14. Performance variability of the ETSIE of Seville according to the degree of energy rehabilitation

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Abstract The objective of the present paper is to study the profitability of the improvement energy efficiency actions through the analysis of several proceedings in an educational building, in order to compare the economic investment with the performance of energy improvement achieved with the intervention. The study is conducted on a University Building, a traditional construction building of the 60s in Spain, considering energy rehabilitation for minimal regulatory compliance. However, as evidenced by this paper, not all the actions represent a clear economic viability, leaving pending a plus in some proceedings, also because of economic reasons. Once the results of the improvement actions are obtained, an economic and energy comparative is carried out, assessing economic considerations related with costs savings of the energy efficiency actions and with their economic investment, taking into account amortization period as the basis of the viability analysis. The underlying idea of this study is to propose possible alternatives to improve energy efficiency, according to initial situations, in order to go further into valid indicators for energy efficiency actions in educational buildings.

Keywords Energy rehabilitation, Energy efficiency, Educational buildings.

1 Introduction

Nowadays, a large number of energy efficiency studies are revolved around the residential sector [UE.2010]. Nevertheless, energy consumption grows in parallel with economic development, so it seems advisable to optimize energy demand in public buildings, especially, those with high-energy consumption. In this sense, energy rehabilitation in public buildings is considered as a key potential area [M. Fomento. 2014], not only in reduction of energy consumption, but also in relation to public money saving. Increasing energy efficiency of this sector studying the relation between energy savings and economic benefit is an essential step in social stimulation for the paradigm change.

In a concise way, energy interventions in this type of building can be justified with the following approaches:

- Firstly, because the reduction of activities costs is one of the obligations of Public Administrations, serving as an example for the citizens.
- Secondly, because there has to be great availability towards energy efficiency in public sectors to reach technical and organizational agreements, and to identify the most suitable resources, with the practical commitment to improve them.
- Finally, because it is not enough to apply technical solutions and define possible improvement actions. In order to achieve energy efficiency, local, regional and national governments ought to know what critical points are and their possible solutions to be able to influence policy-making and to dispose of appropriate tools depending on energy needs.

Energy efficiency evolution in Public Service Sectors can be assessed through energy indicators, comparing energy consumption with economic or productive activity. In 2004, energy consumption related with Public Service Sectors in Spain – last year with disaggregated statistical data - [IDAE.2007], was around 3.300.000 tonnes of oil equivalent (Toe.), or in other words, 35% of total consumption of the Service Sector and 3% final energy consumption. Over half of this consumption corresponds to electrical consumption, mostly, derivated from building lighting requirements.

However, service heterogeneity of public buildings (health, education, office…), gives rise to different explanatory parameters of energy consumption associated with it. In the case of Public Service buildings, those parameters can be explained mostly because of the number of users and their energy use. In this way, the number of students is used for teaching buildings [IDAE.2007].

The problem is that there is a wide variety of factors that contribute to a rational and efficient energy use: suitability to the context and condition of the building, efficiency of equipment and installations, technologies used, habits and behaviour of users… Thus, when energy performance of a building is being analysed, the first step is to assess the real situation of energy consumption, in order to propose appropriate actions. Moreover, it's needed to bear in mind that energy saving in a building has to be focused on achieving a reduction of energy consumption, without decreasing productivity, quality, etc. nor producing a higher environmental impact than in the initial situation [Sartori. 2007].

On the other side, it's important to record the heterogeneity of installations in an educational centre, buildings that can go from higher educational or University centres to nursery schools, institutes or primary/secondary schools. Besides, it should be distinguished from different types of classrooms and working areas, including spaces such as communal areas, bathrooms, changing rooms, cafeterias, sports facilities, etc. Even though our main objective is energy saving and comfort conditions, the existing variety in educational centres makes it necessary to differentiate several factors, because of the type of activity and user, which will be crucial to focus and analyse different energy projects, considering exhaustive healthiness and hygiene conditions.

Furthermore, although Public Administrations in Spain propose actions to improve their buildings and installations, these proceedings don't consider the relation between final energy saving and the effort required to achieve it [Charlot-Valdieu. 2011]. That's why it's very interesting to provide resources to help in decision-making for the reduction of public buildings consumption with energy rehabilitation projects.

This study shows the analysis of energy efficiency in the Higher Technical School of Building Engineering (ETSIE), University of Seville, which is a building from the 60s and, as we have verified, with a low level of energy efficiency, with the consequent economic cost for the public purse.

In order to analyse the energy rehabilitation and intervention, we've used as a reference the Basic Documents of the Technical Building Code (Spanish regulations), where minimum quality standards can be found. However, the direct application of these standards can lead to a high economic investment, discouraging an intervention from a socio-economic point [Vega. 2010]. These documents are based mostly on the assessment of annual CO2 emissions; nevertheless, several indicators such as annual consumption of primary energy or investment cost of improvement actions aren't taking into consideration [Rúa. 2011]. This information has a significant relevance in terms of knowing the possibilities of an existing building to improve its performance and to foster actions.

2 Objectives

On the basis of arguments developed, this paper is intended to carry out an energy study of the ETSIE through a building comprehensive analysis and its energy situation, in order to obtain a diagnosis that allows us to compare different interventions to improve its energy efficiency and, at the same time, to verify their viability from a technical and economical point of view.

The main idea is the generation of valid, technical and economical indicators, which can be compared with the energy improvements of the building, comparing the estimated cost and the amortization period. With this method, baseline data for energy rehabilitation in similar buildings is provided, especially for those buildings with comparable construction regulations.

What is really important is that this study has been conducted taking into account the current performance of the building, considering influencing factors such as real climate data and temperature values for the thermal enclosure, verifying the inadequacy of some equipment and installations, and being unambiguous about the proposed rehabilitation solutions. Since we have access to utility bills and maintenance manager and users' opinions, it's possible to justify economic savings and financial benefits. Although this last point is vital because technical and economic solutions are crucial in terms of energy management, it cannot be forgotten that the key ingredient is to understand the relation between users and building.

On the other hand, although the building is not a constructive standard model, its use is, so energy efficiency solutions must be objective and meet the needs of energy improvement of current systems. All this will contribute to form a database for general criteria and will allow the comparison of similar cases from a multi-approach analysis.

3 Methodology

This study has been raised following a protocol to combine activities related to energy efficiency certifications and audits [C. Economía. 2011]:

A) Architectonic and constructive building analysis:
- Measurement of floor surface and volume of the building.
- Constructive analysis and thermal enclosure and insulation.
- Glass surface area and orientation of windows.

B) Current energy analysis of the building:
- The average number of users, work schedule and timetable.
- Analysis of supply contracts. This study is vital to obtain values to provide information and determine whether or not current contracts meet the real needs of users or if the contracted rate is the most appropriate considering energy consumptions.
- Study of monthly energy accountancy, disaggregating electrical consumptions from other fuels (natural gas).
- Data request from maintenance service: conditions of equipment and installations to elaborate a maintenance log (ordinary and extraordinary).
- Study of the current equipment and installations, carrying out measurements and parameter records of their operation.
- Calculation of the building power required: in quantity and quality, evaluating thermal and electrical parameters
- Verifying the existence of awareness campaigns towards users. As it has been already said, actions taken by Administrations in order to improve energy ef-

ficiency should set an example to users, so the level of awareness of energy saving must be considered.

- An approximation to the current energy efficiency of the building has been carried out. In order to undertake a quantification of its energy efficiency in terms of kWh/m2, which is an energy consumption ratio per built area unit (converted into useful area), it's crucial to know the use of the installations, the volume of the building and the usage time of its equipment. Thanks to this, we'll be able to assess lighting energy consumption from installed power per area unit.

C) Diagnosis and analysis of different interventions. All the data is registered for later use with computer tools, which will allow us to propose several actions in order to improve the basis of the rational, technical and economic viability.

3.1 Architectural and constructive definition of the building

The building studied in this paper was built in 1964. It has reinforced concrete pillars and beams, in situ concrete and ceramic joists and an enclosure of 11,5cm ceramic face brick, with interior plaster, 7cm air chamber without isolation and 7cm ceramic brickwork internally garnished. The global volume of windows represents 42% of the facades. All constructive data has been introduced in the computer software, creating a virtual image to perform different energy calculations.

3.2 Current energy analysis of the building

Although the building meets the construction requirements in terms of the Technical Building Code (CTE) [M. Vivienda. 2006] and the Regulations for Thermal Installations (RITE) [MIET.2007], we've entered the explained data in a computer software called CE3X [MINETUR.2016] (promoted by the Ministry of Industry, Energy and Tourism of the Spanish Government through the Public Agency IDEA, 2015/06_2.1 supported version as energy certification software since 14-01-2016), in order to conduct an energy rating [MIET.2013] obtaining a kg of CO_2/m^2 emission indicator of around 86.80, which means a D grade, and which could be improved. These results allow us to consider, as a starting point, a primary energy demand for cooling of 2,656 kW and for heating of 2,621 kW.

Moreover, thanks to the utility bills provided by the Maintenance Service of the University of Seville, we know that the average daily electrical consumption was around 0.1223425 kWh/m^2 in 2014. In other words, a global and yearly consumption of 371,529.70 kWh which has been distributed in: Lighting 23%; Equipment 13%; Air conditioning 50%; Offices 9% and Others 5%; and unevenly spread among the year. In the following chart (Figure 1) corresponds to energy consumption in 2014 and it can be observed that in summer months (except for

August, month with no working activity) the consumption rises as a result of air conditioning consumption.

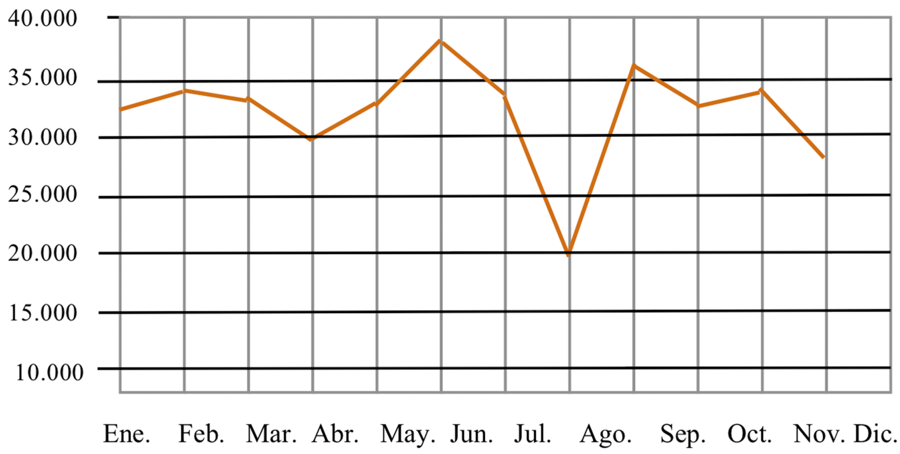

Fig. 1 Monthly energy consumption of the ETSIE expressed in kWh (2014)

3.3 Diagnosis and analysis of different interventions

In order to get to know the current energy conditions of the building, we've used two computer software, CYPECAD-MEP and CE3X [MINETUR. 2007] both based on the Technical Building Code (Basic Document of Energy Saving, DB HE), obtaining energy improvements applied on systems and rehabilitation strategies that achieve a reduction in energy consumption and improve energy efficiency significantly. We've entered the building data in the computer program CYPECAD MEP (Figure 2), which allows a thermal loads calculation and to export data and information to the energy rating software used.

Fig. 2 Virtual images created by CYPECAD MEP

This paper is essentially focused on four parameters [U.E.2013]:

- Building enclosure systems: including roofs; facades; type, size and location of windows in facades.
- Lighting system: type, power and number of luminaries
- Different air-conditioning systems (cooling, heating).
- Ventilation system (forced and natural)

The diagnosis of these parameters is in summary form:

- Lack of isolation in facades and roofs
- Deficient carpentries in terms of thermal conditions: since they are single glazing steel carpentries, there is a high heat transmission into the building.
- There isn't a ventilation system, so air renovation is virtually non-existent.
- There aren't any alternative energy systems.
- A massive number of different air-conditioning systems have been found (all of them inefficient and with lack of maintenance).
- Nearly 100% of the luminaries are fluorescent: they aren't as efficient as they could be, taking into consideration operating hours.

From this diagnosis, it was decided to propose rehabilitation actions focused on energy efficiency improvement and divided into two groups:

- Proposals to improve the building enclosure system:
  - Incorporation of an isolated material in roofs
  - Incorporation of n isolation material in facades
  - Replacement of carpentries and glazing in windows
  - Placement of a solar film in windows faced South
- Proposals to improve installations:
  - Replacement of luminaries
  - Modification of air-conditioning systems

3.3.1 Proposals to improve the building enclosure system

Proposals considered are focused on obtaining an improvement of constructive and installation systems, in order to check how they affect energy performance. Although we've had the opportunity to evaluate different types of improvements considering life cycle assessment, we haven't been able to include conclusions on this matter because of the length demanded for this paper.

To summarise, a table with the conclusions and final results has been incorporated at the end of this section (Table 1):

A1) Incorporation of an isolated material in flat roofs.

Incorporating an isolated material in roofs means a direct reduction of interior heat loss in winter and avoids excessive heating in summer.

Therefore, building energy demand, both in heating and cooling, is decreased, while comfort increases.

An uncomplicated, economic and technical alternative is to conserve the existing flat roofs and place an isolated material above them, such as 50mm of extruded polystyrene, a geotextile sheet and a gravel layer. With this solution, roof thickness only grows 16cm; however it derives a sustainable energy improvement.

A2) Incorporation of an isolated material in facades.

Between all the possible alternatives to isolate facades, an injection system of isolated material into the air chamber has been chosen because it's the most feasible method from a technical point, as the studied building has to be operated 11 months a year. This proceeding also means a cost reduction while allows similar energy improvements to other systems. That's why we consider it to be an appropriate solution in order to verify energy efficiency in terms of climate aspects, before constructive parameters. In order to study a specific case, we've opted for a polyurethane injection (Um: 0.49 $W/m^2 \cdot K$) into the air chambers.

A3) Replacement of carpentries and glazing in windows.

The original and existing carpentries of the building are made of steel and they're sliding windows with single glazing of 4mm. The glass frame and glass renovations are usually an effective action because new systems (which are much more efficient from an energetic and thermal point of view) allow the introduction of comfort improvements and provide an aesthetic rehabilitation of the facades. Likewise, we're aware of the fact that decreasing energy consumption utilizing an appropriate window essentially depends both on the type of glass and shading elements used, such as setbacks, overhangs, awnings or blinds. That's why we've opted for maintaining the existing system and incorporating double-glazing with internal air chamber solution.

A4) Placement of a solar film in windows faced South

Since more than 30% of windows are faced South, this intervention is considered to be appropriate for this study. Moreover, these windows have roller blinds as the only shading elements to darken the classrooms, so sometimes it is necessary to consume artificial light, due to teaching activities.

This type of system is characterized for acting as a sun protection filter for the glazing material, reflecting more than 80% of infrared energy. In other words, only 15% of sun energy responsible for global warning passes through, dramatically reducing heat gain.

Nevertheless, the problem is that besides reducing sun's damaging effects and heat, sunlight is decreased as well. Unlike the existing systems, this kind of intervention does not force to global dimming. Moreover, the majority of the manufactures of these products ensure an increase of the effectiveness of air-conditioning and heating systems and, consequently, an energy saving.

We've studied this improvement choosing the model PRESTIGE 70, whose main features can be found in the official website of the trading house 3M.

Table 1 New performances and costs of constructive improvement actions

Improvement type/ Energy rating	Improvement's cost (€)	Primary energy savings (kWh/year)		Global saving (€/year)	Total saving (%)	Amortization period (years)
		Cooling	Heating			
A1/85.0 D	37,902.00	58,240.00	-4,742.40	4,442.50	1.71	8.50
A2/77.8 C	265,800.00	231,795.20	23,961.60	21,238.30	4.80	12.50
A3/77.8 C	316,500.00	281,382.40	-15,641.60	22,067.38	1.95	14.35
A4/79.6 C	18,000.00	221,478.40	-8,320.00	17,700.90	1.51	1.06

3.3.2 Proposals to improve installations

At this point of this paper, we have to state that three basic problems with the building installations, which do not favour energy efficiency, have been detected during the diagnosis: the studied building doesn't have air renovation systems, electrical consumption is very high because of the long hours luminaries are operating and the poor performance of air-conditioning systems.

In relation to air renovation, a complex and technical process, the building's air-conditioning systems don't have mechanical ventilation systems to allow heat recuperation in winter in order to heat the cold air from the outside or to cool the air, significantly improving air quality. Spanish regulations (Technical Building Code for residential buildings and the Regulations of Thermal Installations in Buildings for public buildings) demand a ventilation system providing air renovation, which considerably reduces energy consumption. In this sense, we consider that it'd be convenient to carry out a more thorough analysis of this subject, as the length of this paper inhibits further development.

With regard to air-conditioning systems, we've verified that heating systems (mainly radiators) operate four months a year (November, December and January – months when work activities decrease – and February), because of the latitude. However, cooling results show disproportionate performances, which is one of the most critical issues in terms of energy. Concerning the orientation, it's important to indicate the high number of classrooms (nearly 50%) faced South, with large windows and without any type of cantilever to provide shading during the summer. This results in a quickly indoor air overheating

The main problem presented is that the studied building was designed without cooling systems, which has driven to incorporate individual air conditioners for each teaching space. Some of them are cool production systems and others combine cool and heat production; however, all of them are gas-cooled. The main drawback is that there are almost 300 hundred units and most of them are Casette or Split type, without air return, from several manufacturers and with different frigories (similar to BTU) and technical properties. We've also found numerous "fan-coils" for heating in winter and cooling in summer. Nevertheless, these machines don't allow an optimum use of the heating system since they need high water temperatures (from 70º to 75ºC), with the resulting energy waste. Furthermore, maintenance and cleaning requirements of these systems is crucial because dust and dirt on the interchange surface must be avoided to prevent from a decrease in heating performance.

Given the size of this paper and the huge number of different air-conditioners, we haven't been able to include this improvement in the analysis. However, we believe that it'd be an essential part to reach final conclusions, since a great fraction of energy consumption is produced during spring and summer months (except August) and early autumn, as it can be verified in the electricity billing.

For these reasons, in the installations' improvement actions we'll focus in the reduction of energy consumption caused by luminaries, because they can easily operate up to 16 hours a day in certain areas of the building. The approach used has centred on the replacement of the existing luminaries (fluorescent tubes) by LED lamps. With this technology, a higher performance is obtained and, at the same time, energy consumption is decreased around 50%.

Although we've been able to verify that in some areas, such as study rooms, the brightness of the existing luminaries is superior to that required by the regulations, the followed process has been to maintain the level of light (luxes) and check primary energy saving obtained, meeting the requirements of the implementing regulation (CTE-DB-HE3). In this sense, we've obtained the following results: Current installed power: 49,618.00W; and improved power with LED lamps: 25,427.00W (Table 2).

Table 2 New performances and costs of installations' improvement actions

Improvement type / Energy rating	Improvement's costs (€)	Primary energy saving (kWh/year)	Global saving (€/year)	Total saving (%)	Amortization period (years)
B/63.74 C	146,826.16	58,240.00	49,212.88	51.24	3.70

4 Conclusions

From this paper, we can draw the following appropriate conclusions:

Firstly, we have presented an analysis in an individual way with improvements related to energy efficiency and consumption that derived from intervention proposals, which allows us to obtain a comprehensive view of their financial viability and profitability. Although we believe data provided is a first approximation to the main objective of this paper, which is to analyse the variability of performance efficiency, we have to place on record that this analysis should be completed with detailed calculations, considering the simultaneous combination of improvements.

Either way, with this study, it can be confirmed that the replacement of luminaries or any other of the improvements proposed can lead to an energy rating of C (between 54.7 and 84.1 $kgCO_2/m^2$ annual emissions) or even B (between 33.7 and 54.7 $kgCO_2/m^2$ annual emissions).

In relation to the subsequent conclusions, it is verified that interventions regarding the building enclosure system (both for thermal improvement of roof and facades, and the replacement of carpentries and glazing, which are simple interventions from a constructive point of view) seem disproportionate if their financial cost is compared with their efficiency improvement, since their amortization period is over 10 years, limit considered efficient for amortization period by Andalusia University Administrations, since what we propose in this first step of energy efficiency analysis is to evaluate solutions directly related with a real economic reduction, leaving for a later study qualitative, environmental… assessments.

One notable feature is the evaluation of constant energy consumption caused by the amount of time lights are on. That's the reason why the replacement of the existing luminaries by others with higher efficiency and less energy consumption (LEDs) is believed to be technically and economically feasible.

It's also interesting the assess of the effectiveness of solar films in windows faced South, thanks to the great contribution of direct solar radiation. It is a simple technical intervention with a short amortization period. Although solar films may have a negative impact on the heating systems, they are quite effective to reduce cooling energy consumption, reaching acceptable costs.

With regard to air-conditioning rehabilitation (cooling and heating systems), although it's an analysis that exceeds the limit of this paper, we believe it would be an essential intervention in terms of energy rating and efficiency improvement of the building's existing air-conditioners. Nevertheless, it must be borne in mind that there are three different possibilities to thermo regulate educational buildings, due to rooms' diverse heating requirements. On the one hand, classrooms, study rooms and labs occupied by a large number of people; on the other hand, administrative and service staff and teachers' offices; and, finally, transit areas and corridors. For this reason, a complete analysis should take note of the usage of spaces as thermal areas, incorporating a thermo-regulation system to allow keeping different temperature in each area and improving lighting systems, for instance, with presence detectors or lighting flow dimmers, etc. or analysing in detail aspects related with comfort, temperature, humidity…

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