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Research article

Energy audit method applied to tertiary buildings: Case study of a University campus

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Abstract: Energy audits are an essential tool for improving energy efficiency and saving energy in various sectors, especially in the building sector. It is a vital tool for supporting the renovation of buildings and attaining carbon neutrality in this sector. In this article, we report an energy audit of a university campus based in Fez, Morocco. A detailed diagnosis combined with an accurate analysis of the electrical consumption of each system on campus has enabled us to identify the energy consuming systems and to propose a suitable energy saving strategy. A photovoltaic plant has been implemented at the campus to reduce its dependence to the electrical grid. The proposed actions resulting from this energy audit revealed that the campus can save 161 MWh of electrical energy and avoid 120 tons of CO_2 emissions per year. This corresponds to a 33% reduction compared to the initial situation. The total investment has been estimated at 55 800 $ and the overall payback period does not exceed 2.8 years.

Keywords: educational buildings; energy audit; electricity bill analysis; passive harmonic filter; energy saving; CO_2 emissions

Nomenclature: AER: Annual emissions reduction of CO_2, kg/year; AES: Annual energy saving, kWh/year; AP: Apparent power, kVA; APmax: Monthly Maximal apparent power, kVA; CF: Consumption fee, $; CO_2: Carbon dioxide; DPF: Displacement Power Factor; E_Grid: Energy injected into grid, kWh; EArray: Effective energy at the output of the array, kWh; ECx: Electrical consumption associated to the time slice x, kWh; EPx: Electricity prices for the time slice x, \$/kWh; FEPC: Fee of the excess of subscribed power, \$; GlobHor: Horizontal global irradiation, kWh/m²; I_{DPF}: Increase for a Displacement Power Factor below 0.8, \$; \$: American dollar; P: Active power, kW; PB: payback, years; PerI: Performance Index; PF: Power fee, \$; Pmax: Maximal active power, kW; $P_{red-min}$: Minimal power reduction, kW; PSP: Subscribed power price, \$/kVA; PV: photovoltaic system; Q: Reactive power, kVAr; SP: Subscribed power, kVA; T Amb: Ambient Temperature, ℃; TEC: Total energy consumption, kWh; THD I: Total harmonic current distortion, %; THD V: Total harmonic voltage distortion, %; Vi RMS: RMS value of the voltage of phase i, V

Acronyms: AVG: Average; CO_2: Carbon dioxide; Div: Division; h: hour; k: thousand; M: million; t: tonne; y: years

1. Introduction

1.1. Background

The building sector is responsible for 32% of the total energy consumed in the world. Also, this sector counts for approximately 20% of global greenhouse gas emissions [1]. To deal with this problem, countries around the world have developed and put in place projects and public policies to boost energy efficiency in the building sector [2]. Energy audit programs in the building sector are at the top of policies to improve energy efficiency and achieve national energy savings. These programs have been launched in several countries around the world. For example in Tunisia, the government imposes buildings that exceed a threshold of energy consumption to perform energy audit every 3 years. This law has been applied since 2004 [3] in Tunisia. In Lebanon, energy audit programs have been within the national energy efficiency strategies since 2002 [4]. In 2012, the member states of the European Union have made the energy audit applicable and periodic for every 4 years to all the buildings according to numerous conditions [5].

Morocco possesses little conventional energy resources [6]. It has recently adopted a law on energy efficiency (47-09) [7]. This law makes the energy audit mandatory for buildings exceeding a certain threshold of energy consumption.

1.2. Case of educational buildings

The category of educational buildings contributes a considerable share of the energy consumed within the building sector and their energy budget expenditure represents a heavy financial bill for the country [8]. In the recent years, several energy audits have been carried out for university buildings or for higher education institutes. It was shown that considerable savings can be achieved by practicing energy audits. Semprini et al. [9] conducted an energy audit for a graduate school of engineers and architects in Bologna. The audited building was a new construction but the energy audit showed several energy losses. The results of the audit show a potential energy saving of 32%, only by improving the energy efficiency of the heating. Hussain [10] carried out an energy audit for a for a graduate engineers school. The author proposed an action plan to improve the energy efficiency of the building envelope, heating and lighting systems. The potential energy saving has been demonstrated to be about 35.3% of the total energy consumption. Singh et al. [11] conducted an energy audit for a university in Malaysia. The authors dealt only with electrical energy and an action plan for lighting and air conditioning were suggested. It was found that the electrical energy saving potential is 10% of total of the treated loads. Alajmi [12] performed an energy audit to examine energy conservations opportunities for an educational building located in a hot environment (state of Kuwait). Author found that the electrical and mechanical systems in the building were not properly operated and not well maintained. By proposing some recommendations, saving of up to 49.3% of the building annual energy consumptions with a payback periods of less than six months was possible. In city of Paris (France), a program concerning energy efficiency in schools has been launched in 2008 to reduce consumption by 30% [13]. The program included more than 600 school buildings. The refurbishment of the insulation and fenestration and the heating systems have been treated. By assessing 100 schools, it was found that a total of 10 700 MWh economy on final energy and a reduction of 2300 t of carbon dioxide and 85000 € can be saved annually. Thewes et al. [14] presented the results of an energy consumption analysis and potential savings on 68 school buildings. The study revealed that simple solutions such as insulation and air tightness can reduce considerably the energy demand. The authors estimated a potential saving equivalent to 1% of the national annual fuel oil and gas consumption in the tertiary sector. In Slovenia, a study was conducted by Butala [15] on 24 old schools to improve their energy efficiency. The diagnosis showed significant energy losses (about 89% than standards). The paper revealed that the proposed actions plan can reduce the losses and allow the buildings to respect the recommended values. Sarto et al. [16] reported the results of an energy audit campaign practiced on 49 school buildings situated in Lombardy (North Italy). A simplified procedure of energy audit is adopted in order to verify the energy quality of the buildings concerned and to define strategies for improving the performance of space heating. Dimoudi and Kosterala [17] discussed the potential energy savings in educational buildings located in Greece. They demonstrated via simulation studies, that it is possible to reduce 28.75% of the heating consumption just by improving the insulation level. Gbadegesin et al. [18] carried out an energy audit of the University of Lagos in Nigeria. It was found that potential energy savings for the lighting systems is 47.07 kW which represents 88.18% of the total lighting load. Sesana et al. [19] carried out a comprehensive review on the recent energy improvement refurbishment strategies and conceptualized a methodology which was applied to two educational buildings in Italy. Salvalai et al. [20] focused on identifying the most attractive renovation options applicable to school buildings in Lecco municipality, based on energetic and financial assessment. Results delivered valuable guidelines to the Public Administration in planning with respect to best energy efficiency approches. Economic insignts were also deduced based on the conducted anlyses.

Samira et al. [21] described the process of building auditing and the process of accurate evaluation of enhancing energy efficiency startegies and indoor air quality. The case study concerned the campus of Azerbaijan University of Architecture and Construction. Mahmoodzadeh et al. [22] conducted a detailed analysis of energy use for the University of Victoria (UVic), Canada. The evaluation of the current building envelope found that several walls of the cponstruction were inappropriate and need restoration in the coming few years. The same analysis, revealed that roofs were in acceptalabe state.

As can be seen from the reviewed literature, there are many investigations regarding energy audits in educational buildings. Looking into the proposed action plans, one can observe that the most treated efficiency measures concerned principally the building envelope and HVAC systems. Electrical analysis is often disregarded and when practiced, it only deals with lightings systems or renewable energy integration. Further, for the majority of energy audits conducted in educational buildings, the main focus was put into direct energy savings while other indirect energy gains resulting from the implementation of energy efficiency strategies are often missed. The particularity of this study is the estimation of the indirect gains along with direct gains resulting from the energy audit process. Also, the audit actions are diversified with pronounced and valuable effects on the energy use within this particular building class.

To sum up, this study presents the results of an energy audit conducted for a large educational institution in Fez city, Morocco. It addresses the following research questions:

- Proposal of a method for detailed analysis of electricity bills in educational buildings.
- Proposal and sizing of a passive filter to attenuate harmonic pollution at the general circuit breaker.
- Proposal of a new method for sizing photovoltaic systems for self-consumption without interaction with the national grid, taking into account the current energy use situation.
- An estimated calculation of power reductions achieved by each proposed action.
- Determination of a suitable subscribed power taking.
- Resizing and changing the transformer after calculating the new absorbed powers by the building.
- Global evaluation of the impact of the energy efficiency measures and their potential reduction of CO_2 emissions.
- More specifically, the paper quantifies both direct and indirect financial gains resulting from the implementation of the energy audit.

2. Audit methodology

This section describes the general input data of the audited facility which include technical equipment specifications and monthly electricity bills. It also overviews the methodology of the conducted energy audit highlighting the audit procedure, measurement devices, analysis methods and calculations.

2.1. General presentation of the faculty

The audited building is the Faculty of Sciences and Technologies located in Fez city, Morocco. The faculty was built in 1995 and has a floor area of approximately 54,000 m². Each year the faculty of Fez manages more than 3000 students, supported by an educational team of more than 181 professors. Educational activities are present from mid-September to the end of June according to the academic calendar of the university. During the teaching period, the building is occupied from Monday to Friday from 08:00 am to 06:00 pm. The building includes 4 residential homes for administration staff which are occupied along the year. The Faculty is made up of 20 buildings containing several teaching rooms, ateliers and laboratories (Figures 1 and 2).

Figure 1. General view of the faculty.

Figure 2. Classrooms of the Faculty.

The faculty uses only the electrical energy, which is mainly used for lighting, electrical machines and equipment used for practical work and research equipments, air conditioning and heating and computer equipment. The total Annual electrical consumption is 460 MWh/year, on the basis of year 2019.

2.2. Energy audit process

Energy audit is one of the most effective measures to diagnose, analyze and improve the energy performance of existing buildings [13,24]. This is multi-dimensional project that aims to determine actions to improve energy efficiency and calculate the economic benefits. This study is a type II energy audit according to the ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers) ranking [25], and it deals with the majority of electricity-based consuming systems in the audited building. The various stages of the present energy audit are described as follows:

❖ ***Step 1: Quick preliminary visit***

The main objective of this visit was to collect the required data for driving the energy audit activities. The following data were reassembled:

-Architectural Mass plan of the institution

-Electricity bills for the last three years in order to:

- Study the variations in the monthly electricity consumption and how it is affected by outdoor temperatures;
- Define the energy consumption during each time slot;
- Check if the subscribed power is well selected;
- Compute the maximum load rates of the transformer;
- Assess the Displacement Power Factor (DPF) of the electricity system;

-Single-line electricity diagram of the building;

-Inventory of external/internal lighting systems;

❖ ***Step 2: Diagnosis and measurements***

This step is about examining the operating points of the faculty's electric installation. Using the measuring devices, it was possible to determine the sources of energy losses and propose an appropriate actions plan.

The following measurements were performed:

- Installation of a network recorder at the general circuit breaker of the Faculty. The analyzer recorded all the electricity parameters for 48 hours continuously. The purpose of this measurement was to analyze the quality of the electrical energy supplied as well as the identification of daily power demand variation;
- Using the multi-meter clamp for examined the operation of the capacitor banks installed in the transformer station.

❖ ***Step 3: Audit report preparation***

After completing step 2, the auditors drew up an in-depth energy audit report gathering all the information collected, the investigations carried out, as well as the recommendations and the proposed actions plan.

❖ ***Step 4: Decision-making***

Finally, the research team assists the decision-maker in validating and e the implementing the retained energy efficiency projects depending on the available financial resources and other technical constraints.

2.3. Medium-voltage billing in Morocco

The faculty is powered by a 630 kVA power transformer. The total price excluding tax for monthly billing in Morocco is given as the followings [27]:

2.3.1. Consumption fee (CF)

The consumption fee (CF) is expressed as Eq (1). The electricity price (EP) changes with the time according to the time slice (i.e., normal, peak, and off-peak hours). Time slices are given by the electricity supplier and are reported in Table 1.

$$CF = EP_{Normal} \times EC_{Normal} + EP_{Peak} \times EC_{Peak} + EP_{Off-Peak} \times EC_{Off-Peak} \quad (1)$$

Table 1. Electricity prices for medium-voltage in Morocco.

	Off-peak hours	Normal hours	Peak hours
October-March	[10 pm–7 am]	[7 am–5 pm]	[5 pm–10 pm]
April-September	[11 pm–7 am]	[7 am–6 pm]	[6 pm–11 pm]
Electricity price ($/kWh)	0.0740	0.1010	0.1416
Price of subscribed power ($/kVA)	51.252		

2.3.2. Power cost (PC) and fee of excess of subscribed power (FEPC)

The power cost (PC) is computed annually and is billed on a monthly basis by one twelfth. It is obtained by Eq (2):

$$PC = \frac{PSP}{12} \times SP \quad (2)$$

For a given month, if the maximum power demand is greater than the value of the subscribed power, the positive difference between the two powers will induce an additional fee denoted by FEPC. The FEPC is expressed as Eq (3):

$$FEPC = 1.5 \times \frac{PSP}{12} \times \left(AP_{\max} - SP\right) \quad (3)$$

where SP, AP_{max} and PSP are the subscribed power, maximum apparent power and price of subscribed power, respectively.

An optimum choice of the subscribed power has the potential to minimize the sum of PC and FEPC.

2.3.3. Penalty for a displacement power factor below 0.8

The electricity supplier attributes a penalty for each month when the average displacement power factor (DPF) is <0.8. This penalty is calculated taking into account the following: for every hundredth of insufficient power factor identified, the total amount of fees will be increased by 2%. Therefore:

$$I_{DPF} = 2 \times \left(0.8 - DPF\right) \times \left(CF + PC + FEPC\right) \quad (4)$$

3. Analyzes, diagnoses and measurement

3.1. Analysis of electricity bills

3.1.1. Electrical energy consumed

The history of monthly electricity consumption for the year 2019 is presented in Table 2. Figure 3 shows the variation of the monthly electric energy consumption between 2017 and 2019 according to the average outdoor temperature of the city of Fez.

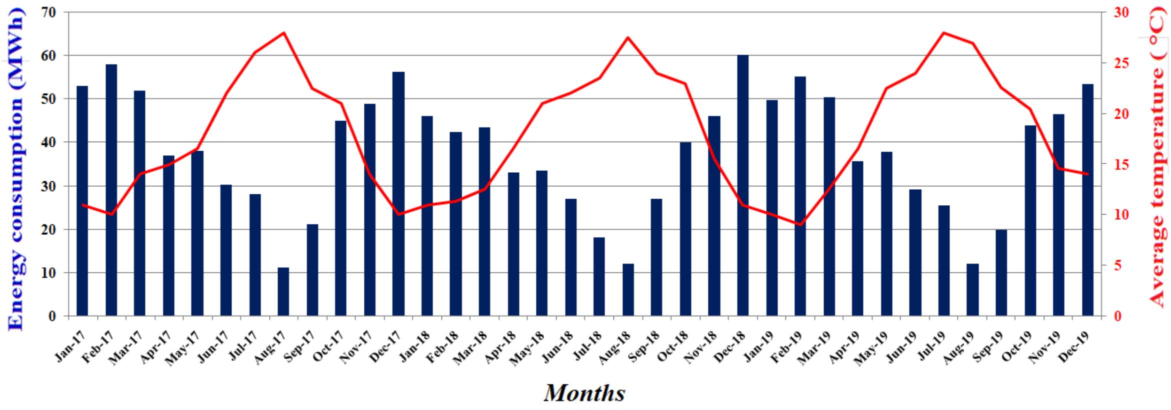

Figure 3. Monthly average monthly electrical energy consumption and temperature.

Analyzing the obtained curve, one can notice the following:

- The energy consumption curve (in blue) is almost the same for the three years studied 2017, 2018, and 2019.
- The higher energy consumptions are recorded during December and January which correspond to cold outdoor temperatures. This increase of energy consumed is mainly due to the use of electrical space heating.
- In April and May, the consumption is stabilized around an average of 35 MWh. During these two months the air conditioning and heating equipment are not functional since the outside temperature is ideal (Spring season). Accordingly, this consumed energy represents the energy of all equipment except heating and air conditioning equipment.
- In August, when the Faculty is in closure, the energy is at its minimum value, which is an average of 11.66 MWh (see Table 2). Therefore, it can be confirmed that the energy consumed is generated by administration, staff housing and outdoor lightin.

Table 2. Characteristics of the energy bill (year 2019).

Months (2019)	Energy consumption (MWh)					CF ($)	SP (kVA)	P_{max} (kW)	AP_{max} (kVA)	DPF	PC ($)
	Off-peak hours	Normal hours	Peak hours	Total	Total AVG of 3 years						
January	16.81	20.46	12.59	49.86	49.62	5093	150	120.49	134.71	0.94	641
February	16.41	24.61	14.25	55.27	51.92	5718		139.56	146.02	0.94	
March	15.56	22.03	12.74	50.34	48.61	5181		104.48	119.35	0.92	
April	9.78	16.62	9.29	35.69	38.90	3718		77.02	90.95	0.91	
May	9.99	18.04	9.71	37.73	35.91	3936		72.45	84.59	0.90	
June	8.61	13.31	7.21	29.13	28.78	3003		64.06	74.80	0.90	
July	7.64	12.35	5.49	25.48	23.83	2591		64.82	73.24	0.93	
August	4.02	5.19	2.77	11.99	11.66	1215		31.27	34.96	0.94	
September	6.11	10.08	3.54	19.73	22.58	1972		68.63	81.04	0.89	
October	11.89	19.11	12.91	43.91	43.00	4638		96.85	111.84	0.91	
November	13.94	20.24	12.32	46.50	47.17	4820		107.52	125.56	0.90	
December	16.19	23.41	13.78	53.38	56.59	5514		115.15	131.54	0.92	
Total	136.96	205.45	116.61	459.02	458.57	47397	-	1062.29	1218.58	-	7688

3.1.2. Maximum power and power factor

Since the last three years are almost identical in terms of energy utilization and for the sake of simplification, only the analysis of the year 2019 is represented. Based on the electricity bills of the year 2019, Figure 4 displays the maximum apparent power demands, subscribed powers and average monthly power factor.

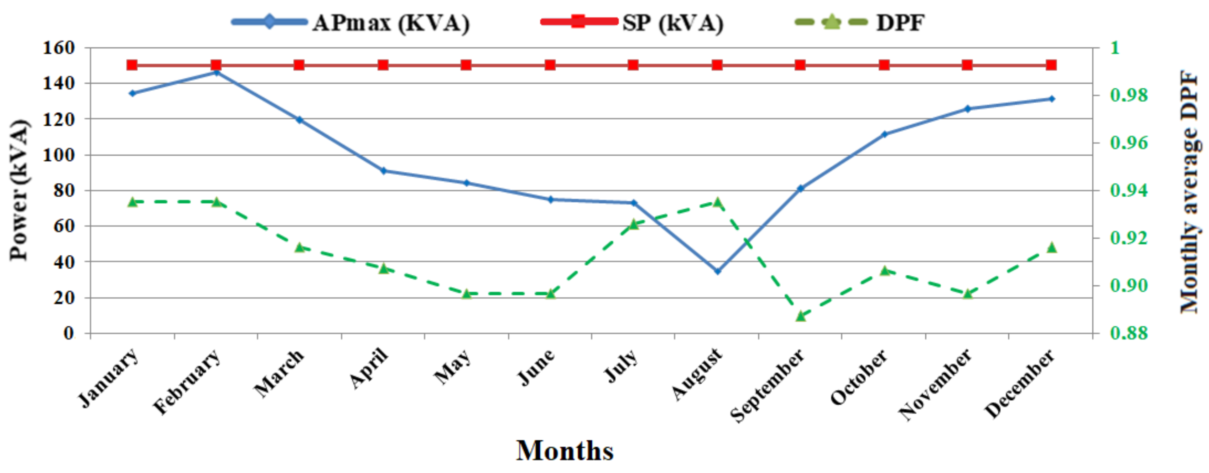

Figure 4. Power demand, subscribed power and monthly average power factor.

By analyzing this curve, it can be concluded that:

- The maximum of the apparent power during the year 2019 vary between 34 kVA and 146 kVA. This means that the maximum load factor of the installed transformer varies between 5.5% and 23% (knowing that the transformer power is 630 kVA). These charge rates are low which indicates an oversizing of the transformer.
- The subscribed power is 150 kVA. The subscribed power is well chosen and no overrun has been recorded.
- The power factor varies between 0.89 and 0.94.

3.2. Diagnostics of lighting

The lighting is used throughout the year, in classrooms, workshops, hall, school yard ... etc. The artificial lighting of the Faculty is generally controlled manually by switches. To calculate the lighting consumption, the following formula was used Eq (5):

$$E_{light} = \sum P_i \cdot h_i \quad (5)$$

P_i is the total power of the lamps for each occupied space, h_i is the number of operating hours corresponding to space i. The detail of lighting is presented in Table 3. The total lighting consumption is 177.89 MWh/year.

3.3. Electrical energy balance

It is difficult to make energy assessments per station without using energy meters and sub-meters at the stations. For the case of buildings that are not equipped with energy sub-meters, below a new method based on the analysis of electricity bills.

Based on the conducted survey, each year, the electricity consumption is spilt according to the following uses (see Eq (6))

$$E = \sum_{j=1}^{j=5} E_j \tag{6}$$

E_1 to E_5 represent the annual electricity consumed by the indoor lighting, outdoor lighting, staff-housing and administration, heating and the other specific uses (computer equipment and machinery).

The following assumptions are made to carry out the required computations

- Monthly of staff housing and administration is practically constant every month;
- Monthly consumption of outdoor lighting is practically constant each month.

a. Estimation of indoor and outdoor lighting energy consumption (E_1,E_2)

As indicated previously in Table 3, indoor and outdoor lighting systems are currently respectively consuming 130.07 MWh and 47.8 MWh.

Table 3. Annual energy consumed by lighting.

	Lamp type	Total power (lamp and accessory)	Number	Energy consumed (MWh/ year)
Inside lighting	Recessed Modular Fitting-4x18 W	92 W	139	14.93
	Fluorescent tube 2×36 W	92 W	275	30.10
	Fluorescent tube 40 W	50 W	1071	82.09
	Spiral CFL Lamp 50 W	50 W	09	0.28
	Spiral CFL Lamp 23 W	23 W	16	0.67
	Halogen lamp75 W	75 W	109	2.00
Exterior lighting	Projector 150 W	150 W	19	10.40
	Projector 250 W	250 W	12	10.95
	Streetlights 125 W	125 W	17	7.75
	Fluorescent tube 36 W	46 W	18	3.02
	Projector 100 W	100 W	32	11.68
	Incandescent lamp 100 W	100 W	11	4.015
	Total			177.89

b. Estimation of staff-housing and administration energy consumption (E_3)

During the month of August, there is no teaching activity at the faculty. The only locals that consumes energy during this month are staff-housing, administration and exterior lighting. It is therefore possible to calculate the energy of staff accommodation and administration by Eq (7):

$$E_3 = 12 \cdot E_{\text{August}} - E_2 \tag{7}$$

c. Estimation of the heating consumption (E_4)

The consumption of April or May is about 35 MWh and this energy corresponds to the energy consumed by all the stations, except heating and air conditioning equipment since the period is spring. This is clearly evidenced in practice as no operation of the heating/cooling devices is observed. Heating is normally used during the cold season covering the months: December, January, February and March. The energy used for heating can be given by the Eq (8):

$$E_4 = (E_{January} + E_{February} + E_{March} + E_{December}) - 4 \cdot \frac{E_{April} + E_{May}}{2} \tag{8}$$

d. Estimation of energy consumption for other uses (E5)

Consumption E5 corresponds to the consumption of computer devices and devices used for practical work. As all types of energy consumptions are already quantified, it is easily possible to deduce the energy consumption E_5. It is corresponds the total energy consumption excluding the sum of the energy consumptions previously calculated.

Finally, the breakdown of electrical consuming stations is presented in Figure 5.

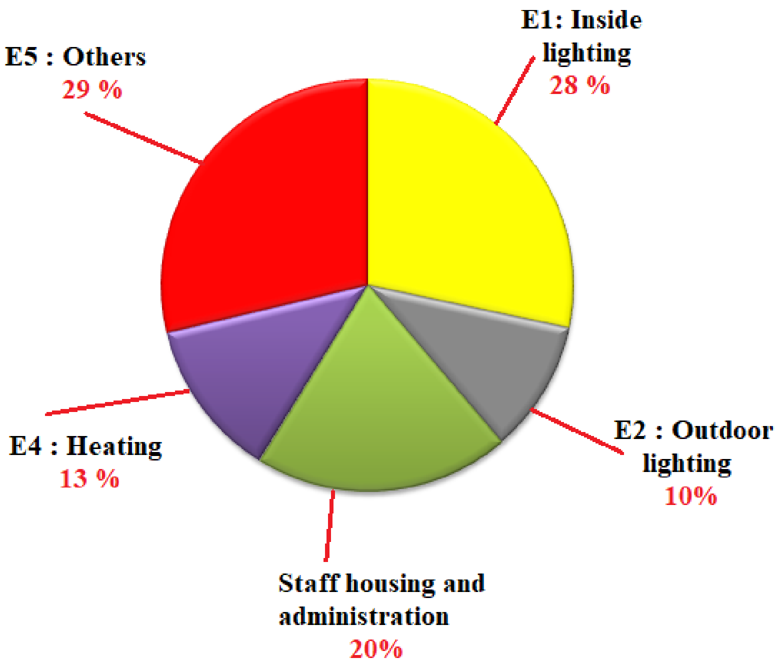

Figure 5. Electrical energy balance.

3.4. Measurement of electrical power quality

The Faculty of Science and Technology of Fez has a 630 kVA power transformer that supplies the general and secondary switchboards. In order to analyze the quality of the electrical energy supplied, a three-phase network analyzer was installed for 48 hours continuously at the general circuit breaker of the establishment (Figure 6).

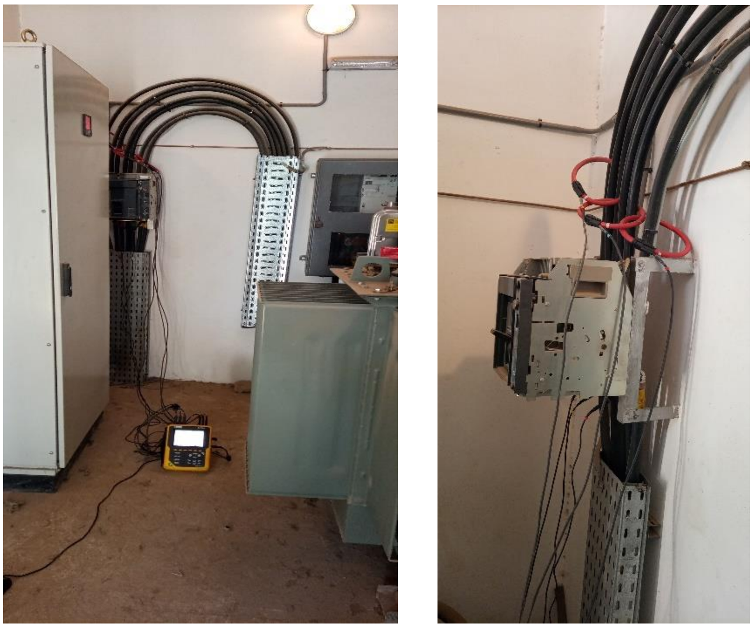

Figure 6. Three-phase power analyzer recorder installed at the main circuit breaker.

The recordings are presented in Figures 7, 8, 9 and 10. The four recordings were analyzed and the following was found:

- The active power (Figure 7) varies almost periodically. During the night when the Faculty is closed there is a stable power demand of 15 kW on average. This power is consumed by the external lighting, staff housing, laboratory fridges, computer equipment and other loads that remain in standby mode. As soon as the day begins at 7:00 a.m. the Faculty activity starts and the power consumption increases progressively and reaches its maximum of 60 kW at noon. In the evening from 7:00 p.m. the power demand decreases to a fixed value of 15 kW.
- The reactive power in green (Figure 7) varies between 15 kVAr and 40 kVar in general.
- The power factor (Figure 8) is quite low at night and acceptable during the day.
- The voltage harmonic distortion rate (Figure 9) is acceptable and lower than the values recommended by the standard which is 5%.
- The rate of current harmonic distortion is quite high (Figure 10). We notice that the overall rate of harmonic distortion of the current has a level higher than 25% and higher than the value recommended by the standard which is 10%. This high level therefore requires a special treatment for these harmonic currents. These harmonic currents are generated by non-linear loads used in the Faculty: fluorescent lamps, computers, electronic cards, etc.

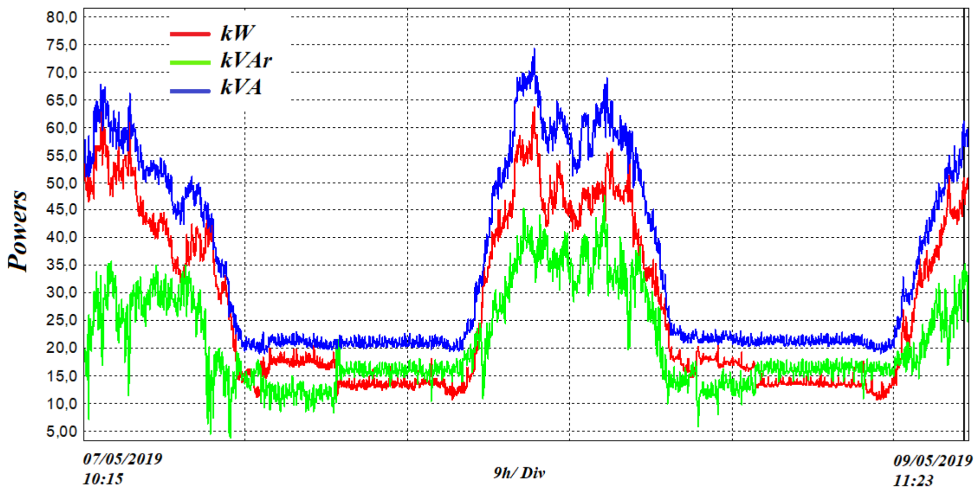

Figure 7. Recording of the absorbed powers.

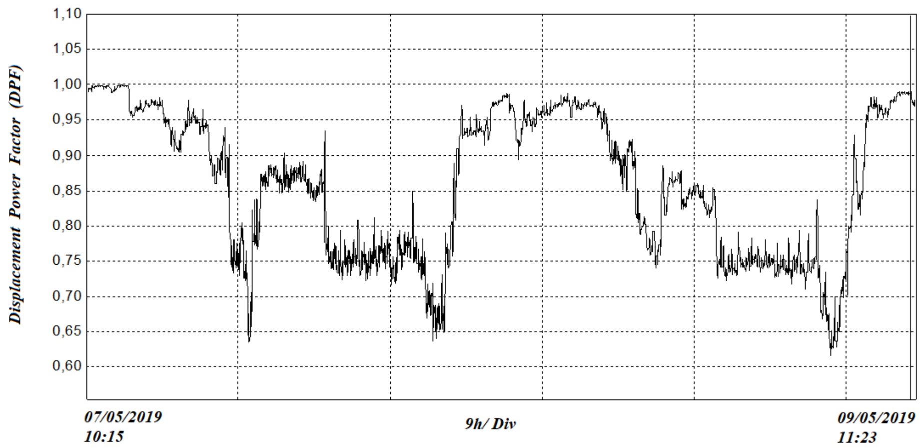

Figure 8. Global power factor recording.

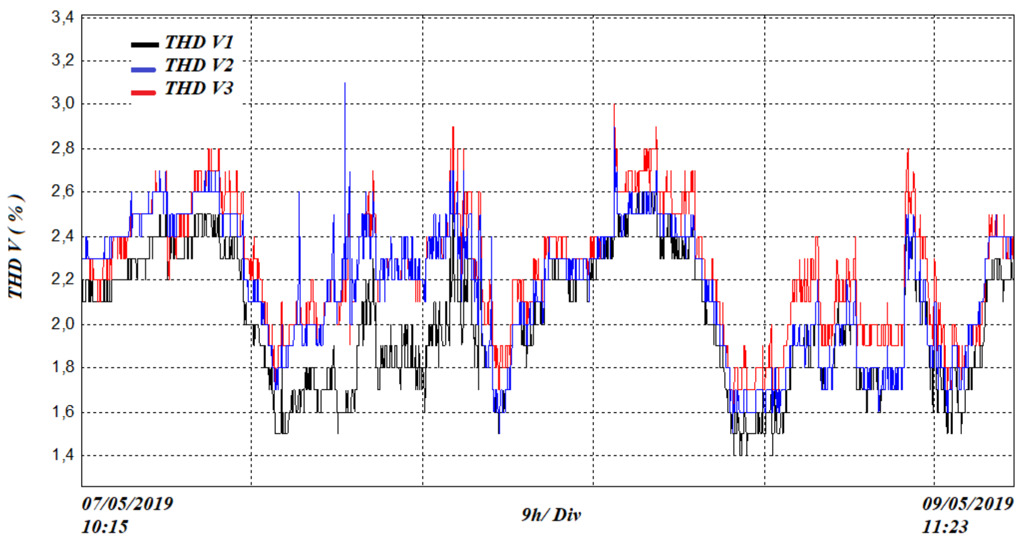

Figure 9. Recording of harmonic distortions of voltages in (%).

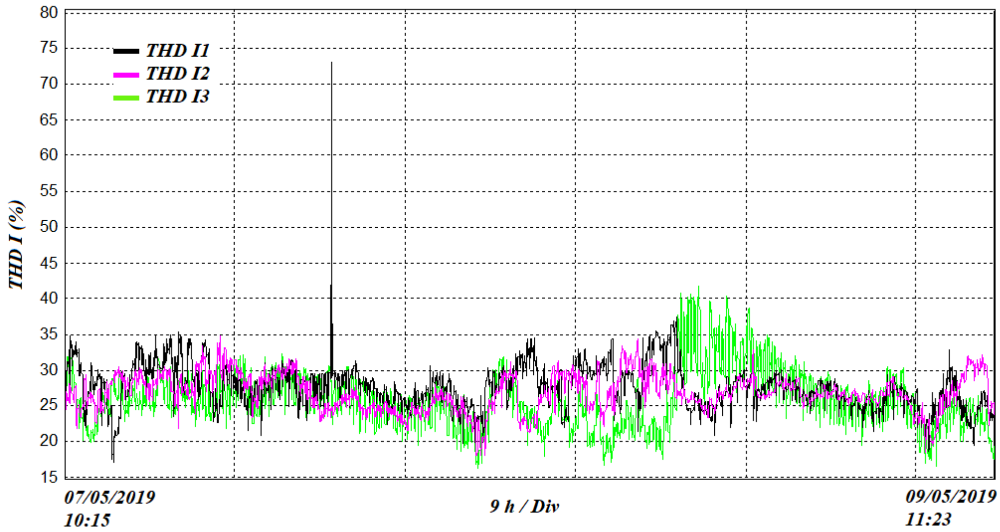

Figure 10. Recording of current harmonic distortions in (%).

4. Action plan and Economic assessment

The quantification of annual energy savings (AES) depends on the nature of the equipment and the action plan proposed to improve its energy efficiency. Generally, it is required to compute the difference between the actual energy consumption and the future energy consumption after the application of the energy saving measures. Therefore, the annual energy saving for equipment (i) can be given as Eq (9):

$$AES_i = \left(EC_i\big|_{before} - EC_i\big|_{after}\right) \tag{9}$$

where EC_i is the annual energy consumption.

The Annual emissions reduction of CO_2 associated with this energy saving is given by Eq (10):

$$AER(CO_2)_i = AES_i \cdot 0.746 \tag{10}$$

The ratio 0.746 presents the amount of CO_2 in kg emitted for the generation 1 kWh electricity according to the Moroccan context [27].

The simple payback period denoted by PB for the suggested energy saving strategies is expressed as Eq (11):

$$PB_i = \frac{Investment\ \ Cost}{CE \times AES_i} \tag{11}$$

The term CE an AES express the cost of electricity and Annual energy saving, respectively. The product corresponds to the annual cost of energy savings resulting from the improvement. An average cost of electricity (CE = 0.1 $/kWh) is used in the current calculations.

The Net Present Value is used as a second economic index for the evaluation of energy efficiency strategies. It is given by Eq (12):

$$NPV = -C_T + \sum_{j=1}^{j=N} \frac{Q_j}{(1+i)^j} \tag{12}$$

C_T represents the total investment of the project, i is the discount rate and Q_j is the difference between the cash input generated by the investment and the payment (cash output) the investment requires for a certain instance in time (year j). The Net Cash Flow for a year j is expressed as Eq (13).

$$Q_j = (Cash\ \ input)_j - (Cash\ \ output)_j \tag{13}$$

For the case of a PV system installed with total self-consumption and without injection to the grid, Eq (13) becomes:

$$Q_j = EP_{Normal}.E_{PV} - C_{c\&M} \tag{14}$$

where EP_{Normal} is the normal hour kWh price and EPV is the energy produced by the PV system, and CC&M are the expected maintenance costs for the PV system.

4.1. Filtering harmonics

Harmonic treatment has become essential for the protection of harmonic-sensitive loads, reduction of power consumption and reduction of maintenance costs [28]. Harmonics treatment can be performed by installing passive, active or hybrid harmonic filters [28]. Harmonics treatment allows improving the quality of power supplied and important results.

The analysis of the electric bill 2019 revealed that the Faculty has an overall power factor of 0.91 on average. In addition, high current harmonic pollution was measured. We plan through this action to improve the power factor to a value of 0.99 and treat the harmonics using passive filters. According to the recording, the harmonics of orders 5, 7, 11 and 13 are the most significant.

In order to calculate the reductions that can be obtained by installing anti-harmonic filters, we have carried out simulations by Matlab/Simulink. A load was chosen which breaks down from a non-linear part and another linear part, the powers of which were chosen according to the measurements obtained by the analyzer. Figure 11 presents the circuit realized on Simulink.

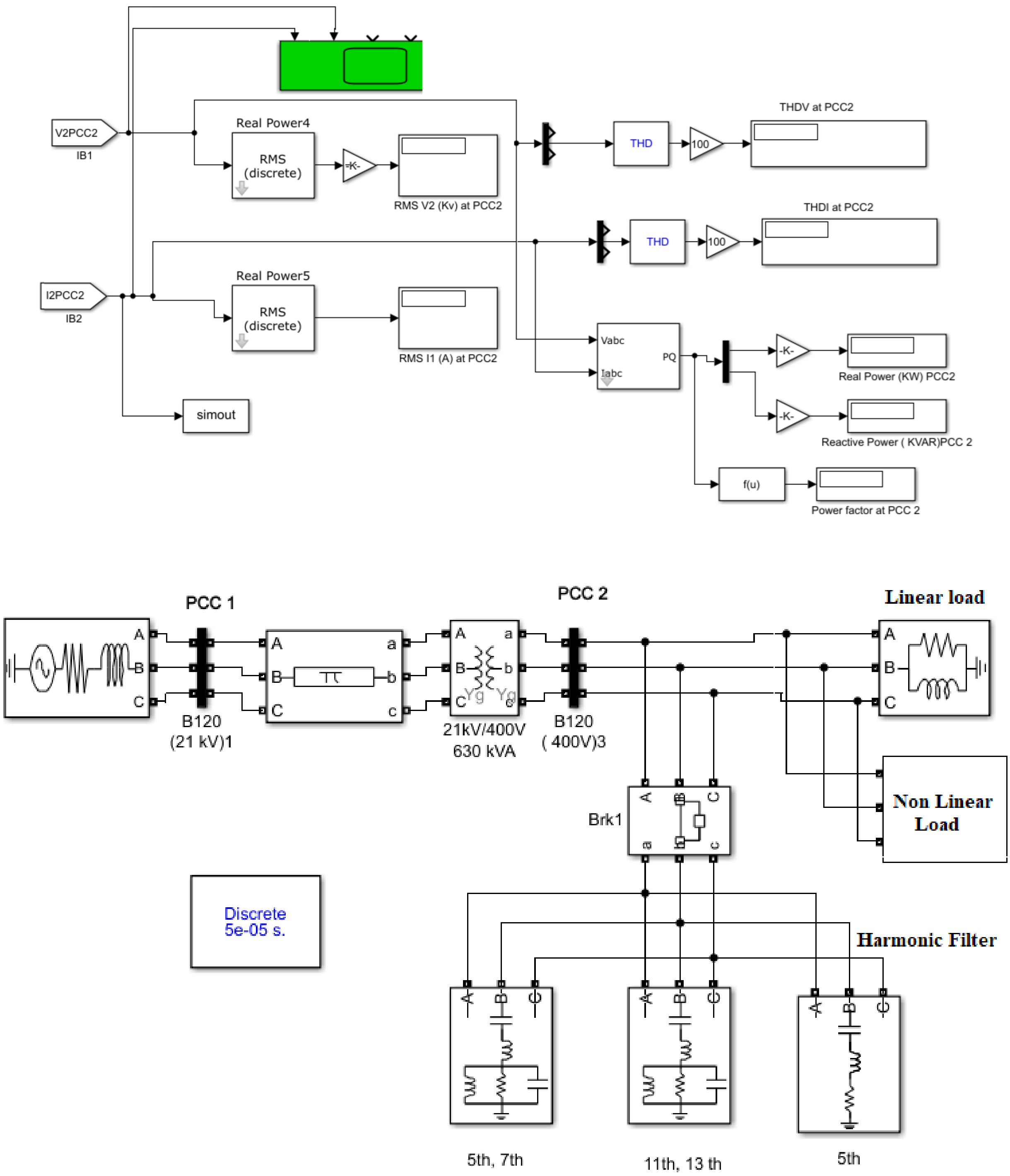

Figure 11. Electrical circuit to be simulated.

For the simulations the following assumptions were taken into account:

- The source: THDV = 0% (Total harmonic voltage distortion), f = 50 Hz, 21 kV,
- Transformer: Voltages U_1 = 400 V, U_2 = 21 KV, U_{cc} = 4%,
- Voltage and current unbalance = 0%
- Length of the cable between the source and the transformer of the establishment: 6000 meters

It is always difficult to size the filter at the overall level of the installation. The performance of the filter varies depending on the power demanded by the load. So the filter was sized according to an average reactive power (30 kVAr) and to see the advantages obtained by the filter when the load varies, simulations were made for 3 power levels. Table 4 summarizes the simulations performed for the three power levels and for the two scenarios without and with anti-harmonic filter.

Table 4. Results obtained by the filter for different powers chosen.

	P = 50 kW		P = 40 kW		P = 15 kW	
	without filter	with filter	without filter	with filter	without filter	with filter
THDV (%)	2.5	1.07	2.3	1.02	1.3	0.75
THDI (%)	21	8.34	22.76	9.2	25.34	9.3
Total Current (Arms)	89.5	70.7	72.6	54.2	30.5	24.85
PF	0.82	0.99	0.8	0.999	0.68	0.93
kVA	62,01	48,98	50,30	37,55	21,13	17,22
KVAr	34.72	6.03	30.09	1.48	15.88	−13.01
kW	50.02	48.96	40.02	38.04	15	13.66

According to Table 4, the dimensioned filter allows to have good results for the three chosen powers. Analyzing Table 4 we can notice:

- Reductions of 50% and 60% of THDV and THDI respectively, which will improve the power quality and meet the requirements of the standard.
- An improvement of at least 20% for the power factor,
- Active power savings of 1.06 kW, 1.98 kW, 1.34 kW when the load is operated at 50 kW, 40 kW and 15 kW respectively.

So, for a minimum reduction of 1 kW, the annual energy saved is 8760 kWh/year which gives a gain of 876 $/year.

To this gain, must be added an indirect financial gain related to the reduction of the subscribed power obtained thanks to the reductions in kVA power deduced from the filter installation.

According to the usual operating conditions of the Faculty, it is possible to consider that the maximum power demand should occur between 8:00 and 12:00 or from 14:00 to 18:00 the activity of the Faculty is its maximum. In this time range the new power factor is 0.99. The new power demands can be obtained by the Eq (15).

$$AP_{\max} = \frac{P_{\max} - \mathrm{P}_{red}}{DPF} \tag{15}$$

where P_{red} is the realized power reduction in kW and the DPF for this project is 0.99.

The new optimal subscribed power that must be chosen according to these new AP_{max} (Monthly Maximal apparent power) values is the one that minimizes the term (FEPC + PC). For different simulations of the choice of subscribed power (Figure 12) it is clear that the optimal subscribed power is 135 kVA.

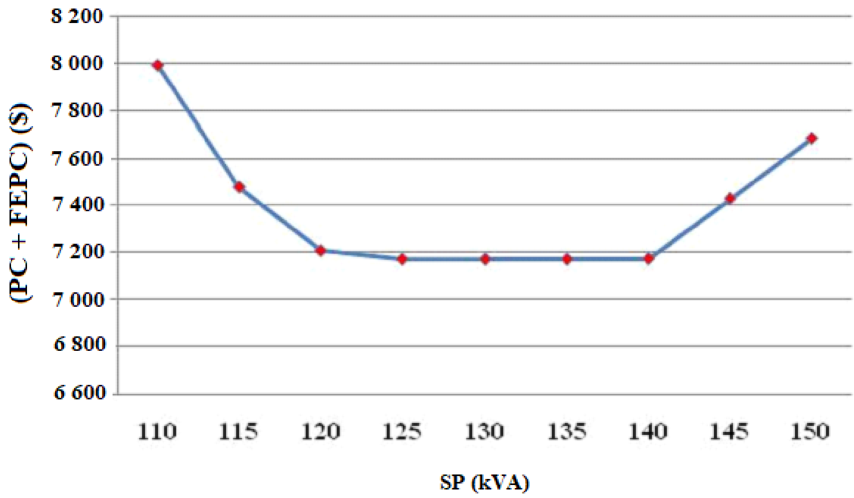

Figure 12. Values of the function (PC + FEPC) for different SP.

The financial gain is the difference between (PC + FEPC) before and after, so the gain is evaluated at 514/year. The total gain is the sum of the two sheaths obtained which is evaluated at 1390 $/year, this gain represents 18% compared to the initial situation.

The investment is 3000 $ related to the purchase and installation of the anti-harmonic filter where a return on investment time of 2.15 years.

4.2. Replacement of existing lamps with LED technology lamps

The replacement of fluorescent lamps or other types by LED lamps (Light Emitting Diode) is always beneficial, the LED technology lamps allow significant energy savings, improve the quality of power and last longer compared with other types of lamps [23]. In this project, it was proposed to change the set of lamps used in indoor and outdoor lighting by its equivalent of LED technology in terms of visual comfort. Table 5 summarizes the two situations before and after replacing the lamps. As can be seen, a total energy saving 106.30 MWh/year (equivalent to 9837 $/year) can be achieved. This saving represents 57.7% of the initial consumption of lighting.

The lifetime of the LED lamps that will be installed is of the order of tens of years and offers other indirect benefits:

- They need neither ballast nor choke, as they are connected directly to electrical grid. So, the energy consumption of the ballast is eliminated.
- The thermal characteristics of LED lamps are much better compared to the performance of other lamps. This decreases the heat rejected inducing better lighting efficiency [29].
- They do not contain heavy metals, poisonous or dangerous gases.
- The use of LED lamps generates a decrease in the total apparent power, which induces a decrease in the power AP_{max} (see Table 5). Figure 13 shows the utilization rates for each type of lighting and from the reductions already calculated in Table 5 we can present in the same figure the hourly reductions in kW. During the probable time period of peak power demand in kVA the power reduction achieved is 27.5 kW. In the same way for the choice of the optimal subscribed power which must be chosen according to these new AP_{max} values, we

proceed in the same way used in the previous project. The suitable power to choose is 110 kVA, the financial gain is 1886 $. So the sum of the two sheaths realized is 12516 $.

- An improvement in the overall power factor of the installation as a result of the large number of lamps to be installed because this type of LED lamps do not consume reactive power. This will further reduce the power calls in kVA but remains difficult to quantify.

The investment is relative to the purchase of the economic lamps, and it is evaluated at 33800 $, which gives a return on investment of 2.7 years.

Table 5. Summary of the project to replace existing lamps with LED lamps.

	LED equivalent lamp	Total power reduction (kW)	Price unitary ($)	Price total ($)	Saving (%)	Energy saving (MWh/y)
Inside lighting	Recessed Modular Fitting 4 × 9 W	7.784	40	5 560	60.87	9.09
	LED tube 2 × 22 W	13.2	22	6 050	52.17	15.7
	LED tube 24 W	27.846	15	16 065	52.00	42.69
	Spiral CFL lamp 25 W	0.225	10	90	50.00	0.14
	Spiral CFL lamp 18 W	0.08	8	128	21.74	0.15
	LED 20 W	5.995	9	981	73.33	1.47
Exterior lighting	Projector LED 20 W	2.47	50	950	86.67	9.01
	Projector LED 40 W	2.52	60	720	84.00	9.2
	Streetlights LED 54 W	1.207	70	1 190	56.80	4.4
	LED tube 22 W	0.432	22	396	52.17	1.58
	Projector LED 20 W	2.56	50	1 600	80.00	9.34
	Lamp LED 12 W	0.968	10	110	88.00	3.53
	Total	65.287		33 800		106.3

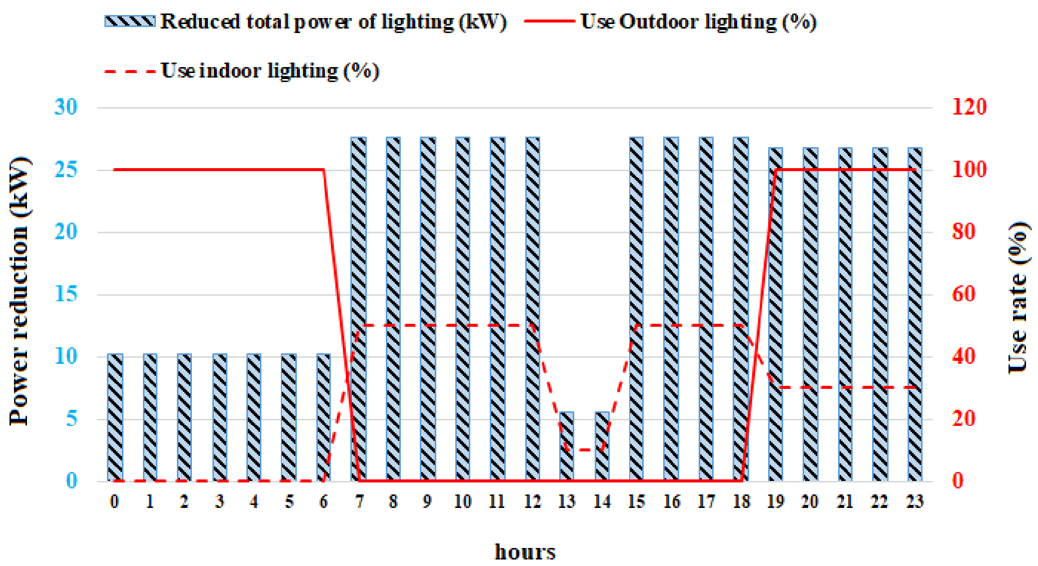

Figure 13. Total hourly power reduced by the LED lighting (kW).

4.3. Photovoltaic system integration

Photovoltaic system (PV) integration is among the most important projects to bring huge energy savings and reduce greenhouse emissions [30–32]. Since, the city of Fez enjoys a valuable solar energy potential, it was proposed to install a number of photovoltaic modules on some roofs of the Faculty. The installed panels will be connected to inverters with an output voltage of 400 V. The inverter outputs will be connected directly to the transformer substation board. To reduce voltages drops, the distance between the production field and the transformer should be minimized.

Generally, when the electrical energy generated by the PV exceeds the energy demand, the surplus production is transmitted to the grid. However, this solution imposes various challenges for distribution network operators, such as, reverse power-flow and voltage-rise problems at LV networks [33–35].

As a result, to avoid any issues related to the grid injection, the PV capacity has been dimensioned in such a way as to meet the minimum power demand of the Faculty at each hour of the day.

By analyzing the Faculty power demands, it was deduced that the suitable PV power capacity is 20 kW. This sizing is proven also by annual simulations indicating that there will be negligible surplus of produced energy. PVSYST was used for sizing and simulating the solar PV field [36]. The main design parameters including PV modules and inverter characteristics are reported in Table 6.

Table 6. Grid-Connected System: Main system parameters.

Total power chosen	20 kW
Area	220 m^2
PV Field Orientation	Tilt: 30 °, azimuth: 0 °
PV modules	250 W_p, consisting of 60 mono crystalline cells
Number of modules	84
Inverter	-Three-phase power 20 kW, -Operating voltage: 175V/950 V -Frequency: 50 hz

Table 7 shows that the annual produced energy is 38.814 MWh with a performance ratio of 0.828. Figure 14 shows the maximum power per hour injected by the PV system obtained by the PVSys software. As shown in Figure 14, the measured power demand curve is above the injected power, which shows a total self-consumption. As shown in Figure 14 and as the power injected by the PV system varies from one hour to another it is difficult to predict the power reduction. For a minimum reduction of 10 kW the new subscribed power to choose is 130 kVA and this choice allows to realize a gain of 980 $/year. Therefore, the total gain realized by this project is 5246 $/year.

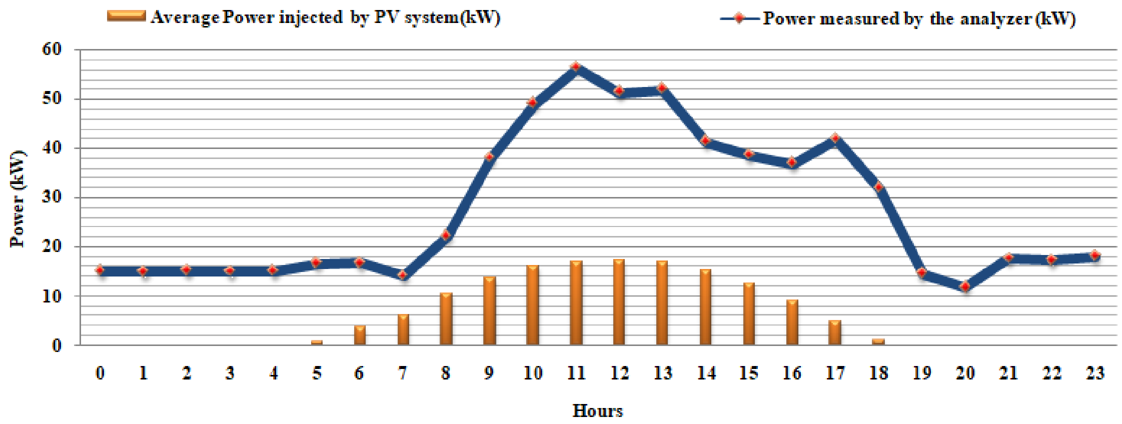

Figure 14. Average powers injected by the PV system (kW).

For the purposes of economic analysis, it was retained a discount rate of 7%, the life of the generator is taken equal to 25 years [37] corresponding to the life of the project. The initial investment is 17500 $ as shown in Table 8.

Table 7. Photovoltaic system simulation results 20 kWc.

	GlobHor kWh/m ²	Earray (MWh)	E_Grid (MWh)	PerI
January	98.6	2.928	2.87	0.886
February	103.1	2.595	2.539	0.865
March	161.8	3.547	3.472	0.846
April	184.2	3.546	3.469	0.844
May	208.9	3.53	3.452	0.827
June	232.2	3.63	3.547	0.796
July	245.5	3.835	3.747	0.779
August	223.2	3.811	3.722	0.779
September	170.2	3.367	3.291	0.805
October	140.6	3.25	3.18	0.824
November	101.9	2.879	2.82	0.865
December	89.6	2.76	2.703	0.876
Total	1959.8	39.681	38.814	0.828

Table 8. Investment for the realization of the solar photovoltaic project.

	Unit price ($)	Number	Total price ($)
Three-phase inverter 20 kW, 175 V/950 V, 50 hz	3000	01	3000
Photovoltaic Power Panel 250 Wc mono	150	80	12000
Accessories	500	01	500
Workforce	2000	01	2000
Total	-	-	17500

For the annual maintenance cost, it is estimated at 1% of the total investment cost [38] where only the inverters will be replaced twice during the project lifetime.

So, from the above and based on Eqs (12) and (13) the payback time of this project is estimated to be 4 years (see Figure 15).

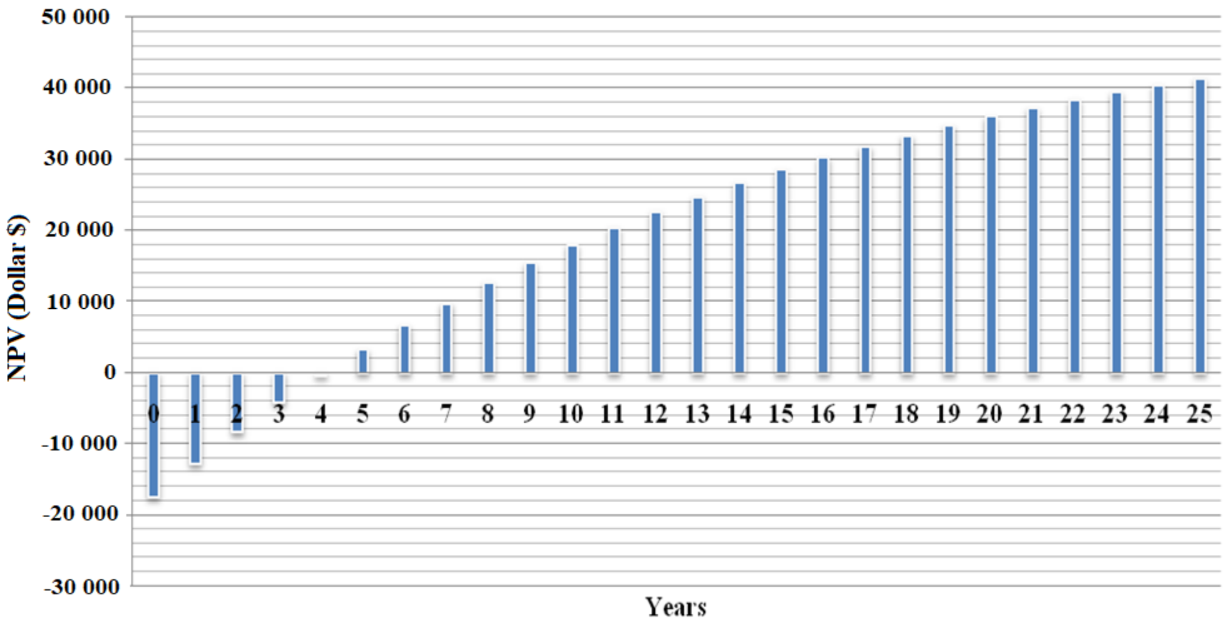

Figure 15. Net Present Value ($) by years.

4.4. Replacement of the existing transformer with another of high energy efficiency:

The voltage transformer of the Faculty is of standard energy type with a nominal power of 630 kVa. The maximum load rate of the installed transformer is 23%, annually. This charge rate is low which indicates an oversizing of the transformer. If we take into account the power reductions achieved in the projects previously discussed seen above, the load rate will be further decreased to around 20%.

This will lower the efficiency of the transformer and accelerate the end of its life [39]. As a result, it is proposed to resize this transformer with a nominal power of 200 kVA and belonging to the amorphous energy class with higher efficiency.

The estimated energy savings achieved by this project can be estimated by:

$$AES = AEU \cdot (E_{ee} - E_{std}) \tag{16}$$

where AEU is the annual energy consumption (kWh), AES: annual energy savings (kWh), E_{std} is the standard transformer efficiency rating (%), E_{ee} is the energy-efficient transformer efficiency rating.

Table 9 tabulates the net energy savings resulting from applying the above action plan compared to the initial situation. As can be seen, the annual energy savings are estimated to be 7.19 MWh/year. The investment is assessed to be 1 500 $ which gives a PB of 2.32 years.

Table 9. Annual energy savings achieved by an amorphous 200 kVA transformer.

	Current situation	Future situation
Transformer power	630 kVA	200 kVA
charge rate max	23%	80%
energy consumed by Faculty (MWh)	479.45	
Transformer efficiency	98%	99.5%
AES (MWh/year)	7.17	

5. Conclusions

This article presents an energy audit methodology for tertiary buildings where the activity starts in the morning and ends in the evening. This is the case of administrative buildings, educational buildings, universities, museums, etc. The example of audit presented was carried out for a university establishment of higher education located in Morocco. From the analysis of the history of the electrical energy consumption of the last three years and the inventory of the lighting systems of the Faculty, it was possible to make a global energy balance of the electrical balance of the Faculty. The lighting system accounts for approximately 38% of the overall electrical consumption, the heating system 13% and the staff housing 20%. The remaining equipment such as air conditioning, ventilation, etc. was estimated to account for 29% of the total energy consumption. The 48-hour continuous power quality measurement of this facility showed the existence of non-standard harmonic pollution. This harmonic pollution is general for all tertiary buildings due to the massive use of electronic devices. Based on these measurements and analyzes, an energy efficiency improvement plan was identified. For each proposed action it was calculated the energy to be saved and the associated financial gain related to the power reduction. This last gain is often disregarded in energy audit reports. The proposed actions were harmonic filtering, LED lamps, installation of a PV system and resizing of the transformer.

For the harmonic pollution it was proposed to install a passive anti-harmonic filter. The simulations showed an improvement of the power quality and reductions in the called powers. For the installation of the PV system on the roofs of the Faculty we have proposed a method of analysis to have a dimensioning in total self-consumption and without injection. Another remark that we have indicated in this article is the change of the transformer, given that the actions proposed in the energy audit reports allows reducing the power demand in kVA which makes the existing transformer undersized. Therefore, the reduction of the power of the existing transformer is among the profitable actions to propose.

The AP_{max} power reductions resulted in reducing the subscribed power and achieving a financial gain on the power charges (PC + FEPC). For the three proposed projects: filtering of harmonics, LED lamps, installation of a PV system, the calculated financial gains are significant and represent respectively 18%, 24% and 12% compared to the initial situation.

Conflict of interest

The authors declare no conflicts.

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