Continuous Improvement Meets Energy Auditing: An Energy Audit Tool for IST

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Abstract

Although many steps are being taken to improve energy use in buildings, current energy audit tools, and the energy audit process itself for large buildings still do not address continuous improvement over time. Despite many tools have already been developed to help energy auditors, and the energy audit process itself is well defined by now, no tool leverage the possibility of reusing measures from both Energy Conservation and Operation and Maintenance data from the audit report to identity appealing opportunities if the prices of the materials involved drop. This work aims at developing and validating a complete data model, that is able to store all the information relevant to the energy audit process, and give auditors the possibility of testing different scenarios and store them, in order to be applied when the costs involved are worth the investment. Moreover, the tool includes actual energy prices and working periods, so the auditor can get an estimate of the period costs, presented in graphs that can be viewed according to the auditor preferences. The validation of this model is accomplished by comparing the results obtained to the ones gathered throw a classical energy audit. The results obtained allow us to say that the model developed can cope with an energy audit.

Keywords: Energy Audit, Audit Tools, Audit Process, Scenario Creation, Data Model

1. Introduction

Energy Auditing (EA) aims at inspecting and analysing the energy flow of a building or system through a database in order to reduce the amount of energy spent [22]. EA became a very important field during recent years, since it can be used to implement energy efficiency measures and achieve energy conservation, mainly in the industry sector that was responsible for 43% of the final energy used worldwide in 2011 [10]. Since most energy sources are finite [2], their cost will keep rising [8] and therefore energy usage has to be traced and understood to be better managed. Therefore, there is a need for Energy Auditing [16].

Since EA requires gathering, analysing and evaluating all the relevant information of a facility, an Energy Auditor is needed [5]. This information is saved for later analysis in order to suggest possible improvements, that will result in energy efficiency measures. Although this may look simple, and straightforward, it is not [21]. And if a tool would be able to easily create and save scenarios over the current conditions, allow the continuous update of data without needing to redo all calculations, or to alert the energy auditor to changes in the building, this tool would vastly increase the ease of EA.

EA gathers data regarding the building envelope, and power consumption sources, schedules or periods, weather factors and energy prices into databases that end up containing a lot of information, which is very hard to explore manually. EA should be done taking into account a vast variety of information about the building (e.g. walls, ceilings, floors, doors, windows), the energy appliances (e.g heating, ventilation, air conditioning equipment, lights), environmental aspects (e.g. weather, solar orientation), and the energy bills of the previous years as well as data regarding the time at which the building is operating, and at what capacity. This is done in order to identify if there are areas in which the costs raised more than expected, and also, to detect appliances that although didn't suffer from an increase of use cost, have become outdated and can be replaced for newer, more efficient technologies, that have proved to be more efficient [3, 15, 19].

The EA process is by now well defined and includes a number of proven steps that should be taken to assure positive results. These steps will be detailed in the next chapter. Although several tools have already been developed, some auditors are currently still using ad-hoc approaches to analyse data, such as spreadsheets [1], which although easy to use and a cheap solution, do not meet the performance requirements of state off the art EA. These approaches often require a lot of manual interaction, delaying the acquisition of relevant information. Sometimes these approaches also lead to data corruption resulting in false assumptions and inadequate measures to improve the energy efficiency.

Other barriers to the use of energy audit tools have also been identified [17], for example, due to transaction or hidden costs related to these tools, and even organizational and behavioural constraints. Since most tools available although offer an appealing price and a huge variety of solutions, they some times require extra modules to be bought or don't fully implement the functionalities promoted. At the organizational and behaviour side, these barriers usually relate to the lack of information and the notion that a computer program cannot be as thorough as the auditor and will end up raising the costs of EA unnecessarily. Another shortcoming of current systems is the ease of use when dealing with a large amount of information. And, most importantly, they don't allow to accurately predict and implement possible improvements, through the creation of different scenarios, and the ability to recall old measures that were discarded before, due to its costs.

Nowadays, auditors after performing an EA propose solutions to current shortcomings and try to estimate how much time is needed for these changes to be paid, taking into account their benefits. A value for the Return of Investment (ROI) is given and all changes made should fit within the established limits. Otherwise, most often, improvements are discarded, regardless of future drops in the costs involved, that can result in lower ROI periods that may fit within the established limits, and vastly decrease current energy costs.

1.1. Motivation

Consider that an Energy Audit has been requested on a large building. The auditor will start by retrieving all the relevant data that he has access to, and store it. The auditor then needs to make a more thorough assessment and goes around the building inspecting, (among other detailed in Section 2.1), the Heating, Ventilation and Air-conditioning (HVAC), the building characteristics, as well as windows and doors to check for possible insulation problems. Actual measures from a different set of devices are also retrieved in order to get a more precise estimate of their consumptions. The auditor will then include this information in a tool and perform an analysis over it, recommending possible Operation and Maintenance Measures (OMs) and Energy Conservation Measures (ECMs). This analysis is extremely labour-intensive, since the data gathered from different sources can prove to be quite different than expected. Furthermore if a mistake is made it is almost impossible to track it backwards since there is a lot of different data and sources. Moreover, any changes made in the original data can affect the final results and the auditor will need to perform a new analysis. The auditor, then needs to compute the costs of any measures he wants to recommend. Taking into account the market prices of the materials he recommends replacing equipment, depending on estimates of ROI.

Sometimes, replacement measures can prove to be expensive given the possible savings and are discarded, making all the work previously done pointless, furthermore the following energy audit will most likely report the measures pointed before. But, as new ones, hence entering on a full cycle. Therefore the need for a new tool, and a new look at the current process, one that can vastly improve the ease of use of these processes, and the final efficiency results achieved through the implementation of the suggested measures, by saving them and alerting the auditor when they become feasible.

1.2. Problem Statement

So far there are no tools that can continuously analyse scenarios and calculate their ROI measures. Furthermore, current tools lack the ability to easily update costs of materials and equipments, or to update measures of energetic efficiency, and even, one that can, based on saved scenarios, automatically recalculate the ROI periods of these, and if this scenario measures become more advantageous, or within the selected range, accordingly alert the auditor.

Auditors would benefit largely if a tool could deliver the features stated above, since they would be able to perform the following tasks:

a) Create, save and update scenarios with new information.

b) By updating the prices of materials and equipments, and being automatically alerted to changes in saved scenarios the auditor would be able to implement the proposed measures, change these, or modify the ROI period at which the auditor desires to be alerted.

c) Easily change efficiency values of current equipments and be alerted to changes, that make currently saved scenario measures more appealing.

d) Be able to make a complete EA using a tool that allows the auditor to have access to all relevant information at hand and updated.

2. Background

2.1. Energy Auditing

Energy Audits are an analysis process aiming at discovering operational and equipment improvements that will reduce energy consumption [18]. These audits follow a process that is by now vastly well established [20]. We will now detail all the relevant concepts that relate to Energy Auditing.

The Audit Process itself, involves three key subprocesses, coarsely speaking, that involve gathering information about the building, confirming the information and process it [20].

An energy audit, depending in the level of detail desired, will be included in one of the following three levels of analysis, with increasing complexity: *(i)* Walk-through assessment, *(ii)* Energy survey and analysis, and *(iii)* Capital intensive modifications and computer simulation. These levels have been defined by the ASHRAE 100-2006 standard [4], that also introduces a level 0, where a preliminary analysis is made taking into account the total costs compared to similar buildings.

Information regarding each space in a facility (e.g. office, room, meeting room, hallway, etc.) needs to be prepared first. Only then the power consumption sources are to be modelled. Besides physical location, power consumption sources are modelled taking into account their power characteristics (Watts). This information enables the auditor to compute multiple indicators such as the total consumption on each floor, or the total consumption of, for example, all the light sources in the building. Indicators are fundamental in order to understand and prioritize areas for closer attention.

Apart from these data, the energy auditor must also have access to the electric demand, load factor, base load and seasonal load. The first of these states the amount of electricity being consumed at a given time, this value often varies during the day, while the second, the load factor [23] relates the average load by the peak load at a specific time period. Base load defines the minimum amount of power needed to keep the facility working, and seasonal load relates to the energy needed to power heating or cooling, usually apart from the base load.

2.2. Energy Information Systems

The rising energy cost have led to a growing awareness regarding energy efficiency both in residential, and industrial buildings, as well as government buildings. This demand led to the appearance of Energy Information Systems (EIS). EIS are broadly defined as performance monitoring software, data acquisition hardware, and communication systems used to store, analyse, and display building energy data [9]. In other words these systems intend to turn the data recovered trough several types of analysis, electric bills or real time measures, into useful information in order to provide managers with the knowledge not only to know how much they are spending and where, but more important with the ability to make informed decisions about how to reduce those bills and increase the energetic performance of buildings. These improvements are even greater when accompanied by a permanent monitoring and metering of data [14, 12, 6].

2.3. Energy Auditing Databases

Energy Auditing Databases allow energy auditors to save the data acquired in a well defined database. These databases are generally modelled in a restrictive way that does not allow the users to access or alter as much information as they would like. These should also take into account security measures that can be taken in order to prevent the adulteration of data, such as, user privileges or a history of the data modified by each user. This section will detail the most common practices in audit databases, and how auditing database are built and being used.

2.4. Building Information Models

Building Information Models (BIM) represent, characterize, and relate concepts of a given facility, involving physical and functional characteristics of a building in a digital representation. The resulting models allow users to acquire knowledge about a facility in order to support decision-making processes through the Architecture, Engineering, Construction and Operation (AEC/O) phases with several benefits regarding other approaches [7].

2.5. Discussion

As stated above, most EIS do well when it regards to modelling the building and the power sources but both IFC and gbXML have proved to be better at this point. TRACE 700, performs very well when dealing with the HVAC system, but do not address any other areas. Another aspect in which EIS proved to have an advantage over the others, is the scenario creation, although AD systems also perform well. Most of AD systems however do not allow to properly model the building envelope or power sources, neither they produce a real audit report. Since they just compare results with existing old reports. Also the ease-of-use of the tools described before could be better. The analysis of each of the systems presented in this section can be seen in the thesis.

Most importantly they all miss the possibility of, after creating the scenarios, being able to resume then at a later time, to implement some of the measures left on hold due to excessive costs of the involved materials that result in high ROI periods, or simply the lack of funds.

The solution proposal presented in the next chapter, will address specially these constraints, and detail measures to improve others that are missing or that have flaws in the current systems.

3. Proposed Solution

To achieve the goals depicted before and to address the faults identified in the work already done, see Section 2, this document presents now a solution proposal. We present an EIS solution that takes into account the concepts related to EA and the positive aspects of the work previously done in this field, namely the work done regarding BIM, with Industry Foundation Classes (IFC) and gbXML, or the existing databases that allow to compare scenarios and the Energy Use Intensity (EUI) of similar facilities.

3.1. Database Modelling

To fully satisfy the requirements of the EA tool, detailed in previous chapters, the model must support different buildings, power sources and schedules, plus all the variable data, such as energy costs or product costs. Since both IFC and gbXML have already implemented a good model, they are a good starting point, despite their limitations. IFC uses a model that includes a huge number of elements that do not pertain to the nature of EA. On the other hand, gbXML uses a simple model, but lacks some key features, such as the ability to model adaptable or joint schedules or to model scenarios.

Data Required Facilities are usually organized according to floors and offices, and can have more than one building. This means that apart from the data needed to model a building, other kinds of information also have to be represented about the campus itself. Furthermore, specific to the subject of EA, data about the construction materials need to be retrieve and kept. Apart from these, the building envelope, the lighting and HVAC systems must also be modelled. Lighting systems include, among other, information about the space in which they are installed, the amount of fixtures, the condition of luminaries, or the power of these. This is needed to enable the audit to predict localized consumption (not only the total building).

Materials and Power Prices To accurately perform an EA, the auditor needs to be able to have access to up-to-date information about the prices of materials he intends to use or replace, and the cost of energy at a given time. This information plays a big role when calculating the ROI period and any changes can made in the audit proposal. For this reason a list of materials with prices and specific information must also be kept. Apart from that, costs of energy must also be kept, taking into account the time of day and load factor. This final information is provided by the electrical company and a complete list of materials is usually provided by manufacturers and resellers.

Modelling Schedules and Periods The auditor should be able to select different schedules and periods that represent the most common patterns of activity and energy usage. Schedules are often related to the time of day, or to the season, among others. For example the database needs to be able to relate at any given time different schedules or periods. An example of this would be to state that in the winter season, the HVAC system and luminaries will be performing at a given capacity from 8AM to 6PM, and at reduced capacity from 12AM to 8AM. In contrast during the summer season, although the time periods may be kept, the weather conditions will change. The tool presented will allow auditors to fully adapt these schedules and periods to the needs of the building being audited.

Scenarios Scenarios are views over the current facility, that allow to implement changes and have a perspective of what would happen if, for example, a given facility would replace all light bulbs by new ones, with a lower power consumption. These scenarios grant auditors with the capability to test different solutions and estimate the outcome of the measures being equated. Scenarios will be created and stored using both current data and new information, by updating the state of the facility or the prices of energy and equipments. Updating the values of efficiency on current electric appliances can have a great impact on the energy consumption of the building, possibly making previously created scenarios more appealing. Furthermore, changes made to the energy cost, or to the price of new materials will also affect saved scenarios. Despite being able to change current values, it is very important to make sure that the data stored is not changed by mistake and that only when improvements are implemented these are visible in the building outlook, all other changes should be made on the scenarios.

Audit Reporting Our tool will be able to report about the conditions of the building in a summarized manner allowing the auditor to easily

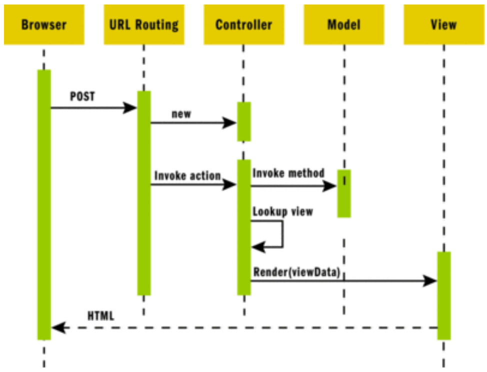

Figure 1: The Model View Controller application model sequence diagram, where it is possible to see how the requests are treated.

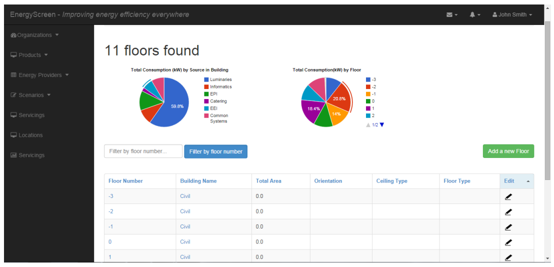

Figure 2: Overview of the layout in Desktops. On the top centre of the image it's seen how the results are displayed, and on the bottom the list of floors in the building being audited.

identify possible improvements and test them. All the data used for the analysis will be presented in tables, and the results of the analysis will be displayed on graphics so the auditor can easily access it. This data will be presented according to the space that is under analysis, for example although all the building data can be reached by the auditor at all time, he will also be able to view the consumption in each floor, room or building individually, with the results being grouped by source type, product or space and displayed in watts consumed or Euro.

4. Implementation

4.1. Development Environment

The developed application is intended to be used as a Software as a Service (SaaS), with well known benefits mainly with respect to integration, costs and availability [11]. Taking this into account, we choose to use the Play framework in order to develop the application as a scalable web application in Java. Play applications follow the Model View Controller (MVC) architectural pattern, used to design user interfaces for web applications. MVC divides the application in two main layers: *(i)* Model, and *(ii)* Presentation. The presentation layer itself is then divided into: *(i)* View, and *(ii)* Controller. Figure 1 illustrates a MVC sequence diagram where it is possible to see how a request is handle in a application. The Controller layer is responsible for receiving HTTP requests and sending HTTP responses, after a HTTP request the Controller layer extracts the relevant information and send commands to the Model layer to update it's state, if necessary, this layer is also responsible for updating the View layer to make it reflect any changes implemented. The View layer retrieves information from the Model and renders it into, typically, a user interface. Finally the Model layer is the domain specific representation of the information the application uses, all the application logic should be performed in this layer.

4.2. Database Management System

As stated in Section 3.1 the developed application will take a large number of data and needs a complex database to support it. We decided to use MySQL since it is a free solution with large support, and both scalable and flexible. Plus MySQL was designed and optimized for web applications powering 9 of the 10 most used websites [13], such as , Twitter or Wikipedia. The database is located in the same server has the application thus improving the performance while performing all the calculations related to the EA.

4.3. Hardware

Since the developed application can be used as a SaaS, the server just needs to comply with the minimum requirements of Play Framework and MySQL, Play recommends a minimum of 728 MB of memory but in most cases 512 MB are enough. In order to accomplished that we choose to use the Amazon EC2 platform in which the we can use a free virtual machine that grants access to the application everywhere, as long the user has access to the internet. The application can be accessed by the auditor has a simple web page, see Figure 2, removing the need to have access to a powerful computer. Furthermore the web application can be accessed throw mobile terminals, allowing auditors to make quick surveys or to fix possible problems without much effort.

In order to deploy the developed web application in EC2 virtual machine, the only steps required are to set-up the Play framework and MySQL in that machine.

4.4. Web Application

This section details the choices made during the development of the web application regarding the main topics that were approached.

Database Model In order to fully satisfy the requirements of a EA we present some of the entities that were created in the database:

Building Envelope, in order to model the physical aspects, and characteristics of the building under analysis, the building envelope contains several entities, such as organization, building, floor or room.

Room Equipment entity relates, to three other entities: *(i)* Room, *(ii)* Servicing, and *(iii)* Product. It's main purpose is to join equipments with a specific room. The servicing entity, that will be detailed next, is used to set the periods of time that each room equipment is functioning.

Product contains the general description of each product, additionally the specifications of each of these products are detailed according to the product type, seven different type of products are allowed

Model Layer As said before this layer not only specifies how the information is stored but also performs all the logic associated with the application. When defined the models it's necessary to assure that all the data that will be later inserted by the auditor complies with the database definition. In order to do this Play provides a set of constraints that are used to verify the data fields when an update or insert action is trying to be performed by the application. Several constraints are used across the Model layer.

@Constraints.Required This constraint defines the attribute as required, this definition relates to the MySQL as a NOT NULL value.

@Constraints.MaxLength(value = X) Used to set the maximum length of an attribute. Since most values in MySQL have default maximum lengths it's necessary to set this constraint in order to prevent conflicts between the database and the Model layer that would result in an error.

@Constraints.Email Verifies that the attribute were this constraint is set follows an acceptable pattern for an email, for example abc@ist.pt.

@Constraints.Pattern(value = PATT) This constraint allow the application to verify if a data field being updated or inserted follows the correct syntax for that attribute. This constraint is used to verify that the zip code attribute is saved with the following pattern: 0000-000, or if a TIME attribute is saved as: hh:mm:ss.

@Id Specifies the attribute as a primary key in the model, this means the Model layer will not allow any data to be saved if the attribute marked as id does not have a value.

Besides defining the attributes and guaranteeing that they are used correctly, the Model layer also assures the application logic. This means that all calculations that are relevant for the EA are performed in this layer. As an example when the auditor accesses a web page where there is information about the total consumption, in watts, of a building, or the total estimated costs, in Euro, for that same building, the View layer asks the Model layer to performed all the actions necessary to return the data. All functions are defined in their related classes, for example to retrieve the information about a building the View layer asks the Model layer to use the building class in order to get the data, if the building class needs data from other classes to perform the needed calculations, the building class is the one responsible for accessing other classes, the View layer only has access to the related model.

View Layer The View layer is responsible for rendering the data received by the controller and for displaying it. For each entity in the application there are usually three different views associated, *(i)* List, *(ii)* Create, and *(iii)* Edit. This is done because each of this views require different attributes and perform distinct actions that could not be done in the same view. Additionally, a set of filters can be applied to each view, these have been implemented to aid the auditor and were chosen taking into account the attributes of each entity and their relations with other entities.

Controller Layer The Controller Layer handles the requests made throw the View Layer and applies them in the Model Layer, when necessary, it is also responsible for rendering this information to the View Layer. In order to do this the Controller implements six main methods, for most of the entities detailed before. It's important to notice that the Controller view does not implement any logic in its methods. Errors are checked using Play framework methods, that on their own verify the data present in the forms, and after data is inserted or updated in the database using Ebean.

Audit Results Audit results are presented in a graph. Like this the auditor can get a visual aid to understand how much energy each facility or equipment uses when working. The graphs allow the user to navigate throw all the possible choices with the mouse while the results are being displayed. If the user wishes to focus in a given result he can select that area of the graph and it will become highlighted and display both the percentage of the total consumption as well as the amount of energy that the select facility or product type uses, if the graph relates to installed power consumption. The results are displayed under three main areas: *(i)* Installed Consumption, *(ii)* Period Consumption, and *(iii)* Euro Consumption. In order to obtain the final results, under each main display method, the application needs to retrieve several data taking into according each equipment type.

Scenarios The ability to create and update scenarios was seen as a key functionality in the development of the web application. It involves several entities, and allows the auditor to verify if changes in the current environment will result in long term saving. After all the changes are saved the auditor can request for an estimate about the ROI period. The ROI period calculations are done taking into account the costs involved in, for example, replacing a equipment, and the savings estimated by using the new products. If the auditor desires he can also reflect the expected energy variation on the graph obtained.

5. Evaluation

To validate the implemented solution, real data, regarding IST, was used to populate the database and validate the solution presented in this work. The data was acquired resorting to the current equipments present at "Pavilho de Civil", in IST, that has already been audited and will be used as ground for comparison. Among others, this includes, information about the building envelope, power sources and periods.

5.1. Audit Data

Entity	Number of Entries
building	1
floor	8
room	592
room_type	17
product	115
room_equip	1705
servicing_tt	85
servicing	8168

Table 1: Describes the total number of entries under each entity, retrieved from the audit report.

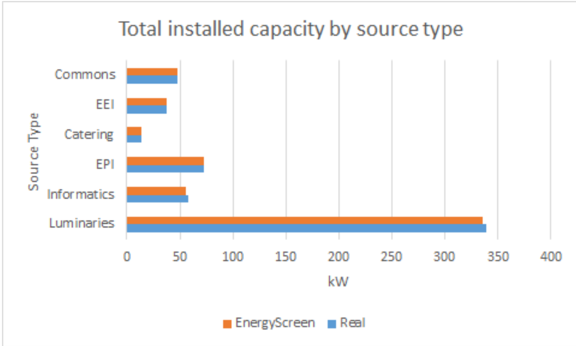

Figure 3: Comparison between the results of the audit report and the toll developed, taking into account the total installed power.

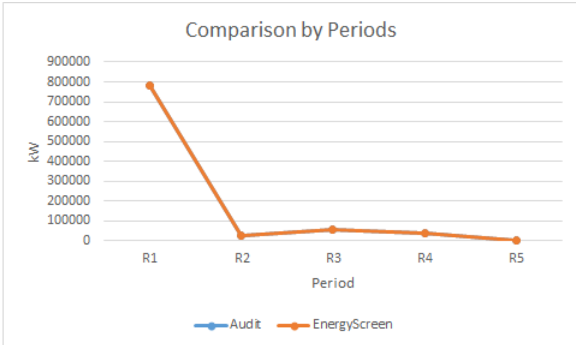

Figure 4: Comparison between the results of the audit report and the toll developed, divided by each of the periods modelled.

Since the available audit was not developed with the intention to be used as ground for this work, we had to process the entire data, in order to be able to use it to populate our database, while maintaining all the relevant data, in the end we obtained a total of 10691 entries, as seen in Table 1, that were loaded into our database so they could be used to validate the solution presented.

5.2. Audit Results

In order to validate our solution we retrieve the total consumptions under two main areas. Total installed power, by type of equipment, and total used power, by period and type of equipment.

Installed Power Consumption We started by computing the total amount of power installed in the building, this represents the maximum number of watts a facility can consume. Figure 3 presents the results obtained with our tool in red and the audit results in blue. It is possible to see that both bars are very similar, in order to calculate the similarity we start by calculating the relative difference:

$$\frac{|X - Y|}{(X + Y)/2} \quad (1)$$

Then to retrieve the similarity we subtract from one the result and multiply it for 100, to get the similarity percentage:

$$(1 - (\frac{|X - Y|}{(X + Y)/2})) * 100 \quad (2)$$

Product Type	**Similarity Percentage**
Commons	99.9916
EEI	100
Catering	99.9773
EPI	99.58
Informatics	94.7354
Luminaries	99.0623

Table 2: Describes the similarity percentage calculate taking into account the results obtained with our toll against the one retrieved from the energy audit, regarding the total consumption sources installed.

Table 2 shows the similarity percentage obtained by applied the above formula to the results seen in Figure 3. In Section 5.3 we will discuss this results.

Period Consumption At this point we applied the formulas to get the consumption under each period. Figure 4 present the relation between the results obtained with our tool, in red, and the results from the energy audit, in blue, by period. It is possible to see that the lines overlap throw the results, with only the informatics source type having a slight difference.

In Table 3 we present the similarity percentage obtained for each of these cases tests.

	Similarity by Period				
Type	**R1**	**R2**	**R3**	**R4**	**R5**
Commons	100	100	100	100	100
EEI	100	100	100	100	100
Catering	93,31	100	100	100	100
EPI	93,95	99,83	97,09	100	100
Informat.	99,94	60	64,77	64,77	100
Lumin.	100	100	99,84	100	100

Table 3: Describes the similarity percentage calculate taking into account the results obtained with our toll against the one retrieved from the energy audit, regarding the total consumption by product type taking into account all periods.

5.3. Discussion

Considering the data retrieve from the audit report and taking into account the results obtained and presented in here, we can conclude that the purposed model completely copes with the objective that has been defined, developing an EA tool that can aid the auditor while performing an audit.

We can observe from the results that the total installed power, obtained throw the tool developed, has a very high similarity percentage, above 99 %, as seen in Table 2, except in the informatics product type. We ascribe this to the fact that the original audit report has some issues regarding equipments that are not attributed to a given space, and we decided not to include them in our model. The same problem was been identified for the luminaries product type, but in this case in a much smaller scale, with only seven bad entries, as observed in the results.

When grouping the results obtained, after applying the time periods servicing, and according to the product type, it's possible to see that the Plug-In Equipment (EPI) are the only ones that fall under the 95% barrier, although the catering equipments are only a small percentage above that limit. We impute this results to the fact that the original audit report includes some mistakes, when dealing with decimal numbers. It was observed that the total consumption is higher than 0, even when the total number of hours is 0. After evaluating the data, we assume that when copying the results on the original audit report the decimal numbers were, in some cases, rounded to the closest number. This fact has proved to have a higher impact, when analysing the results obtained according to the product type and splitting them into the periods set previously. It is possible to observe in Table 3 that the similarity percentage in the product type informatics is not acceptable for the periods R1, R2 and R3. This deviation is specially noticeable because the total consumption in this periods for this product type is very low, bellow 4000 kWh/year.

Taking into account the results obtained, and their comparison with the original audit report, we can conclude that the developed model and the logic associated with it, fully comply with what was desired when developing this work.

6. Conclusions

This work presented several contributions, of which we can highlight the creation of a web application that allow the auditor to completely model a facility and all the power sources included in it, as well as working periods and energy providers, in order to perform a completely Energy Audit. Furthermore the auditor can create simple scenarios, using has a base the current facility, and see the effects that occur when adding, replacing or removing equipments. We intend to provide auditors with a tool that can be easily accessed and that provides all the relevant information needed, minimizing the effort involved in performing such an audit.

6.1. Retrospective

As discussed through this thesis EA still faces many challenges, but recent concerns made this an area to focus in. We start by introducing the most important concepts related to EA, as for example the current process or the different levels of detail needed for a given energy audit.

The work already done in this field still faces some limitations, and as discussed, the related work in areas such as EIS, AD and BIM, although address some of these limitations still fail when dealing with, for example, the creation of scenarios or the continuous update of data, and the corresponding changes in the scenarios developed that affect the ROI periods. The ROI is usually the main factor when deciding if the investment being made will bring relevant benefits to the energy usage and total costs. Current EIS also have some limitations regarding the data allowed, mostly when it concerns to the building envelope, and most fail to include the possibility of creating schedules. On the other side, BIM based solutions offer a complete solution to the building envelope and power consumption sources but neglect both the user interface and most importantly the creation of scenarios. The available tools concerning Auditing Databases (AD) focus primarily in providing data for auditors to compare their building with, but neglect all other factors.

We propose a solution that vastly increases the potentiality of EA tools, by addressing features as the scenario creation and update, the possibility to change current values of, for example, energy costs or equipment prices. All these factors contribute to the continuous improvement of EA in a facility.

6.2. Achievements

The main focus of this thesis has been to develop a tool that can cope with Energy Auditing while also addressing it's related subjects, taking this into account the main achievements of this work are the following:

Existing work and concepts with an emphasis on EA, the processes involved, and levels of analysis associated with them. As well as an analysis about the different technologies being used in this field and their weaknesses and strengths, under three main areas, EIS, AD, and BIM.

A complete database model that copes with all the requirements identified under the EA subject and includes key aspects retrieved from the analysis made to the related work.

A audit application developed as an web application that allow the auditor to model the entire facility and retrieve accurate audit results, while also having the possibility to create scenarios, or include products from several manufacturers and suppliers.

6.3. Future Work

The implementation of this work involved several technologies, that allowed to provide the auditor with a tool that can cope with all the equipments identified in a real audit report, and provide the audit results under different approaches, total power installed, consumption by period or in Euro, taking into account the time at each equipment is active. Apart from this capabilities there is still space for improvement in the following subjects:

User Management with this feature the tool developed would be able to accommodate several auditors, from different facilities, while maintaining the data confidential. It would also be possible to add roles to users so they could access only a set of the total information, or to prevent them from changing the audit data.

Consumption by month would allow the auditor to estimate consumptions according to the month. Although in the current state, of the web application, it is possible to divide the consumptions according to the periods, that already provide a good baseline, the display according to each month would be a good plus.

Extended Scenarios Creation the current scenario creation feature can be further developed to allow auditors to apply changes to entire rooms or floors, and not only to room equipments. Like this it would be easier for the auditor to estimated the total savings when, for example, he wished to replace all the 50W bulbs in a given floor for energy saving ones, that consume less power.

Data Uploading feature would allow users to load, for example, the building envelope to the model using a IFC file or the current equipments list throw an excel sheet. This would vastly increase the ease of use of this tool, since, as an example treating the data from the original audit report has been one of the main difficulties found while validating the solution presented.

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