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Implementation of a Methodology to Perform an Energy Audit with Academic Purpose

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Abstract

This article proposes a standard methodology to implement a detailed energy audit as a tool to quantify the efficiency, executed in four phases: visual inspection, data collection, measurement on the electrical equipment, interpretation of results and analysis and comparison of data with the Ecuadorian Construction Standard NEC-11. The methodology is presented as an academic practice, to teach the engineering student to perform an energy diagnosis in any place or sector where electricity is consumed to encourage an environmental conscience associated with consumption. As part of the proposed method an audit in a Faculty's engineering laboratory is performed, to adjust the proposed steps and verify their ability to detect the energy consumption, electrical distribution facilities and luminaries' types. The audit application allowed to effectively determine the possible improvements that can be made to reduce the power consumption by means of capacitor bank installation to regulate the power factor, redistribution and change of lighting, fixed shade elements placement to avoid natural light glare, maintenance planning of electrical installations in poor conditions, and placing an insulator on the main switchboard. This is an example of some simple improvements for reducing electricity consumption and to optimizing the comfort for lab users. This exercise shows that the proposed methodology can quantify energy efficiency and is a good guide to consumption alternatives.

Keyword: energy audit, energy efficiency, consumption optimization.

INTRODUCTION

Energy is an important parameter for the development and growth of society, and its correct use is key to sustainable economic growth. High demand from the transport and industrial sectors as the main dependents and consumers has allowed the fluctuation of prices of fossil fuels and electricity, affecting the energy and economic structure of countries around the world [1]. Ecuador is part of the Kyoto Protocol; whose overall objective is restricting or reduce greenhouse gas (GHG) emissions [2]. Strategies to achieve this goal include the change in lifestyle, cultural aspects and habits of millions of people, particularly if there is adequate or efficient energy consumption; either scenario contributes to climate change in a positive way [3]. Historically, Ecuador's energy matrix has been based on oil production and they have not given importance to renewable energies. The primary energy demand in the country in 2016 was 95 million barrels of oil equivalent (BOE); the sectors with the highest participation are transport (46%) and industry (19%) that generates GHG emissions of 24.5 million of carbon dioxide tons equivalent ($CO2_{eq}$) accounting for 65% of total emissions; while the residential and construction sectors represent 15% [4]. One of the problems in Ecuador is that many buildings are energy deficient, there have no adequate maintenance programs, it's technology is obsolete, there are no plans for energy savings and they have an inadequate equipment use, all of their generates a high energy consumption. Currently, the Ministry of Electricity and Renewable Energy (MEER) aims to improve energy performance in the public, industrial and residential sectors by promoting the efficient and sustainable use of energy in all its forms through the generation and implementation of policies, plans, and projects [5]. There are different types of energy audits that allow to analyse the current installations, to later identify aspects related to energy consumption and from the obtained data generate a model for the improvement of the detected critical points [6] [7]. Based on the above, the research sought to create a methodology to apply a standard energy audit for academic purposes to determine in a building sustainability standards.

METHODOLOGY

Evaluated buildings

The research was carried out in the buildings that function as laboratories of the Mechanical Engineering Faculty of the Technical University of Ambato-Ecuador. A diagnosis of the use and efficiency of energy, consumption, electrical distribution in the evaluated installations and luminaries types were made to establish an energy-saving plan. This model is intended to be applied in any building on campus so that the student can replicate this energy audit at home other spaces in general.

Energy audit stages

The first stage is known as preliminary evaluation, where the basic information about the facilities is gathered. The second one is called detail; the information is collected for the equipment classification. The third one corresponds to the results analysis, was an energy balance is carried out; analysing the performance indexes detect the measures that allow to demonstrate savings through the energy reduction loss, an analysis to option for better technologies and a study of the improvement of networks distribution. In the fourth stage, a proposal is drawn up and conclusions are made (final report) identifying and analysing the consumption parameters and the reduction of it for energy saving; a feasibility and cost study is included [8] [9].

Ordinal method of weighted criteria correction

This model allows determining a preference order of a valuation of global alternatives, without is use full evaluating aspects of each property, considering the concrete and important results [10] [11]. This in order to get method weighting tables were each point of view is compared with the others, considering the following values: 1 if the row criteria has high level than the columns, 0, 5 for similar criteria between rows and columns; 0 the criterion of the rows has low level in comparison to the columns, see in Table 1 [10]. From the described energy audits, two possibilities are evaluated to select the alternative with better results; therefore, the preliminary energy audit and the detailed energy audit were analysed.

Once the alternative is determined, it's identified the place where the audit will be performed, since the present study has an academic purpose, will be carried out in the Engineering Mechanical Laboratories; it is intended to standardize this process to in other buildings.

Options weighting

For weighting took into consideration the scope, quality, measurements, and opportunities for improvement, the complete facilities description, time and ease. Table 1 shows the valuation given to each of the alternatives, being Alternative I: Preliminary Energy Audit and Alternative II: Detailed Energy Audit.

Operating calculation model

An energy audit requires an advance planning, it's necessary to maintain an established on order specifying what is done and what type of equipment or instruments will be used. Before applying the audit, the following process was established.

Visual inspection

An interview is a tool design to determinate the starting point of the process and observed the current state of the facilities, construction and electrical plans, connections, equipment inventories, electrical installations, and energy consumption billing.

Information collection

Data were recorded for each device or equipment using electrical energy; and classified into lighting systems, office equipment, and laboratory operating equipment, with the installed loads of each device considering their ideal power.

An AEMC PowerPad Model 8335 electrical network analyser was used to examine the energy quality; and the lux meter EXTECH Instruments Model 407026 to measure the luminous within the facility to diagnose and compare measured values with suggested one in the standard and determine if the facilities are efficient. The advantage of these types of equipment is that are portable and accessible in the local, being available to be bought or rented.

Table 1: Comparison between alternatives based on scope, quality, measurement, facilities and feasibility

	S	Q	M	O	D	T	F	Sumatoria	Priority
Alternative I	0,09	0,08	0,06	0,04	0,07	0,04	0,04	0,41	2
Alternative II	0,18	0,15	0,13	0,09	0,07	0,02	0,02	0,64	1

S: Scope; Q: Quality; M: Measurements; O: Opportunity for improvements; D: Description of facilities; T: Time; F: Feasibility.

Simulation

The obtained information was simulated using the free access EnergyPlus calculation engine, which allows the energy efficiency calculation based on modeling the type of building; with the construction parameters specification, such as the type of material, type of luminary, number of people and hours used [12].

Results Analysis

The obtained data determinates the energy quality, the illumination levels, then a comparison of the measurements with the recommended values in the Ecuadorian Construction Standard NEC-11 is made [13], allowing identifying the points where there is a greater electric consumption energy.

Results Contrast

Energy simulation is a very practical tool to get a sustainable building or to modify buildings already in operation, considering compliance with standards and technical specifications [14]. The objective of using this software is to obtain an energy simulation and compare with the information obtained from the measurements [12].

RESULTS AND DISCUSSION

To test and adjust the proposed methodology, a test was carried out at a university laboratory. The results for each stage of the process are shown, and allowing to establish a reference of the actual energy efficiency values.

Analyzing results

To analized electrical energy quantity process, it requires the inspection of the transformer, the connections, and main board distribution, in order to identify the ideal installation site for the electrical network analyser equipment. During this process the following work sequence was carried out; to locate a suitable installation place, to install and program the equipment to evaluate the indications with the national regulation of electrical energy quality and wit the obtained results.

Several tables summarized the results of the measurements. Table 2 shows the frequency; Table 3 indicates the voltage; Table 4 contains the short duration Flickers; Table 5 shows harmonic voltage; Table 6 contains the Power Factor; in Table 7 the Active, Reactive and Apparent Power; Table 8 the active power consumption.

RESULTS ANALYSIS

The energy audit analyses the results obtained in the diagnosis of the energy consumption; the electrical distribution in the installations and the types of luminaries to detected critical points of power concentration are analysed.

The frequency measurements, show a minimum data of 59, 94 Hz being outside the allowable range, but it doesn't represent a considerate, is less than 1%. The maximum frequency data is 60, 03 Hz. The overall average frequency is 59, 99 Hz been this value an indicator of the quality of the frequency supply to the network. For the voltage, the nominal value is 127 V. The values of recorded voltages should not exceed 5% of the total when compared to the allowed limits of the total voltage recording. Permissible voltage variations should represent ± 8% of the nominal voltage value the in urban areas. To comply with the stipulated limits for the maximum regulation it should be between137,16 V and 116,84 V which would represent ± 8% of the nominal voltage (127 V). Analyzing the data in Table 3, we noticed voltage variations that protrude from the minimum permitted values. From the total number of registers obtained, the voltage peaks don’t have any significant problems; in addition, the outside permitted values only represents 0, 17% of the total measurements.

The analysed laboratories don’t cause problems in terms of voltage harmonics; the registered values are almost imperceptible because the laboratories have an academic use. The total average power factor considering all three lines is 0, 9, being a value below the allowed. The minimum value of the power factor is 0, 92. It must not exceed a maximum of 5% of power factor values lower than the limit set by the regulation. The average power factor (fp) recorded is outside the allowed range stipulated by the Electricity Regulation and Control Agency (ARCONEL), producing irregularities in the Electricity Consumption [15].

The value on line 2 was 0, 09 which is critical because according to the regulation the minimum load factor value should be 0, 92. Line 1 and 3 were register at minimum values of 0, 57 and 0, 54 respectively, which, when compared to the minimum allowed, are low these values they appear during the use of equipment such as the Machining Center and equipment requiring a considerable electrical burden.

The maximum apparent power recorded was 10, 91 kvar and represents the total power consumed and the, it's the product of the effective values of voltage and current, the total maximum reactive power was 3, 44 kvar, this value is the product of the effective values of voltage and intensity considering the total measurements. The maximum measurement of reactive power was 10, 44 kW and it's accordance with the measured data mentioned previously.

The Energy data recorded indicate the value of the consumption recorded during the measurement period, it's the active power in units of kWh. The value to be considered is the demand of maximum active power that was recorded during the days of measurement of 160.46 kWh, by means of the analysis of demand for active power can determine the consumption that and it approximate cost. The monthly average consumption is 147770 kWh by the University during the period of 2015 and early 2016.

With the data obtained from the illumination measurement, an analysis and contrast with the values established in the Ecuadorian Construction Standard NEC-11 [13] are performed. Detecting some system failures, so a redistribution of the luminaires is suggested and LED technology is chosen to optimize the consumption. It is proposed to replace the 32W T8 fluorescent lamps with their equivalent in LED which is a T8 of 16 W, reducing to 6216 W of 3216 W of load installed by the luminaries.

Table 2: Allowed and registered frequency in the analysed laboratories based in the nominal value in Ecuador (60hz).

Frequency registration (Hz)			
Registered	**Average**	**Minimum**	**Maximum**
	59,99	59,94	60,03
Allowed	**Minimum**		**Maximum**
	59,95		60,05

Table 3. Measured voltage registration of values provided by CONELEC Regulation 004/01 in order to quantify the supply quality.

Voltage values			
Voltage	**Maximum (V)**	**Average (V)**	**Minimum (V)**
V1 RMS	129,00	126,75	123,90
V2 RMS	129,10	126,89	124,10
V3 RMS	128,50	126,43	123,00
V1 RMS MAX	130,90	127,86	125,10
V2 RMS MAX	130,50	127,95	125,30

Table 4: Flickers data registration for short-term measurement in the analysed laboratories.

Flickers data registration			
Voltage	**Maximum**	**Average**	**Minimum**
Line 1	1,70	0,39	0,15
Line 2	2,41	0,40	0,16
Line 3	3,15	0,39	0,14

Table 5: Total harmonic distortion registry for the three lines.

Total harmonic distortion values (%)			
Line	**Maximum**	**Average**	**Minimum**
V1 TDH L1	1,30	0,66	0,30
V2 TDH L2	1,40	0,86	0,40
V3 TDH L3	1,60	0,84	0,40

Table 6: Load factor value registered with network analyser.

Load factor registres			
Line	**Maximum**	**Average**	**Minimum**
Line 1	0,99	0,96	0,57
Line 2	0,97	0,86	0,09
Line 3	0,98	0,88	0,54

Table 7: Apparent, reactive and active power registration.

Apparent power				
Load type	**Maximum**	**Average**	**Minimum**	**Units**
VA Total	10,91	1,19	0,00	k VA
VA 1	3,95	0,56	0,00	k VA
VA 2	3,50	0,23	0,00	k VA
VA 3	5,19	0,40	0,00	k VA

Reactive power				
Load type	**Maximum**	**Average**	**Minimum**	**Units**
var Total	3,44	0,25	-1,04	k var
var 1	939,17	19,03	-616,08	k var
var 2	1,32	0,09	-0,26	k var
var 3	1,54	0,14	-1,23	k var

Active power				
Load type	**Maximum**	**Average**	**Minimum**	**Units**
W Total	10,44	1,12	0,00	k W
W1	3,85	0,54	0,00	k W
W2	3,33	0,21	0,00	k W
W3	4,96	0,36	0,00	k W

Table 8: Energy values registration, considering the maximum demand.

Energy registers		
Load type	**Maximum**	**Unit**
Wh Total	160,46	k Wh
Wh1	78,34	k Wh
Wh2	30,02	k Wh
Wh3	52,10	k Wh
VAh Total	171,19	k VAh
VAh 1	80,66	k VAh
VAh 2	32,82	k VAh
VAh 3	57,70	k VAh
varh Total	36,49	k varh
varh 1	4,88	k varh
varh 2	12,45	k varh
varh 3	20,08	k varh

DISCUSSION OF RESULTS

The adoption of energy efficiency and it's direct influence in the consumption reduction of costs and carbon emissions that pollute the environment has gain attention of academics and professionals from emerging countries.

Unfortunately, energy audits are not commonly practiced for the monitoring of energy use so the non-execution of public policies in Ecuador for energy management and the lack of awareness about the with obtaining and using of has become a barrier to the application of the term energy efficiency in the country.

This paper describes a methodology for the application of an energy audit with for academic purposes, limited to the application in a laboratory, but it can be used in the domestic and industrial level. It has been demonstrated the energy audit utility to collect useful information to define a model that analyses the energy balance of the place, detecting the critical points and possible solutions, to reduce energy costs.

The energy audit is a useful tool to help identify problems and opportunities to improve, directly related with the energy cost consumption, the present constructions in the country consider the minimum requirements in terms of efficiency in their facilities. A study needs to explore the direct and indirect complexities that prevent the adoption of strategies to reduce energy consumption [16]. The sector of industry and construction in Ecuador has not been concerned about the carbon emissions come from this sector; they don't understand the relationship between energy and carbon emissions; which implies an important challenge to the government for the consumption reduction costs and the generation of emissions associated with this sector.

While efforts from the government in recent years have not been enough to reduce energy intensity in the country, the efficient goal construction will be a challenge given the lack of interest or concern of people. A review of existing policy should be undertaken to discuss suitability and design alternative approaches.

In this context, the government can help strategic sectors such as industry and construction to establish training centers to improve knowledge of energy management. The universities should consider energy audits as a learning tool, because a professional in engineering can make it possible to apply the developed methodology and be sustainable to the environment through the time.

CONCLUSION

A proposal has been made for a methodology to the application of a standard energy audit with academic purposes which was implemented in the engineering laboratories. This methodology allows to establish an energy diagnosis is easy to use and can be executed anyplace where there is consumption of electric energy, through the use of locally accessible equipment, that can be rented for a short period (7 days) in order to make the corresponding measurements.

The applied audit in the laboratory will be implemented as a practice to teach students to measure and analyse energy consumption, electrical distribution facilities and types of luminaries. In order to consider alternatives and optimize the system to create an environmental awareness.

The proposed methodology has the advantages that can be used anywhere because the equipment for the measurements are transportable and easily accessible and the used software for the comparison of the results is free access and easy to use. This process seeks to raise awareness of the quality of energy used by the general population in their work or in their homes, and then design and implement energy saving plans that can reduce the cost of energy consumption and apply the concept of energy efficiency.

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