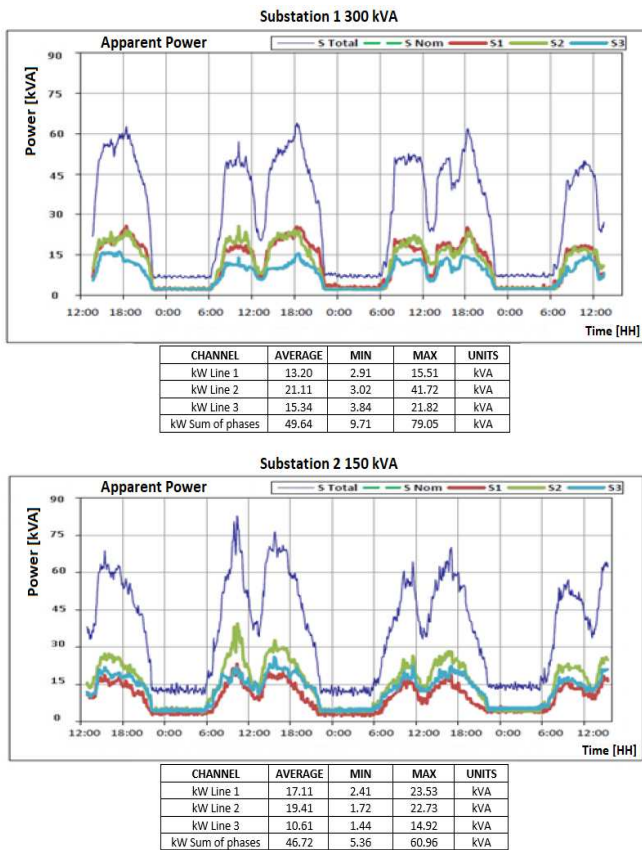


Fig. 6 Maximum apparent power in substation 1 (300 kVA) and substation 2 (150 kVA)

In substation 1, the maximum active power of 6148 kW and a maximum apparent power of 6096 kW are obtained, the average of the sum of the phases in the active power is 4722 kW, and the average of the sum of the phases in power apparent is 4672 kW; in substation 2 the maximum active power is 7796 kW and a maximum apparent power of 7905 kW, the average of the sum of the phases in the active power is 5134 kW, and the average of the sum of the phases in the apparent power is 4964 kW, the results described above are the basis for determining the apparent power demanded by the substations.

According to the measurements made and the information provided by the network analyzers installed in both substations and a reserve factor of 1.20, the calculation of apparent power for each substation is performed, as evidenced in Eq. (1) and Table VII.

$$S_{Total} = S_{max} \times Reserve\ factor \quad (1)$$

TABLE VII  
APPARENT POWER DEMANDED IN SUBSTATION 1 AND SUBSTATION 2

Substation1 (300kVA)	Substation 150 (kVA)
$S_{Total} = (60.96\ Kva) \times (1.20)$	$S_{Total} = (79.05\ Kva) \times (1.20)$
$S_{Total} = 73.08\ Kva$	$S_{Total} = 94.86\ Kva$

#### D. Electrical Energy Consumption of Equipment and Machines

The electrical consumption information of the electronic, electrical equipment, machines, luminaires, and tools present in Unicomfauca is collected, for this process, formats for

the collection of information and energy inventory are designed, in general terms the formats classify the information in location, groups, area, and equipment, identified in technical visits to the headquarters of the University; having as reference the study of the history of electrical energy consumption, the average energy consumption of 21562 kWh is obtained during the last five years and compared with the data obtained from the study of equipment and machines that consume electricity, an estimated value of 20493 kWh is projected monthly, and the correlation of the results is determined, the present variation is due to the data on the utilization factor of the equipment and machines, a subjective factor according to the Unicomfauca schedules.

To classify the results of the areas, equipment, consumer groups and perform the analysis of the information obtained in the collection formats, the annual average of electrical energy consumption of 21562 kWh is taken for the study period of 2015 – 2019; 2781 energy consuming electrical and electronic equipment / machines / fixed elements were identified, characterized in groups as shown in Fig. 7.

Electrical energy consumption percentage by groups - Unicomfauca

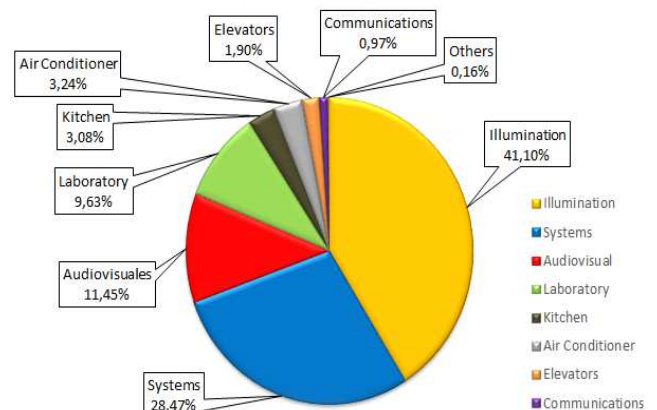


Fig. 7 Characterization of electrical energy consumption by groups

41.10% of the total electrical energy consumption belongs to the lighting system, 28.47% to the systems equipment, 11.45% to the audiovisual equipment and the remaining 18.98% correspond to the equipment of laboratory, air conditioner, communications, elevators and others, the previous results in units of active energy consumed correspond to 8862 kWh for the lighting system, 6138 kWh for systems equipment, 2468 kWh for audiovisual equipment and the remaining 4092, 5 kWh for laboratory equipment, air conditioner, communications, elevators and others, as shown in Fig. 8.

Consumption by area is marked by a higher demand for energy in administrative offices with 26% equivalent to 5175 kWh of active energy consumed, followed by common areas with 25.10% equivalent to 5196 kWh of active energy consumed as the library, cafeteria, parking lot, terrace among others, the halls, system rooms and recording studios demand 23.60% equivalent to 5080 kWh of active energy consumed, laboratories 12.50% equivalent to 2695 kWh of active energy consumed, and finally corridors and bathrooms whose consumption is represented by lighting

and hand dryers demand 10% equivalent to 2156 kWh of active energy consumed.

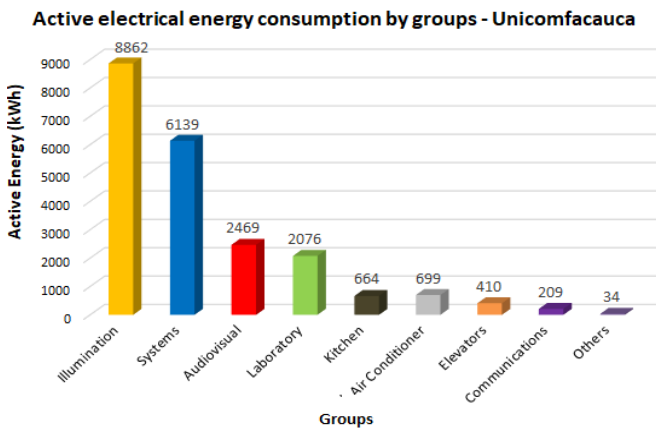


Fig. 8 Active energy consumption by groups

The active energy consumption by blocks is characterized by Block A with a consumption of 3644 kWh, Block B with a consumption of 6296 kWh, Block C consumption of 2458 kWh, Block D with a consumption of 8905 kWh and commercial areas with a consumption of 259 kWh, in Fig. 9, the block with the highest energy consumption is D, which represents 41.30% of the total consumption, followed by Block B with 29.20%.

Electrical energy consumption percentage by blocks - Unicomfacauca

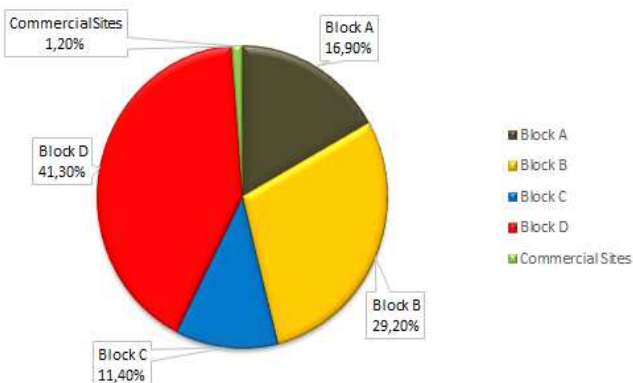


Fig. 9 Characterization of electrical energy consumption by blocks

### E. Energy Analysis of the Lighting System

The assessments of lighting levels were carried out using lux meters which determine the level of lighting in the work areas, to establish the relationship with the indications issued by the Ministry of Mines and Energy through the Technical Lighting Regulation and Street lighting - RETILAP [20]. Also, 15 points are determined as a guideline measurement matrix, distributed evenly in the study areas.

The measurement of the lighting levels in the Unicomfacauca facilities, show that 43.64% of the areas are below the lighting levels necessary to operate within the technical regulation due to the poor state of the luminaires, powers and lumens inadequate and the lack of natural light entry, 19.13% are overlighting due in large part to the entry of natural lighting, which suggests the installation of curtains or window protection and only 37.23% they are in normal operating conditions. According to the analysis performed

above, on 43.64% of the areas that have low lighting, 45.24% corresponds to offices where staff spend about 8 hours a day, a result that is detrimental to their visual health, 30,08% correspond to classrooms, computer rooms and laboratories, while 24.68% correspond to common areas such as hallways, bathrooms and parking. As for the areas of the classroom, 55% are with low lighting levels while 25% are over lighting, which indicates that only 20% of classrooms meet the levels of adequate lighting.

In Unicomfacauca, there are nine different types of light emitters between bulbs and lamps belonging to the lighting system of the institution; these were inventoried and characterized by the formats for collecting lighting information and inventories. Table VIII shows the summary of the characterization of the types of luminaires with their respective percentage of participation in active energy consumption.

TABLE VIII

SUMMARY OF CHARACTERIZATION OF LUMINAIRE TYPES AND THEIR ACTIVE ENERGY CONSUMPTION

Unicomfacauca Lighting Summary			
Luminary Type	Quantity Determined Units	% Type Lighting	Active Energy Consumed (kWh)
Light bulb 4P 26 W	430	13.86	1228
Light bulb U 13 W	79	2.55	226
Light bulb 13 W	17	0.55	49
Light bulb standard	26	0.84	74
Light bulb 3U 15 W	131	4.22	374
Lamp emergency	28	0.90	80
Lamp t8 17 W	1466	47.24	4187
Lamp t8 32 W	923	29.75	2636
Reflector	3	0.10	9
Total	3103	100	8862

Taking into account the analysis and the previous results of energy consumed, for the lighting system there is an active energy consumption of 8862 kWh which is divided according to the type of luminaire as described below: the 17 W T8 lamp consumes 47.24% equivalent to one energy 4187 kWh active, 29.75% equivalent to an active energy of 2636 kWh is consumed by the 32 W T8 lamp luminaire, 13.86% equivalent to an active 1228 kWh energy It is consumed by the 4P 26W Bulb type luminaire and the 9.12% equivalent to an active energy of 811 kWh remaining is consumed by the U 13W bulb, 13W spiral bulb, reflector, standard bulb and emergency lamps.

### F. Energy Efficiency and Savings Measures

The current lighting system of Unicomfacauca is formed by a park of fluorescent lamps of power between 13-15-17-32 Watt and their respective ballasts, incandescent bulbs and their different variations in U and spiral; an analysis and diagnosis of electrical energy consumption for the lighting system are carried out, this presents an active energy consumption of 8862 kWh equivalent to 41.10% of the total energy consumed, the replacement of the current luminaire park to Led luminaires is proposed as described in Fig. 10.

It is observed that when replacing the luminaire park with 1024 led tubes, 41 led bulbs, 401 led panels, 9 led reflectors

and considering a 52% saving factor with respect to the energy consumption of lighting of Unicomfacauca, a potential energy saving is generated annual consumed by lighting of 55299 kWh for an annual energy consumption of 200659 kWh compared to the annual average energy consumption of 255958 kWh, the savings in monetary terms is reflected in the annual billing costs of € 6102,5 , the investment is projected to be amortized in approximately 24 months taking into account the savings potential estimated above.





	Quantity 1204 Led Lamps	( 12 - 15 ) W	<b>Average Annual Active Energy and Average Cost</b>		
	Quantity 41 Led Bulbs		Average Active Energy (kWh)	Total Pay (COP)	Total Pay (€)
	Quantity 401 Led Panels		255958	\$ 93439999	€ 28246,4
	Quantity 9 Led Reflectors		<b>Potential Savings by Replacement of Luminaries</b>		
			Active Energy with Savings Factor (kWh)	Total Pay with Savings Factor (COP)	Total Pay with Savings Factor (€)
			200659	\$ 73252599	€ 22143,8

Fig. 10 Potential savings by replacing luminaires with LED technology

The load studies carried out previously generated the proposal of the technical-economic viability to disconnect all the electrical infrastructure associated with substation 2, suppressing its connections and transferring the 150 kVA transformer load to the transformer of Substation 1 of 300 kVA, concentrating the entire university load on a single transformer, corresponding to substation 1. The main reasons that motivate to evaluate this action are: optimize the use of electrical infrastructure, facilitate maintenance in a single substation, reduce energy consumption through savings in losses in a low-tech and underutilized transformer, in addition to articulating in the general framework of the rational use of energy. According to the measurements made in the field and to the load profile obtained by the Western Energy Company - CEO, it can be concluded that the total load demanded by the university is approximately 108 kVA, of the total 450 kVA available in substations, for which the total overload of lines with respect to what is installed is very low and is of the order of 24% evidenced in the load analysis previously described in this paper. Individually the measurements in the two existing substations also show an overload of lines with low values of the order of 21.12% in Substation 1 of 300 kVA and 44.16% in Substation 2 of 150 kVA, which also allows concluding that the substations have good reserve backup.

Therefore, it can be concluded that it is technically feasible to unify loads of the university in a single substation (that of 300 kVA), to reduce the overall losses valued in the section called energy analysis of the power system, the calculations of the cost of the monthly losses in the 150 kVA transformer, assuming a cost of kWh of € 0,140 , generate monthly losses in energy of 1282,53 kWh equivalent to € 179.9 in the cost of billing, as evidenced in Eq. (2)-(4).

$$P_{cu}P_{dem} = P_{cu}P_{nom} \times \left(\frac{P_{dem}}{P_{nom}}\right)^2 \quad (2)$$

$$P_{total} = P_o + P_{cu} \quad (3)$$

$$Cost_{Etal} = \left(P_{total} \times \#Hours \times \# \frac{Days}{Month}\right) \times Cost_{kWh} \quad (4)$$

In summary, an investment of € 22392,22 is required, disregarding the effect of the variation in the cost of energy, the monthly savings due to loss losses would be around € 179,867, represented in the decrease in the cost of the monthly invoice. According to the previous rate and the monthly value of the saving, a saving of € 2028,9 per year in electrical energy billing is generated, concluding that the time to recover the investment is more than five years.

### G. Power Generation for Self-Consumption

According to previous studies, the generation of photovoltaic energy for self-consumption in Unicomfacauca is feasible, aimed at satisfying the demand for electrical energy of the Electronic and Automatic laboratories; for the design of the photovoltaic system, an analysis of the load profile of the laboratories is carried out, the variables and climatological and meteorological characteristics of the location are determined; subsequently, the system's elements are selected according to the consumption requirements of the laboratories and finally a projection of economic viability of the photovoltaic system is carried out.

Table IX shows the number of types of equipment, its powers and daily, monthly and annual electrical energy consumption; the profile of total electrical energy consumption of the laboratories is 7356 kWh annual equivalent to 613 kWh per month (Table X), the equipment called cellular manufacturing band and robotic arm which include industrial electronic and electrical elements is highlighted.

TABLE IX  
POWER CONSUMPTION OF EQUIPMENT IN THE ELECTRONIC AND AUTOMATIC LABORATORY

<b>Summary of Equipment in the Electronic and Automatic Laboratory</b>			
<b>Equipment Name</b>	<b>Quantity (Units)</b>	<b>Power (W)</b>	<b>Total Power (W)</b>
Router wireless	1	18	18
Router wireless	1	20	20
Lamp T4 32 W	18	41	738
Lamp T8 32 W	18	41	738
Manufacturing station Band drilling	1	1500	1500
Manufacturing station robotic arm	1	800	800
Printer Qbex	1	120	120
Computer desktop Dell	10	184	1840
Computer desktop HP	7	184	1288
Computer desktop Compaq	3	184	522

The availability of solar energy for the Unicomfacauca headquarters, with geographical location 2°26'34.7"N 76°36'27.5"W and altitude 1725 m above sea level, is verified using the Meteororm 7.1 database [21], on the average monthly daily values of solar radiation in a horizontal plane, it is calculated that the average daily solar radiation per month in the horizontal plane, is observed in Fig. 11.



TABLE X  
ELECTRICAL ENERGY CONSUMPTION OF EQUIPMENT IN THE ELECTRONIC AND AUTOMATIC LABORATORY

Summary of Equipment in the Electronic and Automatic Laboratory				
Equipment Name	Use (hours)	Daily Energy (Wh)	Monthly Energy (kWh)	Annual Energy (kWh)
Router wireless	24	432	9.1	108.9
Router wireless	24	480	10.1	121
Lamp T4 32 W	5	3690	77.5	929.9
Lamp T8 32 W	5	3690	77.5	929.9
Manufacturing station Band drilling	0.5	750	15.8	189
Manufacturing station robotic arm	0.5	400	8.4	100
Printer Qbox	0.5	60	1.3	15.1
Computer desktop Dell	5	9200	193.2	2318.4
Computer desktop HP	6	7728	162.3	1947.5
Computer desktop Compaq	5	2760	58	695.5
Total	75.5	29190	613	7356

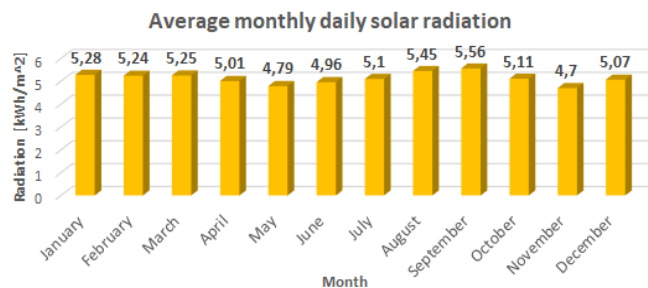


Fig. 11 Average monthly annual radiation on the horizontal plane [kWh / m<sup>2</sup>]

The technical characteristics of the photovoltaic system for self-consumption are detailed in Table XI, 20 solar modules of 320 W with an area of 39.40 m<sup>2</sup> and an MPPT control kit are proposed; these generate a total power of 6400 kW and a total annual energy 7500 kWh. The specifications listed above and Fig. 12 shows the energy data produced by the proposed system.

TABLE XI  
TECHNICAL CHARACTERISTICS OF THE PHOTOVOLTAIC SYSTEM

General Data	
Characteristic	Specifications
Module positioning	Coplanar to surfaces
Support structure	Fixed
Module tilt	35°
Module orientation (Azimut)	180°
Annual solar radiation in the module plane	1563.78 kWh/m <sup>2</sup>
Number of available surfaces	1
Total area available	154.20 m <sup>2</sup>
Total area used	154.20 m <sup>2</sup>
Total potential	6400 kW
Total annual energy	7500.28 kWh
Characteristic	Specifications
Module	
Product – model	YGE-U 1500
Total numbers of modules	20
Total area of the modules	39.40 m <sup>2</sup>
Inverter	
Product – model	PVI 6.0
Total number	1
Inverter sizing (between 70% -120%)	93.75%
Phase type	Three phases

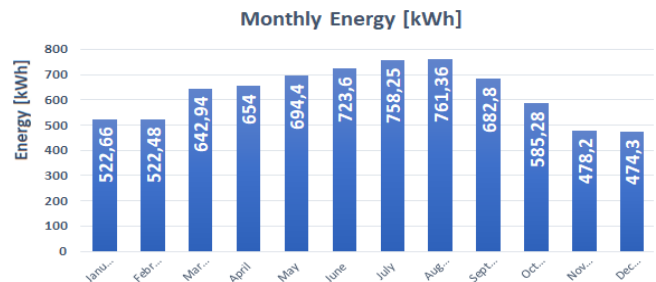


Fig. 12 Monthly energy produced by SFV LAB Unicomfauca

The positioning of the 20 solar modules will be carried out in the joint terraces of the Unicomfauca block C and D with an area of 39.40 m<sup>2</sup> as shown in Fig. 13.

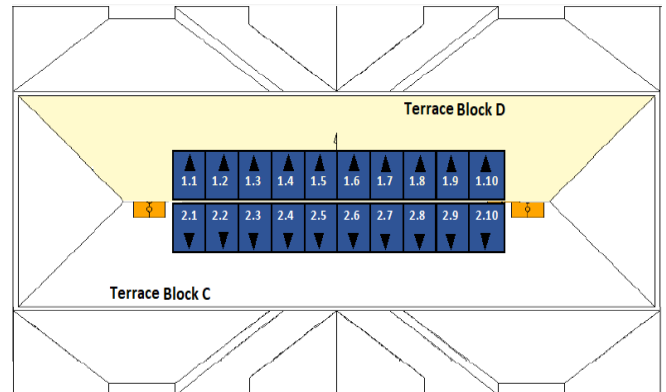


Fig. 13 Positioning of solar panels - Unicomfauca

To estimate the costs of the proposal of the self-consumption photovoltaic system to meet the demand for the consumption of electric power of 7500.3 kWh, with a total power of 6400 kW, the equipment costs are estimated (Table XI), involving the items associated with construction works, technical expenses, among others, obtaining a total cost of € 6151.1, as shown in Fig. 14.

Installation summary		Installation costs		
Total annual energy [kWh]	7500,28	Works cost [€/kW]	833,00	[€] 5331,20
Total power [kW]	6400	Technical expenses [%]	6,00	[€] 319,87
Total number of modules	20	Installation cost, transport to the site		500,00
Total number of inverters	1	Other expenses		
			<b>Total cost [€]</b>	<b>6151,07</b>

Fig. 14 Economic viability - Unicomfauca

#### IV. CONCLUSIONS

The analysis of the electrical energy consumption of the Unicomfauca campus, based on the energy review phase in accordance with ISO 50001, shows an annual average monthly electrical energy consumption for the 2015-2019 period of 21562 kWh of which 41,10% of electrical energy consumption belongs to the lighting system, 28,47% to systems equipment and 11,45% to audiovisual equipment, groups of equipment with significant savings potential through the implementation of measures of saving, efficient use of energy and replacement of lighting system technology and implementation of activities aimed at good consumption habits by Unicomfauca staff. With the above, an estimated annual electrical energy saving 39% of current annual consumption is achieved.

The energy efficiency study carried out on the campus lighting system of the Unicomfauca University, based on

the review phase of the lighting system according to ISO 50001 and the RETILAP public lighting and lighting technical regulation, show a savings potential of 4519 kWh in the annual monthly electrical energy consumption by the lighting group considering a 52% savings factor over the annual monthly consumption of 8862 kWh, equivalent to 41.10% of the total monthly energy consumed; too, there is evidence of a potential for improving the technical performance of the current lighting system, impacting the comfort of Unicomfauca personnel, due to the results in the lighting measurements, obtaining that only 37.23% of the facilities are located in normal lighting conditions, that is to say that 62.77% of the areas do not comply, of which 43.64% have low lighting levels, and 19.13% are over illuminated.

According to the measurements made in the field and the load profile obtained in the energy analysis of the Unicomfauca power system, it is concluded that the total load demanded by the University is approximately 167.94 kVA, of the total 450 kVA available in substations, for which the total overload of lines concerning the installed is very low and is of the order of 37.32%, individually the measurements in the two existing substations also show a loading capacity, with low values, of the order of 24.36% in substation 1 of 300 kVA and 63.24% in substation 2 of 150 kVA, which also allows concluding that the substations have functional reserve capacity. Therefore, the study carried out and considering the reserve values of the substations, the engineering technical feasibility can be concluded to unify the total loads of the University in the 300 kVA substation, in order to reduce the overall losses; if the loads are unified in the 300 kVA Substation, it still has a good technical reserve margin, calculated at 62.68% of the total transformer capacity, which can be considered for projects to expand the university infrastructure.

The studies carried out in Unicomfauca give viability of energy generation for self-consumption for a demand of electrical energy of 7500.3 kWh based on photovoltaic panels in the laboratories of industrial electronics and automation, this result allows directing the actions towards the global guidelines of energy use renewable, efficiency and energy saving, involving applied research studies with social impact in the region.

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