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Electrical Energy Audit of University Buildings: Case Study at Universidad San Francisco de Quito

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A mis padres el motor de mi vida, gracias por siempre estar conmigo, por nunca dejar de creer en mí, por darme su apoyo y amor incondicional; gracias por enseñarme a perseverar hasta alcanzar mis sueños. A mi tutor Diego Benítez por su importante guía y ayuda.

RESUMEN

Este documento se centra en el análisis del rendimiento energético de las áreas clave dentro de los edificios de la universidad, con el fin de identificar equipos potenciales y acciones que ofrecen una gran esperanza para mejoras energéticas. Se utilizó un analizador de potencia industrial para las mediciones relacionadas con la potencia y la recopilación de datos durante dos períodos: uno durante las actividades normales de la universidad y otro durante las vacaciones. Luego se analizaron los datos para determinar las horas de alta demanda y los efectos del factor de potencia de cargas individuales, además se realizaron pruebas manuales de "ON-OFF" para identificar los equipos que más contribuyen a la demanda máxima. Finalmente, las recomendaciones se hicieron en términos de los equipos que ofrencen un mayor potencial para un ahorro energético en un futuro cercano.

Palabras clave: auditoria energética, consumo de energía, eficiencia energética, política de gestión energética, factor de potencia, edificios no domésticos.

ABSTRACT

This paper focus on the analysis of the energy performance of key areas within university buildings, in order to identify potential equipment and actions that offer significant hope for saving energy improvements. An industrial power analyzer was used for power related measurements and data collection during two periods: one during university's normal activities and one during a vacation break. Data were then analyzed to determinate the hours of high demand, and the power factor effects of individual loads, additionally different manual ``ON-OFF" were made to identify the equipment that more contribute to peak demand. Finally, recommendations were made in terms of the equipment that offer most potential for improved energy savings in the near future.

Key words: building commissioning, energy consumption, energy efficiency, energy management policy, power factor, non-domestic buildings.

TABLA DE CONTENIDO

Electrical Energy Audit of University Buildings: Case Study at Universidad San Francisco de Quito

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***Abstract*—This paper focus on the analysis of the energy performance of key areas within university buildings, in order to identify potential equipment and actions that offer significant hope for saving energy improvements. An industrial power analyzer was used for power related measurements and data collection during two periods: one during university’s normal activities and one during a vacation break. Data were then analyzed to determinate the hours of high demand, and the power factor effects of individual loads, additionally different manual “ON-OFF” were made to identify the equipment that more contribute to peak demand. Finally, recommendations were made in terms of the equipment that offer most potential for improved energy savings in the near future.**

***Keywords*—building commissioning, energy consumption, energy efficiency, energy management policy, power factor, non-domestic buildings.**

I. Introduction

Nowadays, increasing energy performance and reducing carbon emissions are becoming important issues for both financial and environmental reasons [1]. Therefore, understanding the energy performance of university buildings is essential for applying energy saving strategies and to promote environmental awareness to reduce carbon footprint. In such sense, University San Francisco de Quito (USFQ) in Quito, Ecuador, has implemented several programs related to the identification of high energy consumption areas around its campus and the enforcement of actions to reduce it, several of such actions have allowed USFQ to achieve the “Environmental Distinction” from the Municipality of Quito for three consecutive years (2015, 2016, and 2017) [3].

In previous studies [1], [2], it was identified that one of the major problems for energy efficiency interventions specially in the higher education sector is the lack of clarity related to energy demand and consumption issues. In such sense, this paper focus on the detailed analysis of the energy performance of key areas within university buildings, in order to identify potential equipment and actions that offer significant hope for improvements.

A. Case Study Building

The power distribution system of USFQ is shown in Fig. 1, as it can be seen there are two main distribution panels after the transformers, Panel 1 supply most of the university buildings such as: Newton, Galileo, Einstein, Davinci, Epicurus, Cicero; all these buildings have most of the classrooms, lecture theaters and professor’s offices. Panel 1 also supply some of the restaurants in campus; six out of the eight existing HVAC (Heating, ventilation and Air Conditioning) systems in the university are also connected to this panel. Whereas Panel 2 supply the Library (3 floors levels, a lecture theater, and a photocopy and printing store facility) and the installations of the College of Hospitality, Culinary Arts and Tourism (CHAT) including main Kitchens and Office areas.

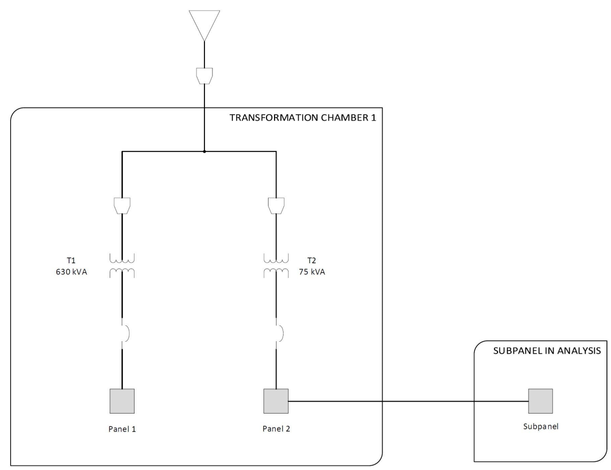

Fig. 1. Unifilar diagram of Transformation Chamber 1.

In previous studies [4], two areas of high energy consumption were identified in the University electrical distribution around campus, 5% of all energy consumption came from the HVAC equipment located in the Main Library (Area 1) and 8% from the Kitchens (Area 2). Electrical corrections were made in the main distribution panels and some actions like Light Bulbs replacement by more efficient LED lights, more control and proper maintenance of HVAC systems, were taken for saving energy and improving the efficiency of the Refrigeration Rooms (Panel 1) and Air Conditioners (Panel 2) [4]. For Panel 1, these actions provide favorable results. However, for distribution Panel 2, it was not possible to implement relevant saving strategies, since due to legacy electrical installations, the identification of loads was not possible. Therefore, a new sub-panel was installed derived from Panel 2 on July 2017 in order to improve the load distribution. This allowed to distinguish and identify most of the equipment connected to the distribution Panel 2.

The aim of this study was to investigate the energy consumption of the loads connected to this new sub-panel and to analyze their electrical behavior in order to implement further energy saving strategies. Table I shows the load distribution of this sub-panel under study.

TABLE I
LOAD DISTRIBUTION DETAILS (SUB-PANEL OF PANEL 2).

Measurement Areas	Circuit Breakers
Induction Experimental Stove	175 A
Electric Oven	125 A
Air Conditioner 1	125 A
Air Conditioner 2	125 A
Dishwasher	100 A
CHAT Offices	60 A
Kitchen Offices	50 A
Cold Rooms	50 A
Photocopy Room	40 A
CHAT Classrooms	40 A

B. Power Factor Analysis

In the study of loads of an electrical system there are very important parameters that should be analyzed. Among them is the power factor which "gives a measure of how effective the real power utilization in the system is. It also represents a measure of distortion of the line voltage and the line current and phase shift between them. Then, the power factor is given by the ratio of the average power and the apparent power" [5], as described by (1).

$$\text{Power Factor (PF)} = \frac{\text{Average Power (W)}}{\text{Apparent Power(VA)}} \tag{1}$$

Power factor (PF) is measured in a scale from 0 to 1. If this factor is lower than 1, the electric company must generate more energy for supplying power to the circuit load. Then, the cost of generation and distribution rise, producing additional fees [6]. For Empresa Electrica Quito, who is the Electrical power supplier in Quito, if the factor goes under 0.92, there are additional fees that are charged in the monthly bill. The Penalty for Low Power Factor (P_{LPF}) is calculate using (2), where the "Penalty Factor" is obtained using (3) [17].

$$P_{LPF} = \text{(Penalty Factor)} \times \text{(Initial Electricity Bill)} \tag{2}$$

$$\text{Penalty Factor} = \frac{0.92}{\text{PF Registered}} - 1 \tag{3}$$

Although the average PF was above 0.92 in the university's utility meter data and the monthly bill did not include penalties due to LPF, it is important to analyze what happens with the PF of individual loads, since focused actions can be implemented to reduce LPF effects, such as increased draw currents and the associated excessive heat generated that may damage or shorten equipment life [8], [9].

As shown in Table I, the HVAC systems have the highest circuit protection breaker, indicating therefore that their Power consumption may be significant as their operation is permanent throughout the day. Thus, it is important to deepen in their operation and understanding of the contribution they have in the total consumption. There are four basic components in an air conditioning systems, which also allow four different sequential processes: compression, condensation, expansion and evaporation [7]. In previous studies it was demonstrated that HVAC represents about 40% of energy consumption in most buildings [10].

II. METHODOLOGY

The methodology used for this study was as follows:

1) Collect quantitative energy data for chosen areas within the distribution panel of a building.
2) Use interviews with key actors to clarify activities and equipment within these areas in terms of their function and time of use.
3) Compare building performance under period of full and low activities within the university in order to identify where significant improvements can be made.
4) Carry out an energy assessment of major loads within the building to identify the reasons behind observed energy performance.

To collect quantitative energy related data an Industrial Power Analyzer (FLUKE 435 Power Quality Analyzer) was used. To analyze the three-phase system, the study focused on the following electrical parameters: voltage, current, power, power consumption and power factor. The analyzer was used as a "Logger" which allowed to collect the aforementioned electrical data parameters during a month, in weekly periods. High resolution measurements (30 sec sampling) were also used in order to try to identify individual power transitions due to equipment operation. Fig. 2 shows a picture of the setup used.

Two major measurement campaigns were carried out. The first measurement stage (Stage 1) was performed under normal University operations. To obtain the measurement with full loads, data were recorded during the normal academic period from February 16 to March 14, 2018. While the second measurement stage (Stage 2) was performed during a half-semester break from March 26 to April 1, 2018 in a week when the university was on vacation. Although the university kept most of its activities on hold during this week, the only days where they completely ceased were from Thursday, March 29 to Sunday, April 1, 2018.

While the FLUKE 435 recorded the data, an introspective investigation was also made for each of the equipment connected to the Sub-panel, according to the size of its circuit breakers. Since the circuit breakers corresponding to the industrial kitchen equipment presented high values, an interview was conducted with the persons in charge of the University's kitchen and bakery in order to understand the

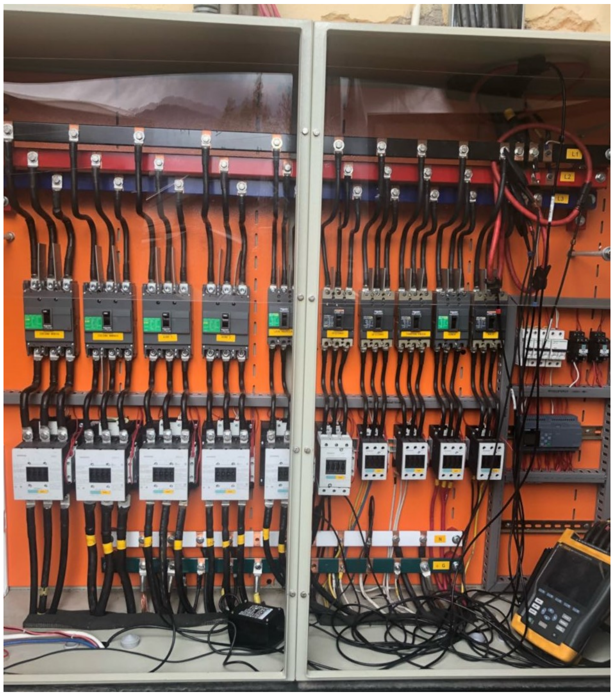

Fig. 2. Equipment Setup inside the Sub-Panel under study.

use that is normally given to such equipment. Subsequently, an investigation was also made with those in charge of the programming and maintenance of the HVAC systems. Additionally, manual “ON” and “OFF” tests were performed on the kitchen equipment, to identify if any of them produced peaks in demand.

III. Results

A. Stage 1

From the data collected with the Industrial Power Analyzer, one of the most outstanding parameters was the PF. During the Stage 1 measurement period it was detected that, in several hours there were values lower than 0.92. The lowest value was 0.58 recorded on Tuesday February 27, 2018 at 7:30 AM, as shown in Fig.3.

Analyzing the entire measurement period, the lowest PF were generated between 6:40 AM and 7:30 AM. This is the time when the activities of the library begin, which produces the simultaneous operation of the air conditioners. This was verified with the personnel in charge of the programming of these equipment, who confirmed that the air conditioners are normally turned “ON” between 7:00 AM and 8:00 AM, depending on the temperature of the library, and then to go “OFF” between 6:00 PM and 7:00 PM.

On the other hand, the total power consumption for the analysis period indicated that power peaks occurred between 12:00 PM and 5:00 PM as illustrated in Fig 4. It is important to clarify that similar patterns were observed from Monday to Friday, when there is normal activity in the university. Fig. 5 shows the total power consumption of March 12, 2018. Power consumption peaks occurred between 12:23 PM and 02:34 PM. The highest peak was 79.3 kW at 1:25 PM.

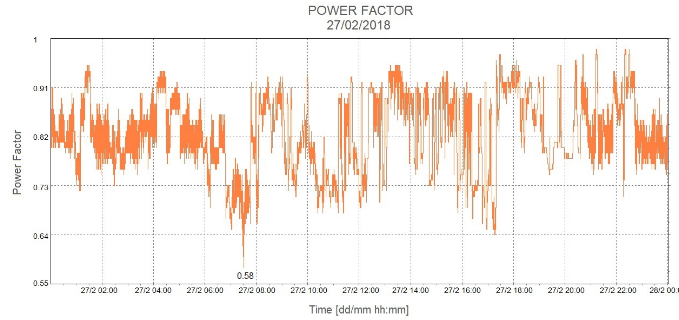

Fig. 3. Observed Power Factor on February 27, 2018 (Stage 1).

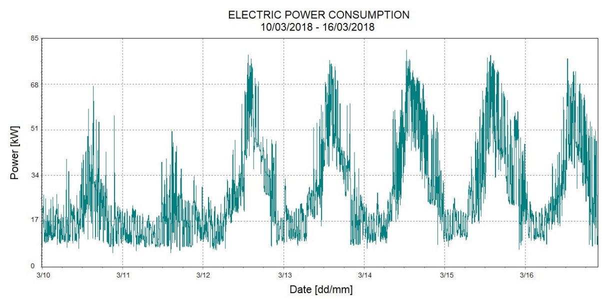

Fig. 4. Observed total electric power consumption during a whole week (March 10 to March 16, 2018) during Stage 1 measurement campaign at USFQ.

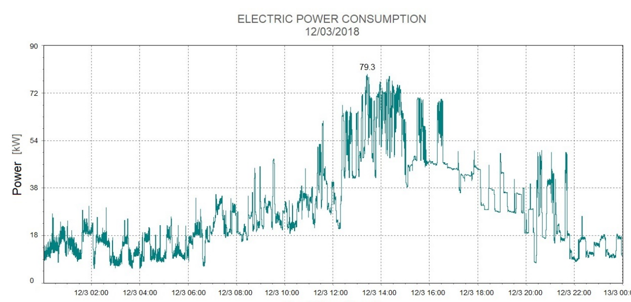

Fig. 5. Observed total electric power consumption on March 12, 2018 during Stage 1 measurement campaign at USFQ.

Analyzing the PF during the period of high consumption that occurred on March 12, 2018, it was observed that during this time the PF does not have values much lower than 0.92, as shown in Fig. 6.

B. Stage 2

After analyzing the data obtained from Stage 2, it was observed that the lower power factor occurred on March 31, 2018 at 2:08 PM., with a value of 0.6, as shown in Fig. 7. It is important to mention that it was the only moment of this stage in which such a low peak was generated. The mean Power factor for this stage is 0.83. When compared with the

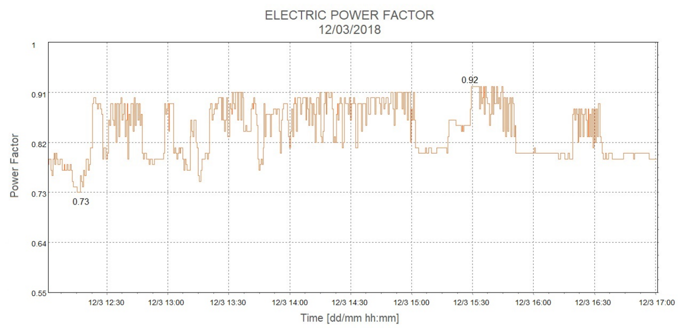

Fig. 6. Power factor during the hours of greatest consumption on March 12, 2018 during Stage 1

average of Stage 1, which is 0.81, showing therefore that some of the equipment connected to the Sub-panel is not working efficiently. This may be due to the fact that some engines, such as one of the air conditioners, were not working at full load.

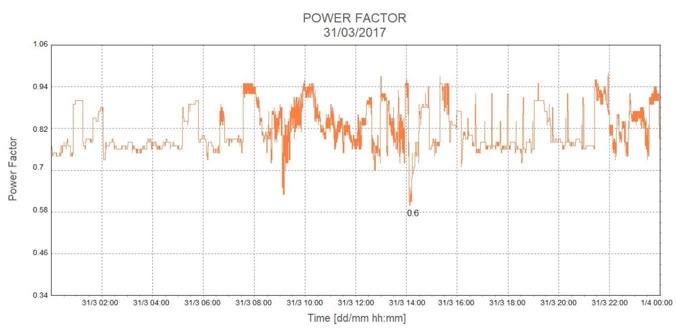

Fig. 7. Day with the lowest power factor of Stage 2 (March 31, 2018)

On the other hand, the power consumption during Stage 2 can be seen in Fig. 8. There is an isolated peak of 36.2 kW at 8:00 PM on Friday, March 30, 2018, which is 50% lower than the value of the peak consumption of Stage 1. This peak indicates that an automatic ignition equipment came into operation.

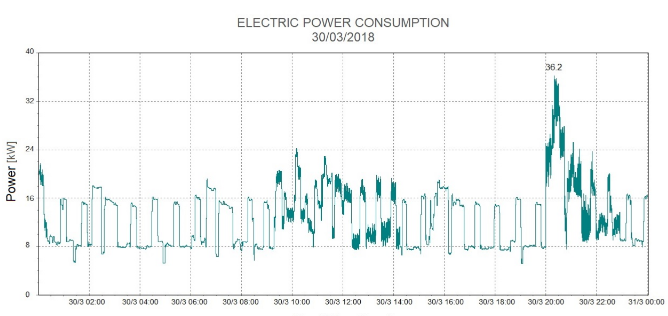

Fig. 8. Observed total electric power consumption during March 30, 2018 (Stage 2) measurement campaign USFQ

For the same day, the value of the power factor at 8:20 PM is 0.96 as shown in Fig.9.

Fig. 9. Power factor on March 30, 2018 (Stage 2)

C. Comparison between measurement Stages

Fig. 10 shows the comparison of power consumption between a week with full load (Stage 1) and a Week during the break period (Stage 2). Consumption during the week of stage 1 was more than 23.5% higher than compared to the days when university activities were reduced. On the other hand, for the days that the activities within the USFQ completely ceased from Friday to Sunday (March 30 to April 1, 2018), this difference was of almost 60%, this happens because all the kitchen equipment was turned OFF except for the cold rooms that never go out to prevent food to spoil. Additionally, the HVACs did not work at their normal pace since the affluence of people to the library was less than on normal days.

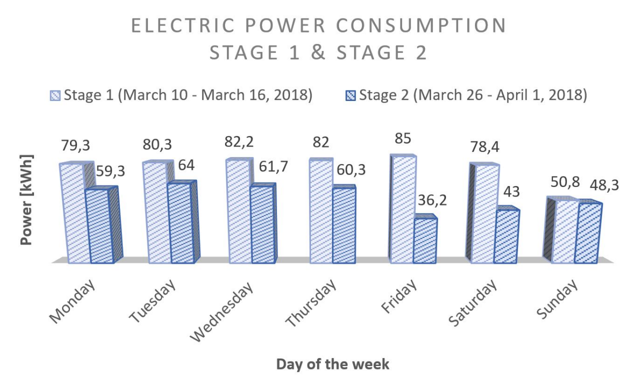

Fig. 10. Observed total electric power consumption per day during a whole week of Stage 1 (March 10 to March 16, 2018) and a whole week of Stage 2 (March 26 to April 1, 2018)

As it can be seen in Fig. 10, in both stages the power consumption has similar behavior for Sunday, oscillating between 50kW. This is because on Sundays the activities in the university are minimal. Tables II and III show the maximum, minimum power demand, the total energy consumption, and the peak demand during peak hours. As it can be seen, the total energy consumed in Stage 2 is 960 kWh lower than for the week of Stage 1.

In addition, as can be seen in III, the demand peak detected during a month and a half of measurement is considerably greater than those detected in state 1 and state 2, 20kW más.

This difference has a significant impact on the increase in billing cost.

TABLE II
TOTAL ELECTRIC POWER CONSUMPTION FOR SUB-PANEL DURING THE MEASUREMENT STAGE 1 (MARCH 3 TO MARCH 9, 2018) AND STAGE 2 (MARCH 26 TO APRIL 1,2018).

Stage	Stage 1		Stage 2	
Parameter	Power kW	Energy kWh	Power kW	Energy kWh
Max	77.8	63	64	49
Min	5.3	5	5	9
Total		3966		3006
Energy Consumption 7:00h-22:00h		2865		2144
Energy Consumption 22:00h-7:00h		953		856
Peak Demand 18:00h-22:00h	57.3		54.7	
Peak Demand 22:00h-18:00h	77.8		64	

TABLE III
TOTAL ELECTRIC POWER CONSUMPTION FOR SUB-PANEL DURING THE ALL PERIOD OF STUDY (FEBRUARY 17 TO APRIL 1,2018).

Parameter	Power kW	Energy kWh
Max	85.4	49
Min	4.5	5
Total		19505
Energy Consumption 7:00h-22:00h		13957
Energy Consumption 22:00h-7:00h		4997
Peak Demand 18:00h-22:00h	62.9	
Peak Demand 22:00h-18:00h	85.4	

The energy consumption of the Sub-panel under study represents approximately 13% of total consumption of the university. The USFQ is in the "Commercial Medium Voltage" category and thus different energy rates apply. Accordingly, the cost of energy consumed from 7:00 AM to 10:00 PM is approximately $1852.98 while for the low cost period that is from 10:00 PM to to 7:00 AM the total cost is $384.77.

D. Manual Test

In addition to Stage 1 of full load measurement, an extra week was analyzed in which manual ON-OFF tests were performed. The only day when the air conditioning systems were OFF was on Sunday March 25, 2018. Fig. 11 shows how the absence of this event produces a considerable lower consumption. On Sundays the HVAC systems are OFF due to the programming of the air conditioners, but they can turn ON if the temperature exceeds 21.6 °C in order to protect the books of the library, but this event does not happen so frequently [11].

Analyzing the PF during the time period of Fig.12, very LPF values were observed immediately after the HVAC system was turned OFF. The HVAC system was turned OFF at 5:05 PM

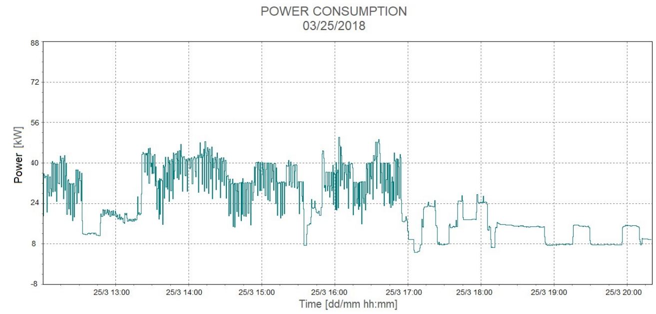

Fig. 11. Decreased potential consumption when the air conditioner was turned Off during the Manual Test (March 3,2018)

and at this instant there was a very LPF of 0.73, this could be due to the HVAC motors stopped working at their maximum power until they were completely stopped.

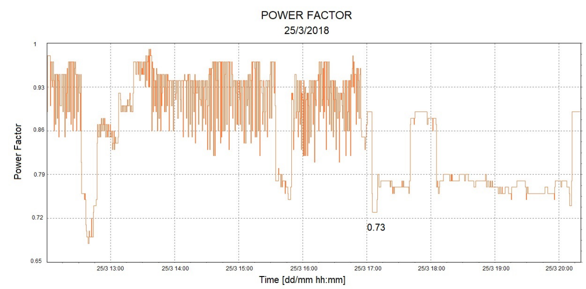

Fig. 12. Power Factor when the air conditioner was turned Off during the Manual Test (March 3,2018)

Table IV shows the values of the total, average and maximum power consumed for all Sundays under study. The reduction in Power consumption is due to the fact that the air conditioners are OFF. Saturdays do not show the same behavior, since the library works from 9:00 AM to 04:00 PM. and some of the restaurants of the university also provide their services to the public. However, consumption is lower than during a normal day of university activities.

TABLE IV
POWER DATA OF SUNDAYS DURING ALL ANALYZED PERIODS (FEBRUARY 17 TO APRIL 1, 2018)

Stage	Date	Pmed [kW]	Pmax [kW]
Stage 1	18/2/2018	52,1	62,8
	25/2/2018	44,0	53,8
	04/32018	53,6	58,8
	11/3/2018	50,8	61,5
Stage 2	01/4/2018	48,3	60,7
Manual Test	25/3/2018	50,2	66,4

When conducting test on kitchen appliances, the kitchen chef pointed out that most of the equipment is used in the early hours of the day. However, the dishwasher normally works from 12h00 AM until around 04h00 PM in the afternoon. For this reason, we proceeded to perform the ON-OFF test of the most power consuming equipment in the kitchen according to their technical plates. The tests shown in Fig. 13, were conducted on Tuesday, March 20, 2018, from 4:50 PM until 5:30 PM and are summarized on TableV. In such tests, it was observed that the individual power peaks produced by the kitchen equipment did not contribute significantly to the peak demand. Furthermore, kitchen equipments were discarded as producers of power peaks by aggregated loads, since their hours of use do not coincide with the hours of peak consumption observed on the sub-panel.

TABLE V
ON/OFF INDUSTRIAL KITCHEN EQUIPMENT (MARCH 20,2018)

Kitchen Equipment	On Time	Off Time	On Time	Off Time
Electric Oven	5:20 p.m.	5:23 p.m.		
Dishwasher	4:55 p.m.	4:57 p.m.	5:01 p.m.	5:03 p.m.
Industrial Pot	5:11 p.m	5:12 p.m.	5:15 p.m.	5:18 p.m.
Induction Stoves	5:25 p.m.	5:26 p.m.	5:27 p.m.	5:28 p.m.

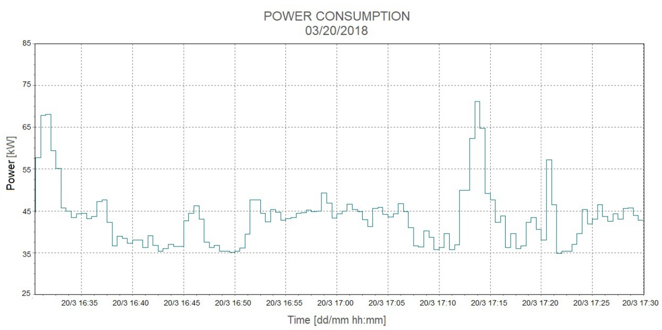

Fig. 13. Observed power consumption when the kitchen equipment was turned ON and OFF (March 20,2018)

As it can be seen in Table I, the highest protection in the Sub-panel belongs to the Induction Experimental Stove. However, when investigating their use, it was confirmed that the induction plates were almost never used. In the hours in which the peak demand was generated, there is only one class, but the instructor in charge affirmed that this equipment is not used during his class hours [12].

IV. CONCLUSION AND RECOMMENDATIONS

In this papers, we have focus in analyzing the effect of individual loads to the total power consumption in areas of interest around an University Campus. There were many elements that produce increased consumption and its related cost. The PF is one of them, and it was observed that in large parts of the periods under study, the PF was found below the non penalizing level (0.92). This is mainly due to the existence of motors that operate at reduced load, an example of this is the HVAC, which normally produces a LPF in such situations [13]. However, the USFQ does not pay any penalties for low power factor. This is because the university has a greater number of resistive loads that compensate the delay in the power factor, for example, the luminaries incandescent and also LED lights. To correct individual LPF, a bank of capacitors should be added in parallel with the connected motor circuits, or applied at the distribution panel described in the analysis [14].

The HVAC systems have a high consumption and contribute significantly to the total power consumed by the loads of the Sub-panel under study. Therefore, it is important to implement an energy efficiency maintenance and operation plan in these HVAC Systems so different strategies can be carried out. One of such strategies is to move the HVAC set-points for comfort temperatures for sedentary works which oscillates between 22 °C and 24 °C [15]. Currently the library's HVAC systems are programmed to maintain a temperature of 21.66 °C. Previous research [7] indicate that by increasing the temperature set-point by two degrees, an approximate saving of 20% in the energy consumption of HVAC systems could be achieved. Another strategy is to vary the temperature set-point with respect to the time of the year, during the winter the comfort temperature can vary by 1 °C with relation to the summer set-point which would produce a notable change in energy consumption according to a study carried out in South Africa, a saving of almost 30.6% in a year could be obtained [16].

Another possible solution to improve the performance of the HVAC systems is to make adequate preventive maintenances such as cleaning or replacement of: filters and condensers every month, evaporators every three months and also lubrication of mechanical components. Finally, to improve the cycle of refrigeration, a high-performance refrigerant can be used, this is usually of hydrocarbon type and less dense, since it is less dense, the refrigerant will operate at lower pressures and therefore produces savings between 10% to 25% [7]. However, it is important to notice that the operation of HVACs depends totally on the weather conditions and the amount of people in the library, these are parameters that can not be controlled.

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