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

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I dedicate my dissertation work to my parents, which supported me throw both difficult and successful moments.

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Resumo

Embora estejam a ser tomadas várias medidas para melhorar o uso de energia em edifícios, as ferramentas de auditoria energética atuais, e o processo de auditoria energética em si para grandes edifícios ainda não abordam a melhoria contínua ao longo do tempo. Apesar de muitas ferramentas já terem sido desenvolvidas para auxiliar os auditores de energia, e o processo de auditoria energética em si estar bem definido, até agora, nenhuma ferramenta introduz a possibilidade de reutilizar as medidas recolhidas, tanto de Conservação de Energia como de Operação e Manutenção de dados recolhidos a partir do relatório de auditoria de forma a identificar oportunidades se os preços dos materiais envolvidos baixarem.

Este trabalho tem como objetivo desenvolver e validar um modelo completo de dados, que é capaz de armazenar todas as informações relevantes para o processo de auditoria de energia, e dar aos auditores a possibilidade de testar diferentes cenários e guardá-los, a fim de serem aplicados quando os custos envolvidos valerem a pena o investimento. Além disso, a ferramenta inclui os preços de energia atuais e períodos de trabalho, para que o auditor possa obter uma estimativa dos custos no período, apresentados em gráficos que podem ser vistos de acordo com as preferências do auditor. A validação do modelo é realizada através da comparação dos resultados obtidos para os reunidos durante uma auditoria energética clássica. Os resultados obtidos permitem afirmar que o modelo desenvolvido consegue lidar com uma auditoria energética.

Palavras-chave: Auditoria Energética, Ferramentas de Auditoria, Processo de Auditoria, Criação de Cenários, Modelo de Dados

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

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List of acronyms

AD Auditing Databases

AEC/O Architecture, Engineering, Construction and Operation

BIM Building Information Models

DBMSs Database management systems

EIS Energy Information System

EA Energy Auditing

ECMs Energy Conservation Measures

EPI Plug-In Equipment

EU European Europe

EUI Energy Use Intensity

HVAC Heating, Ventilation and Air-conditioning

IFC Industry Foundation Classes

IST Instituto Superior Técnico

MVC Model View Controller

OMs Operation and Maintenance Measures

ROI Return of Investment

SaaS Software as a Service

Chapter 1

Introduction

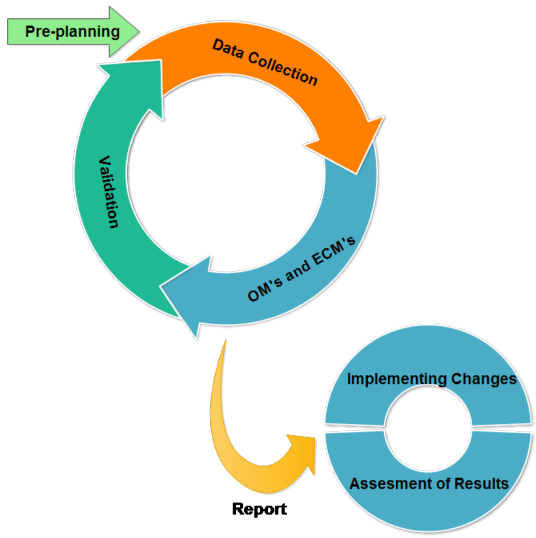
Energy Auditing (EA) aims at inspecting and analysing the energy flow of a building or system through a database in order to reduce the amount of energy spent [1]. EA became a very important field during recent years, since it can be used to implement energy efficiency measures and achieve energy conservation, mainly in the industry sector that was responsible for 43% of the final energy used worldwide in 2011 [2]. Since most energy sources are finite [3], their cost will keep rising [4] and therefore energy usage has to be traced and understood to be better managed. Therefore, there is a need for Energy Auditing [5].

Since EA requires gathering, analysing and evaluating all the relevant information of a facility, an Energy Auditor is needed [6]. 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 [7]. 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 [8–10].

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 [11], which although easy to use and a cheap solution, do not meet the performance

(a) Current Audit Cycle.



(b) Desired Audit Cycle.

Figure 1.1: (1.1a) The current EA cycle involving repeating some tasks multiple times. (1.1b) Alternative continuous check of ECMs and OMs that allows skipping some steps.

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 [12], 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), 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. Figure 1.1a depicts the current EA process cycle, where all steps need to be taken each time an audit is performed, preventing small and cheap changes that can increase savings. 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. Figure 1.1b shows the desired EA cycle in which scenarios are saved after collecting an treating the data, and if the cost involved change later, only a small part of the process needs to be re-done.

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.

1.3 Proposed Solution

To allow a quick change in the scenarios created, and the continuous update of ROI periods making the EA process no longer an iterative process, this work proposes to develop and evaluate a tool that will addresses several points, such as easily updating current data or being alerted to the change of ROI periods, when these change. But also relieves the current EA process of unnecessary repetitions.

To address this task, it's required a different area of expertise that is not usually associated with EA, a Information Systems Engineer, since a Energy Engineer is not usually comfortable dealing with the administration, design of databases, and the modelling of a system like this.

The proposed solution will create an energy audit tool, that will process the data and make it available to energy auditors for consultation and analysis, through a software program. This tool, will take into account all the essential information needed to accurately aid the auditor in his job, this information is depict in Section 2.3.

All the information gathered, is then treated in order to provide actual consumptions by source type, or room type, and presented in different measurements so the auditor can perform a better analysis of the data stored.

The information gathered by this tool, will then aid the energy auditor to make an informed decision about what measures to take, including the possibility of testing different scenarios and all their variants in order to find the most compelling solution taking into account all the information gathered, as stated above.

Moreover, if a scenario cannot be implemented in a given moment, due to the fact that some of the components required may need an initial investment that will cause the project not to be profitable or exceed acceptable ROI periods, this scenario can be saved and resumed, for example, when the costs of the components drop, triggering an alert to the auditor in charge. This functionality will allow auditors to change the current EA cycle and enter a new one, where there is no need to redo all the work done before, but still have the opportunity to make small changes on saved scenarios.

1.4 Methodology and Contributions

To design and evaluate the proposed tool, that addresses in particular data collection and update, scenario creation, and a feature that allows auditors to be alerted when changes to saved scenarios occur, the contributions of this work will be as follows:

– A detailed overview about EA, the processes involved, and levels of analysis associated with them.

– An analysis about the different technologies being used in this field and their weaknesses and strengths, under three main areas, Energy Information System (EIS), and Auditing Databases (AD) and Building Information Models (BIM).

– A proposed solution for the problem described earlier, through a detailed model that allows the creation of scenarios, and the continuous update off most values involved giving the auditor complete control over a facility over time.

1.5 Document Organization

This report is divided into seven chapters. In the first chapter some general concepts are introduced as well as an approach to the problem statement, and the proposed solution. This chapter also introduces a motivation scenario regarding the current approach to EA. In the second chapter, this report, focuses in introducing EA and all the concepts related to it, in order to provide the background required for the later chapters. Chapter 3 presents the state of the art solutions that are available in the different areas involved, EIS (Section 3.1), and AD (Section 3.2), and BIM (Section 3.3), ending with a general discussion about key points of each, both positives and negatives. The next chapter relates to the proposed solution for the problems found and stated throughout this document. Chapter 6 detail how this work was validated and Chapter 5 explains how the final work has been developed. Finally, Chapter 7, this report ends with the presentation of the conclusions withdrawn from the work presented before.

Chapter 2

Concepts

Energy Audits are an analysis process aiming at discovering operational and equipment improvements that will reduce energy consumption [13]. These audits follow a process that is by now vastly well established [14]. We will now detail all the relevant concepts that relate to Energy Auditing.

2.1 Energy Auditing Processes

The Audit Process itself, involves three key sub-processes, coarsely speaking, that involve gathering information about the building, confirming the information and process it [14]. In particular:

Pre-Site Work is related to the gathering of information about the building. This data is gathered through energy bills, the buildings itself (such as plants), and all the electricity appliances.

The auditor should start by collecting the utility bills and inspect these according to different criteria, as for season patterns or unusual spikes. Moreover, transforming this information into graphics aids the auditor in understanding how and where the energy is being used, so he can identify possible savings. Another information that should be kept is the demand, in kilowatts, and the peak demands of energy. Following these steps the the auditor should gather schemas regarding the mechanical, electrical and architectural specifications of the building. Since most facilities don't keep this schemas up-to-date the auditor might need to review these later.

A plant of the building should also be drew, to accompany the auditor in later stages, referencing not only building characteristics, such as gross square meters, but also key aspects to the energy consumption of the facility. The use of audit data forms will also aid the auditor in his work, and should include equipment schedules and all relevant building or equipment information. Information about the building age, occupancy or exposition to weather factors are also required.

Finally the auditor calculates the Energy Use Intensity (EUI), that consists of an expression of building energy use in terms of net energy divided by gross floor area, in order to compare it to similar buildings. Some potential ECMs and OMs can already be developed. ECMs and OMs are also often designated as measures of energy rationalization. Any inconsistency should be noted in order to review it during the *Site Visit*.

Site Visit aims at confirming the information gathered prior to this stage, and collecting any new information that can prove to be relevant, such as occupancy schedules, or operation and maintenance times.

The auditor starts by having a meeting with the building manager to review the energy consumption profiles and discuss other aspects that the auditor couldn't confirm in the *Pre-Site Work*. After this initial assessment the process continuous by confirming the building plant and marking on it all the electric equipments used in the facility, as well as others factors that are found to be relevant. If the auditor feels the need to take real measurements this is usually when they happen. These measures can be taken using portable energy meters or a luximeter, the first ones are used to measure the amount of electric energy used by a electrically powered device, and a luximeter is used to retrieve the level of brightness of a specific place.

At this phase the auditor should revise both ECMs and OMs, as well as organize all the data collected and produce graphs, charts or notes relevant to the audit. He can also take pictures as he goes around the building, since they prove to be a good aid when later producing the audit report.

Post-Site Work is the phase where the auditor should revise all the data gathered during the site visit and organize it into a report.

This is an important phase of the audit process since the auditor will be able to evaluate the information retrieved during the earlier steps and define possible improvements and recommendations regarding mechanical, structural, operational and maintenance aspects of the building.

Both ECMs and OMs are reviewed and those lacking potential are eliminated and an explication is given. Furthermore, and measures that need to be reviewed by a qualified specialist should be noted. All this information should be accompanied by graphs, charts or picture that elucidate and give meaning to the proposed measures.

The report produced specifies the current conditions, followed by possible measures to improve the efficiency through ECMs or OMs measures. This report should follow a given structure and should be written in accordance to the audience. Related literature [14] recommends using the following structure:*(i)*Executive Summary,*(ii)* Building Information,*(iii)* Utility Summary,*(iv)* ECMs,*(v)* OMs, and*(vi)* Appendices.

The steps involved in an EA should follow a given order, as depicted in Figure 2.1, so the audit process can be concluded successfully.

The processes stated above may not all require the same effort, or that all steps are taken. Taking into account the level of analysis desired, some of the intermediate steps can be skipped. For example, if the auditor only intends to conduct a *"walk-through assessment"* the *"Pre-Site Visit"* process can already outline most of the OMs or ECMs required to implement, although without a thorough *site visit*, these can prove not to be as efficient as desired.

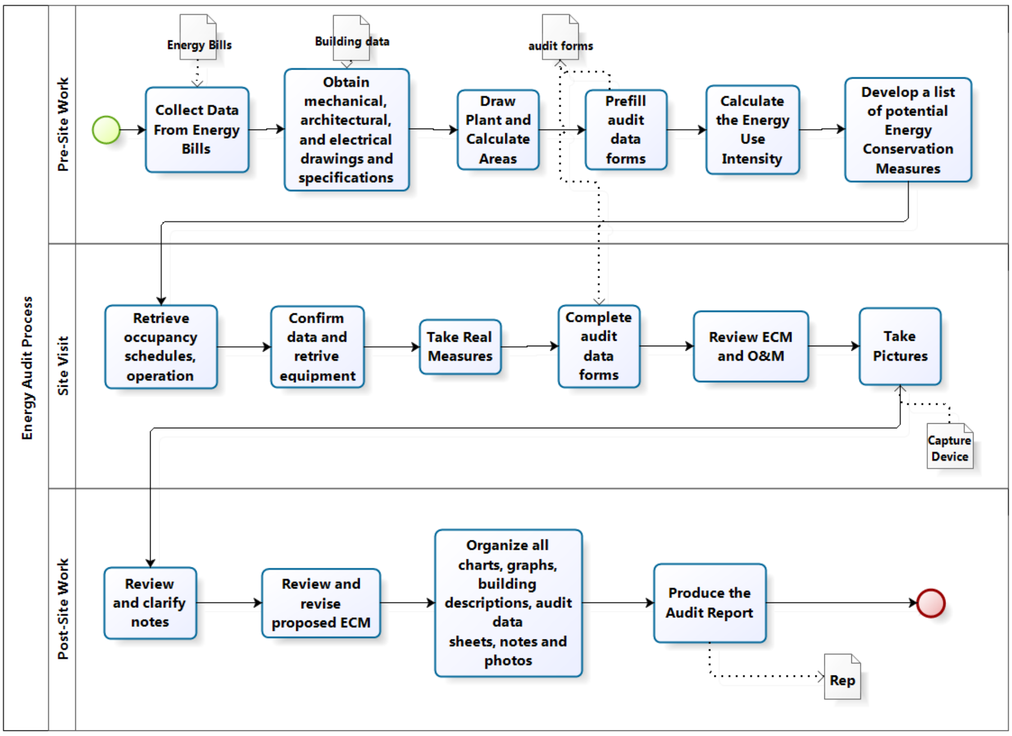


Figure 2.1: BPM of the Energy Auditing processes. Where each lane represents a different phase of the Energy Audit process, and include the most relevant tasks performed.

2.2 Energy Auditing Levels

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:

Walk-through assessment is the least expensive audit and focuses on collecting all the available energy accounts, at least 3 years, and examining the building in order to determine possible improvements and what areas should be more closely examined. This is done by reviewing the collected data and checking for patterns or by comparing the data with other related industries, that are known to have implement what is considered good practices. This level of audit, can also help to determine if a more complete audit is needed.

Energy survey and analysis involves a more complete survey of the building, including the use of energy meters in order to identify important areas for cost reduction, and deviations from a normal pattern. It intends to further analyse energy uses and losses of equipment, systems and operational characteristics.

A complete report should performed and measures on it are usually ranked according to cost and time.

Capital intensive modifications and computer simulation this level includes a more extensive audit in order to evaluate energy patterns. In order to do this, the auditor often develops a computer simulation approach, to act as a baseline, so it can be compared with the actual energy consump-

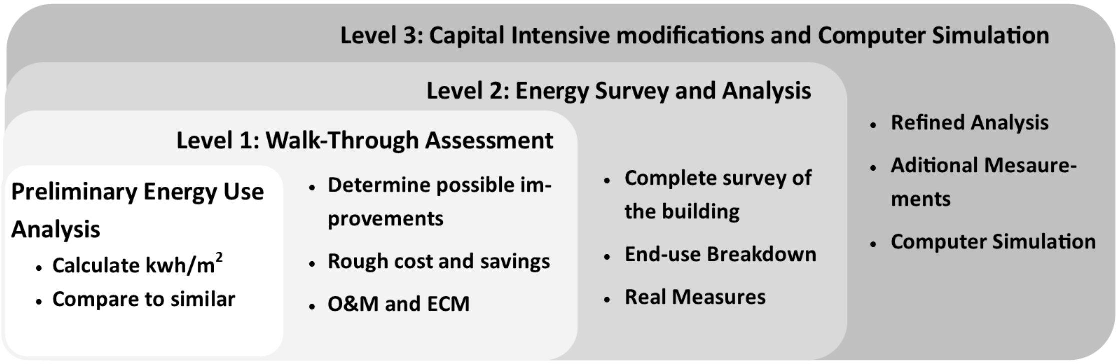


Figure 2.2: Basic levels of Energy Auditing, where each new level includes the above.

tion. Apart from the normal measures used before it can also take into consideration other factors, such as the weather.

Level three is the most expensive, and labour-intensive of the three, but gives better knowledge about the costs, and savings, of major changes made to the building.

These levels, Figure 2.2, have been defined by the ASHRAE 100-2006 standard [15], that also introduces a level 0, where a preliminary analysis is made taking into account the total costs compared to similar buildings.

Although this standard has been broadly accepted as a guideline for energy audits, its recent implementation means that still some auditors use slightly different approaches [16–19]. For example, some auditors divide *level 3* into two, separating the *Capital Intensive Modifications* from the *Computer Simulation*. Furthermore, *level 2* can also be divided into segments.

Most energy audits done today are base on *level 1* since it can, by itself, provide some decent measures, and the costs involved are minimal.

2.3 Auditing Information

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 [20] 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.

This document will now describe the most common data that is retrieved during an energy audit.

2.3.1 Building Envelope

As stated above, information about the building is critical, at least general information about each room is required. Some models [21] specify that at least the size and description of each room must be present in order to be able to make an informed audit. Furthermore, information about windows or room height will also aid the auditor in his job, this last part is more commonly implemented in automated buildings were the lights or HVAC can be turned off remotely according to the time of day or temperature.

The reference book on this field [14], states the following as the most general requirements under three main points:

a) Building characteristics and construction - should include information regarding: Building orientation, Building floor, wall, and ceiling construction details, and Glazing orientation and cooling zones. Such as thickness, conductivity, density and specific heat.

b) Window and door characteristics - detailing Frame type, Window and door area, Estimate of gross wall area, Single or double glazing and their u-value, Glazing coatings, Operable windows, Alignment of operable windows, Cracked or broken panes, Weather-stripping condition, Daylighting, and Skylights.

c) Insulation status - stating the type, thickness and location of the existing insulation, age and condition of the roof, colour of the roof membrane, damaged or wet insulation, and insulation voids.

2.3.2 Power Consumption Sources

Knowing what kind of equipment and where it is installed is of keen importance, it allows not only to know how much energy a room should be spending and to compare it with the actual spendings, but most importantly how much it would spend if, for example, lamps were to be replaced by lower power versions.

In order to be able to make a query about, for example, a floor, the DB schema needs to know how the information is related. Its not only important to model each room and each power source, but also to group them, so that auditors can have the whole view of the building.

The lighting audit should take into account the following two steps: Assess what you have, and Evaluate Lighting Levels and Lighting Quality. The first step includes gathering information about each room classification(e.g. office, storage room, classroom), and room height, width, length, color and condition, as well as the characteristics and number of power sources(e.g. lamp wattage, methods of control, condition of luminaries). The second step evaluates the lighting levels and quality, such as, excessive glare and contrast, or a sketch of the luminary types and their layout in the room.

The HVAC systems are often taken apart from the rest of the electricity appliances due to it's importance in the energy bill. These should include individual audits in each of the systems, heating, ventilation and air-conditioning.

2.3.3 Occupancy Schedules and Periods

Accordingly to the time of day, and week, and month, and even year a building does not consume the same amount of energy. Especially in cases of public buildings since they usually don't work 24/7. In the case of a university, it can be working at full capacity during the week days, but only some rooms are opened during the night period. Furthermore an Energy Auditor needs to be able to distinguish a normal working day from a day during the holidays or even when the university is fully closed.

As an example, the case of the university could have the following schedules:

- Classes
- Exams
- Vacations-Open Building
- Vacations-Closed Building
- Winter
- Between Seasons
- Night

These cases must be defined for each organization performing and EA, so the schedules can be presented in different ways, in order to achieve the desired results.

Other factors, such as the weather must also be considered when performing an audit, since they will affect the total costs especially when performing a month by month analysis, in which for example the outside temperature can have a great impact on the HVAC system use and other electricity costs [22, 23].

Chapter 3

Related Work

This chapter will detail some of the work done in areas that relate to EA. We start by making a short analysis to EIS tools, in Section 3.1, followed by a survey regarding Auditing Databases in Section 3.2 and BIM in Section 3.3. This chapter ends with a discussion regarding these subjects in Section 3.4.

3.1 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 EIS. EIS are broadly defined as performance monitoring software, data acquisition hardware, and communication systems used to store, analyse, and display building energy data [24]. 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 [25–27].

This section will detail some of the most common EIS, since the focus of this study will include measures from both energy bills and energy meters, this section will focus, primarily, on the work done taking into account these restrictions and the known number of users worldwide.

3.1.1 Cake Systems

Cake Systems [1] software is built relying on the SIMPLE algorithm [28] widely used to solve heat transfer problems trough numerical procedures. This software has the ability to provide fast, accurate, and flexible results as it was designed to motivate home owners to reduce their bill through an easy to understand Energy Analysis Report.

The accuracy and efficiency of this system has been put to the test in a 2012 modelling report for energy trust [29] where it was ranked first in the five systems evaluated. This system allows users to

[1] http://cakesystems.com/

introduce several types of data such as space size, type of lighting, or HVAC devices and produces a Home-owner Energy Analysis Report in a easily understood model for energy savings.

Although this system has proved to be efficient in households, it is not recommended for large buildings since it does not perform when many different types of data are included, furthermore this system focus mainly in the building perspective of savings, for household owners, than in the energy appliances used.

3.1.2 EnergyDeck

The EnergyDeck [2] tool, funded by former Google top employee Benjamin Kott, is a community based web platform developed to assist both organizations and individuals to save money with the cost inherent to the energy utilities. It relies on its users to improve the procedures and benchmarks. EnergyDeck follows a simple strategy in order to produce results [30]: *(i)* Track , *(ii)* Analyse, *(iii)* Save, *(iv)* Share. These four points allow the user to track the information received from meters or bills, identify trends, and outliers, as well as benchmarks, and finally save those results. And, if needed share them with other users.

Although well conceived, this system relies in data acquired automatically from data meters, what in the case presented in this paper does not happen frequently. Since most measurements are only done periodically and most data is still acquired through energy bills.

3.1.3 TRACE 700

TRACE 700 [31], developed by TRANE [3], uses dynamic simulation to calculate thermal loads that allow to analyse the costs involved in installing and managing HVAC systems. One of the main problems with this tool relates to the fact that the code is closed and does not allow to add new equipments, the auditor is restricted to the models included originally in their database. Their software tool is accredited by ASHRAE 140-2004 [32], a standard that evaluates the capabilities concerning thermal loads for software programs, thereby assuring the the consistency of the results [33].

It consists mainly by defining the location of the building and loading the respective weather file. Then the auditor is asked to draw the plant of the building and mark where the HVAC systems will be placed and the terminal points, where the system will be used. This modelling also takes into account other factors, such as the lighting system, in a very reduce scale, to perform all calculations.

These calculations go throw five different phases [31]. At first the thermal loads for heating and cooling are calculated according to the user inputs and system used. Second phase, design phase, involves performing the computation of thermal loads, taking into account the conditions the system will be installed. The simulation system air side phase returns the heat gains of the building. Finally the equipment simulation phase estimates the consumption of the system. Auditors are also able to perform an economical analysis of the installation.

[2] http://www.energydeck.com/home/
[3] http://www.trane.com/Index.aspx

Although largely used, this software mainly addresses the HVAC systems, and is thereby insufficient to perform a complete energy audit of the facility, plus, user interaction is hard and users are advised to undergo formal training.

3.1.4 EZ Sim

EZ Sim [4] is a spreadsheet that enables energy auditors and general users to input building information and utility bills. generating graphs and tables for users to diagnose possible problems in the grid. It also allows to get a precise savings estimate for IPMVP protocols [34–36], which estimate the potential of energy savings in order to validate the benefits of improvement operations.

This tool is the closest to what Instituto Superior Técnico (IST) has been using for this last few years, and although, it provides some results, its use in large commercial buildings is not recommended since it will require a lot of user interaction, not only to update the data but also to add new requirements, resulting in the possibility of bad results. Preventing the achievement of the desired performance.

3.2 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.

As stated in Chapter 2, the data is usually divided in two main groups: (i)Building Envelop, and (ii)Power Sources, furthermore to the scope of this work it's has also been include a third group: (iii)Occupancy Schedules and Periods. Each of this, include a large number of information that can be sub-divided, in order to properly access the data. As an example an auditor expects to be able to retrieve information about the power sources in the room 1 of the second floor. Therefore this paper will present some possible solutions to this problem.

There are several databases [37, 38] that include energy efficiency measures and policies that are considered good practices in Europe and should be taken into account. The ODYSSEE database [5], includes information about measures taken in the European Europe (EU) countries and allow users to check the results of those measures over the years, accordingly to the country and sector of activity. MURE [6], allows not only to retrieve measures or technologies implemented in the EU, but also allow users to simulated and compare the achieved results. None of this databases can be modified to include additional elements and, although MURE allows its users to change the data, they are concise to a specific field in a simulation, it's not possible, for example, to simulate the expected results of implementing

[4] http://advancedbuildings.net/ez-sim
[5] http://www.odyssee-indicators.org/database/database.php
[6] http://www.muredatabase.org/

two changes and these can only be made accordingly to the ones stated already in the database. An energy auditor can only find a similar building and simulate the possible improvements of a technology not being able to add key aspects off the building he is auditing.

University of Cambridge presents a paper [39] under the *Personal Energy Meter* project where they encourage users of a building to model it through a software program, OpenRoomMap. Their objective is to develop a model that allows users to model a building and all the electric appliances on it minimizing the initial effort involved in data collection. Returning energy consumption values within 10% of the real values obtained and the possibility of testing scenarios. Despite these theoretical advantages they recognize that such a model is not practical when large buildings are involved due to the fact that, electric appliances although visually well modelled are treated as a group, its not possible to treat for example two HVAC systems separately, since they are seen as one. This solution also makes their scenario creation possibility very limited for most commercial buildings.

The LADY database [40], brings a different kind of energy database, since its use is more indicated for power companies, to support end-use models and load forecasting, but it also allows simulating end-user consumption changes by calculating possible savings that come from, for example, moving off-peak loads. These simulations are very limited and it's not possible to include any other data from a building except from the one being tested.

3.3 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 [41].

This section will detail the most common information models being used and how EIS can make use of these.

The first approaches to data exchange models were made by STEP [42] and COMBINE [43], and focuses primarily in the building design. Recently the Industry Foundation Classes (IFC) has been introduced as the standard format for openBIM, and among other improvements it allows a more extensible and interoperable model [44].

The IFC data model is meant for the full life cycle of buildings, from feasibility, planing and design, until construction and building operation [45]. It was designed to set a consistent data representation of the entire building in an open exchange format. IFC [7] conceptual organization is divided in four layers [46]. At the bottom there's the resource layer in which are defined the basic constructs for the remaining layers, such as Geometry, Actors or Roles. In the second layer, Core Layer, the base entities are then composed in order to define objects for AEC/O, that will be specialized by higher layers. Next the interoperability layer provides modules defining concepts or objects common to two or more domain models providing inter-domain exchange and information sharing. Finally the domain layer provides the

[7] `http://www.ifcwiki.org/index.php/Main_Page`

model with more detail about the processes in AEC/O.

Since IFC main focus is on the building itself, the data stored on it - around 800 entities, 358 property sets and 121 data types - represents a huge overweight for the focus of this document, and some simplified models, specially conceived for the energy analysis, have already been developed.

The EnerXML Schema [47] was introduced has an attempt to standardize a data model for energy simulation representation in XML so that different software programs could use. Its main focus was to simplify the IFC model, since as stated before it includes a huge amount of data overhead, and should be seen as a subset of the IFC that relates specially with energy. It's divided in two hierarchical levels, where the top-level defines seven domain areas, such as Envelop, Schedule or Lightning, and the second level describes the attributes needed to define the top areas. The enerXML project has been dropped, since gbXML was introduced at the same time, and its development gathered a lot of supporters, mainly in the private sector.

GbXML (Green Building XML) schema [8] has been developed to transfer information for the analysis of building envelopes, zones and mechanical equipment simulation in early stages. IFC and gbXML schemas have been reviewed by [48] about their performance to support energy and other environmental analyses. Since it was speciality designed to this purpose, energy analyses, only a small set of information is gathered [49]. Several components that don't play any role are left aside and only those pertinent to the work being done are kept, such as Windows or Roof specifications.

Energy analysis has its own requirements and the models being used today still need to be explored, and further developed, also the energy auditor is still needed. The default schemas proposed still lack a number of functionalities, such as a better scenario testing resource, and are often specially designed to be used before or during the construction of a building.

3.4 Discussion

In the previous sections we have presented several technologies that address the EA problem. Table 3.1 summarizes the features of each, taking into account the features that are more relevant for the nature of this document.

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.

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.

[8] http://www.gbxml.org/aboutgbxml.php

Category	Tool	Features						
		Build. Envel. DB	Power Sources DB	Schedules	Scenario Creation	Scenario Updates	Audit Report	Ease-of-Use
EIS	Cake Systems	◐	◐	○	◐	○	●	◐
	EnergyDeck	◐	●	○	●	○	◐	◐
	TRACE 700	◐	◐	◐	◐	○	○	○
	EZ Sim	◐	◐	○	◐	○	◐	○
EA Databases	ODYSSEE	◐	◐	○	○	○	◐	○
	MURE	◐	◐	○	◐	○	◐	◐
	Personal Energy Meter	◐	◐	◐	◐	○	◐	◐
	LADY database	◐	◐	●	◐	○	○	○
BIM	IFC	●	●	○	○	○	○	○
	enerXML	◐	◐	◐	○	○	◐	○
	gbXML	●	●	◐	○	○	◐	◐

Table 3.1: Technologies comparison between the different systems and the features desired. ● - Fully satisfies the condition, ◐ - Weak to Good performance, ○ - Does not Apply, or its Very Weak on the subject.

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.

Chapter 4

Solution Proposal

To achieve the goals depicted before and to address the faults identified in the work already done, see Section 3, 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 IFC and gbXML, or the existing databases that allow to compare scenarios and the EUI of similar facilities.

The proposed solution, is a tool, partially generated from the model developed and depicted bellow. This tool will address all the key aspects of EA, such as the continuous calculations of energy spent, according to the different spaces involved and different type of energy sources, and combine them with the capability to create and edit scenarios over time. This will allow auditors to model the building under study, or to populate the database by uploading existing data throw MySQL [1]. The tool also aims at being a user friendly tool coping with the user needs, and supported by a well defined model that enables a continuous update of all the information, alerting the auditor to changes in ROI periods when new information is included, or current data is updated.

4.1 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.

This solution will be developed using MySQL in order to properly define the model that feeds the EA tool.

[1] `http://www.mysql.com/`

4.1.1 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. Table 4.1, presents some of the building specific data that needs to be stored in order to properly conduct a energy audit. Besides usual aspects, such as wall heights or windows area, further data needs to be gathered regarding the building orientation, the U-value of windows or the condition of the roof.

Type	Properties	Units
Building characteristics and construction	Building orientation	Cardinal direction
	Glazing orientation and cooling zones	Cardinal direction
	Building floor, wall, and ceiling construction details	m / U
	Room classification	[office, class room, etc.]
	Room characteristics	m / color
Window or door characteristics	Window and door area	m2
	Estimated gross wall area	%
	Single or double glazing, u-value	U
	Operable windows	int
	Cracked or broken panes	boolean
	Weather-stripping condition	[0-5]
	Daylighting	boolean
	Skylights	boolean
Insulation status	Type and thickness	m
	Age and condition of the roof	years / [0-5]
	Color of the roof membrane	color
	Damaged or wet insulation	boolean
	Insulation voids	boolean

Table 4.1: States the most common data, about a facility, gathered to perform an Energy Audit. Unit U measures the flow of heat through an insulating or building material: the lower the U-value, the better the insulating ability.

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). Table 4.2 details the most common additional information that must be retrieved, calculated or stored.

The HVAC system itself contributes to a large share of consumption, making it a big player when it comes to EA and a special attention must be placed on its modelling. Detailed information about the space it is included is vital, plus the information about the system itself. Data about humidity or temperature must be kept, also, the system power (horsepower), the amounts of air that go throw the system at a given point (m^3/s), and most importantly the efficiency of the system.

4.1.2 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

Type	Properties	Unit
Space Characteristics	Lamp Type Numer of Fixtures Condition of luminaries Methods of control Fixture mounting height Ballast Wattage	type int [0-5] boolean m boolean W
Lighting Levels and Lighting Quality	Luminous flux Glare and Contrast Luminous flux recomended	lux g / cr lux
Electrical Consumption	Total Watts Power Density Color of the roof membrane Annual Hours of Use Annual Lighting Energy Cost	W W/m2 color hours €/year

Table 4.2: Shows an overview of the data needed to detail the lighting sources in each space and the corresponding measure unit.

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.

4.1.3 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.

4.1.4 User Queries

Apart from the ability to perform an energy audit, the auditor will be able to view all the data stored and query it. Namely, the auditor should be able to ask the system the amount of luminaries in a given room and their power, on average or individually. Despite being an audit tool the ability to view the digital representation of the facility at any given time is of the most importance, since it many times also helps the auditor.

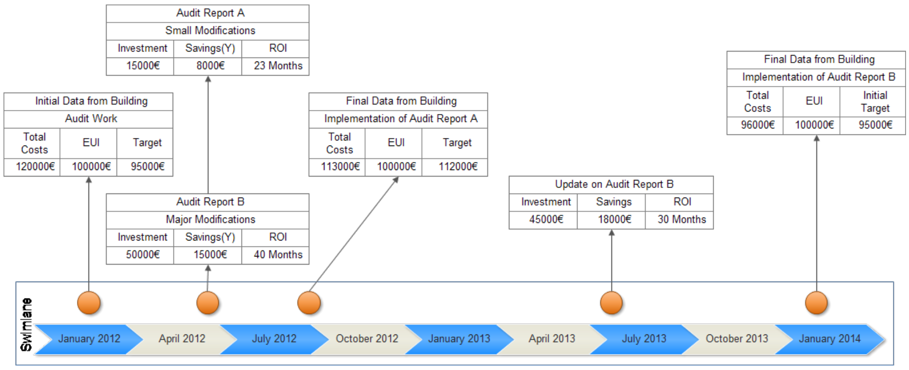


Figure 4.1: Illustration of a scenario of a given facility that is to be audited. Given the initial conditions the auditor the auditor present two reports. Since audit report A has a ROI bellow 30 months it is implemented right away. As for audit report B, the auditor waits until the ROI period falls under 30 months to implement it, in July 2013.

4.2 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.

Scenarios will be saved apart and auditors will be able to resume then, making alterations, marking them as implemented or even completely discard them. Figure 4.1 illustrates a scenario of a given facility that is to be audited. Given the starting conditions the audit tool proposes a solution that can be divided in two. A lighting solution, with a relatively low cost, and changing the HVAC system to a recent one, which involves a greater investment. but has proved to be much more efficient. At first only the first proposal is implement due to the low ROI period. We consider acceptable a ROI bellow 30 months. After some time, the developed tool alerts the auditor that the cost of installing and buying the new HVAC system dropped and further development also raises the savings prediction making this solution acceptable. At this point the auditor can choose to implement more changes or just reuse the old report. This scenario shows how these will work and how the auditor will be aided when the prices of materials drop to a point where the ROI compensates the investment being made.

4.3 Audit Reporting

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

Chapter 5

Implementation

This chapter details the implementation process of the solution, all the phases included in it, and the choices made during the development. We start by introducing the adopted choices regarding the Development Environment on Section 5.1, the Database management systems (DBMSs) on Section 5.2, and the hardware necessary to run the application, Section 5.3. Section 5.4 and its subsections detail how the EA web application was developed and all the resources that are available.

5.1 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 [50]. Taking this into account, we choose to use the Play [1] 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 5.1 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.

One of the main advantages over other frameworks is that it automatically reloads to comply with the changes made in the code, making it easy to scale web applications. Furthermore it uses Ebean [2] to connect to MySQL databases and configure these, through sql files included in the configuration folder, this permits the application to be deployed without having to manually configure the database. Play

[1] `http://www.playframework.com/`

[2] `http://www.avaje.org`

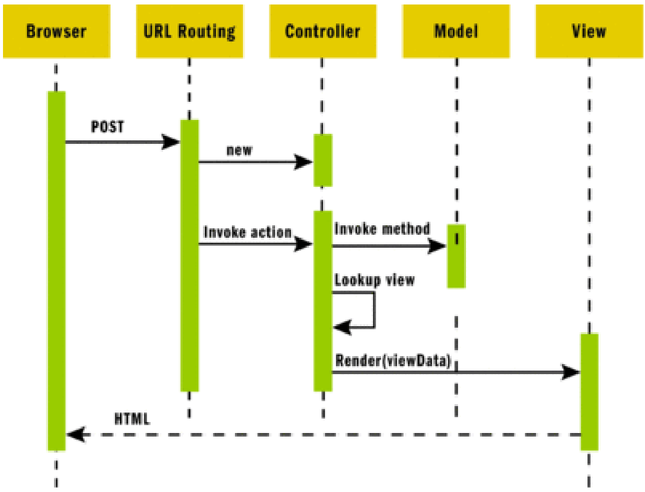


Figure 5.1: The Model View Controller application model sequence diagram, where it is possible to see how the requests are treated.

and Ebean prevent inconsistent data from being introduced in the database by checking that the data complies with the table definition, for example with foreign keys, or data types.

The View layer uses HTML5 making it possible to use several resources to enhance the user experience. The web application page was developed using Bootstrap [3] which is a front end framework that allows for example the application to be used in Desktops, smart phones or tablets without the need to develop any further code. Also JavaScript was used to program the behaviour of the web application, for example to retrieve the consumption data, and Google Charts [4] was used to display that information.

5.2 Database Management System

As stated in Section 4.1 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 [51], such as Facebook [5], Twitter [6] or Wikipedia [7]. The database is located in the same server has the application thus improving the performance while performing all the calculations related to the EA.

5.3 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

[3] http://getbootstrap.com/
[4] https://developers.google.com/chart/
[5] www.facebook.com
[6] twitter.com
[7] wikipedia.org

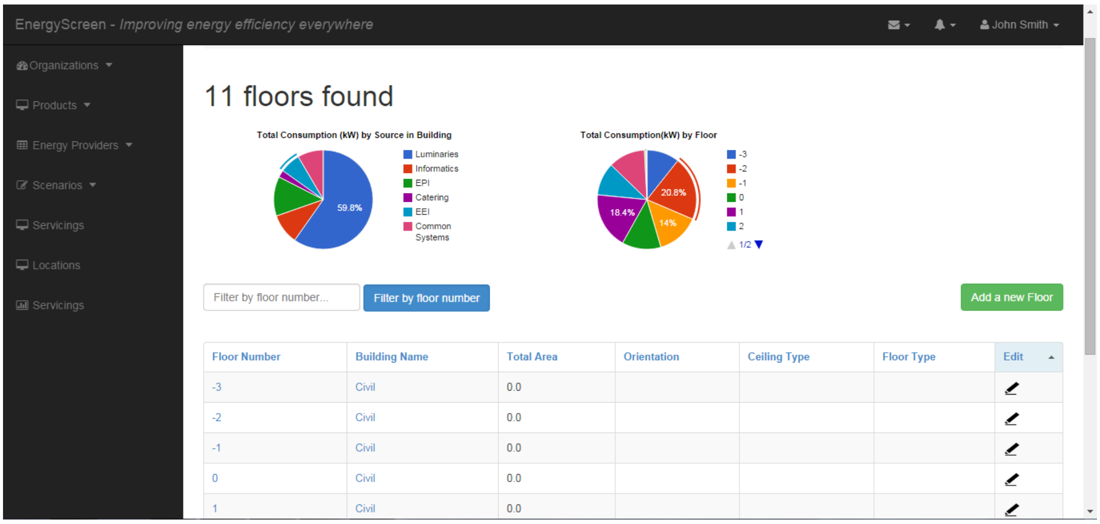


Figure 5.2: Overview of the layout in Desktops. On the top centre of the image it's seen how the results are displayed, and on the bottom the list of floors in the building being audited.

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 5.2, removing the need to have access to a powerful computer. Furthermore the web application can be accessed throw mobile terminals, as seen in Figure 5.3, 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.

5.4 Web Application

This section details the choices made during the development of the web application regarding the main topics that were approached. We start by describing the database model, including entities, attributes and data types,as well as the factors that contributed to it's choice in Section 5.4.1, then we describe the approach taken under the three layers of the MVC model in Sections 5.4.2, 5.4.3 and 5.4.4. Finally in Section 5.4.5 we detail how the audit results are presented and how they were obtained, and in Section 5.5 how the possibility to create scenarios was implemented.

5.4.1 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. Figure 5.4 details how the building envelope has been modelled to comply with the specifications of our test case, and how the associations and multiplicities between entities have been

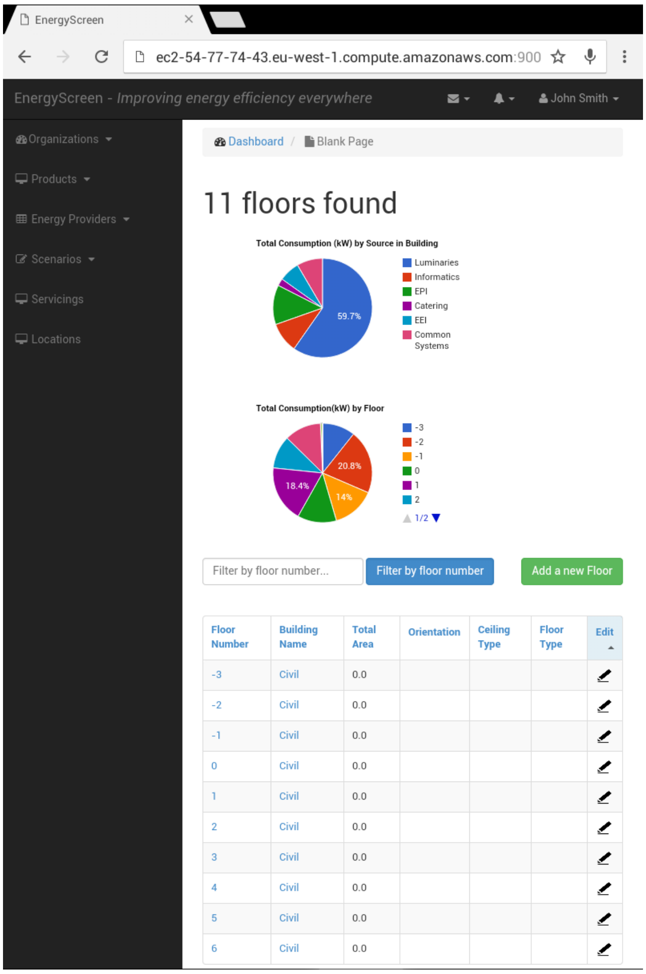


Figure 5.3: Home screen in smart phones or tablets, it's possible to see that the menus adapt automatically to the display size, as well as images and lists.

defined. Although the main focus of the development has been for our test case, the model can cope with other types of buildings, such as residential buildings, just by giving a generic name to the organization entity. Attributes on each entity have been chosen taking into account the relevant data that has been identified in Table 4.1. Additionally, entity relationships and multiplicities were set to prevent errors, such as modelling twice the same building, and to allow the auditor to follow a natural order when walking through the organization. Furthermore, the entity room_type classifies each room according to its specific use, two examples of these would be a room type classroom or office. This allows for example to check the total consumption according to the room type that has been chosen.

Manufacturer and Supplier have been modelled with the same attributes since most times the manufacturer does not handle the distribution of products on it's own, delegating that step in several suppliers, this allows the same product to be sold by different suppliers with distinct prices. Plus, some characteristics about each product are best known by the manufacturers increasing the importance of having his information store for future contact. Products are modelled taking into account general attributes, such as name or price, more specific details about each product can

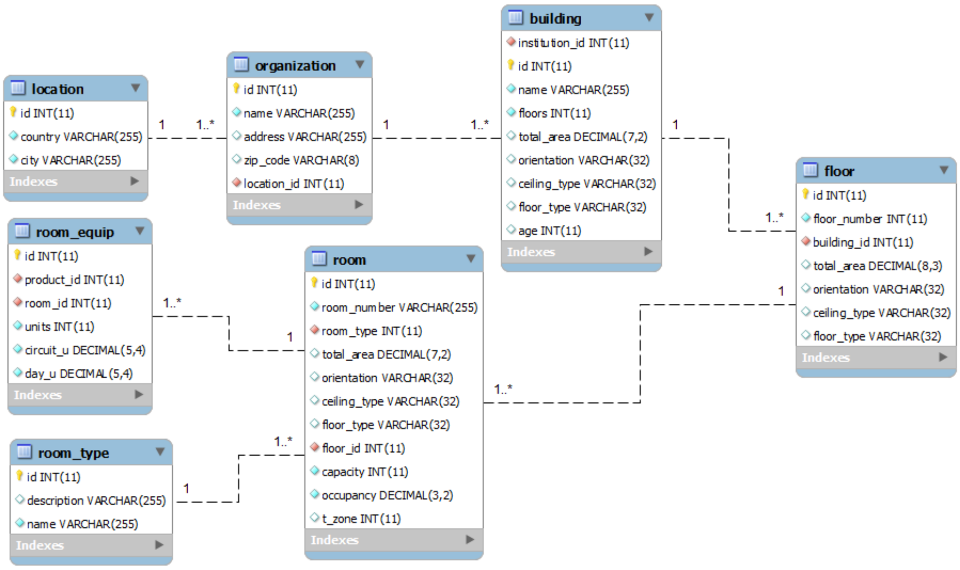


Figure 5.4: Details the building envelope related tables on both its attributes and relations.

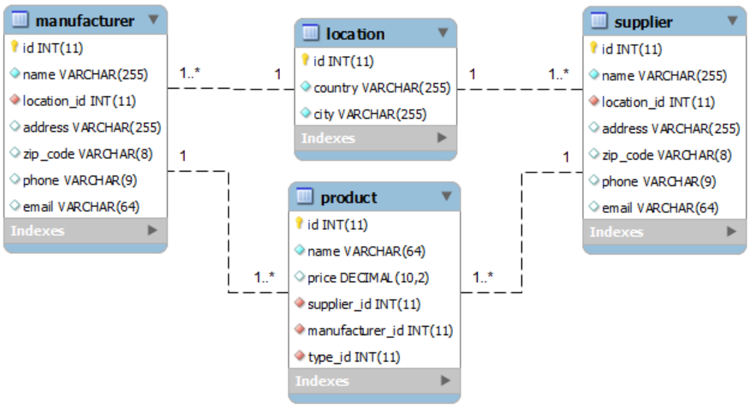


Figure 5.5: Details the suppliers and manufacturers tables on both its attributes and relations.

be retrieve according to the type of product the auditor is dealing with, we will address this issue later in this section. Figure 5.5, details all the relations and multiplicities that relates to both the manufacturer and the supplier entities.

Room Equipment entity relates, to three other entities:*(i)* Room,*(ii)* Servicing, and *(iii)* Product, as depicted in Figure 5.6. It's main propose 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. The model has been developed like this because each equipment has its own working periods and most times they are not the same on all rooms or products of the same type, for example classrooms do not work all under the same schedule. The attributes *(i) units*, *(ii) circuit_u* and *(iii) day_u* define, by the same order, the number of products of each kind that are present in a given room, the circuit utilization defines the percentage of power that each unit will use when active and the finally the day utilization defines, under the related period, the percentage on which

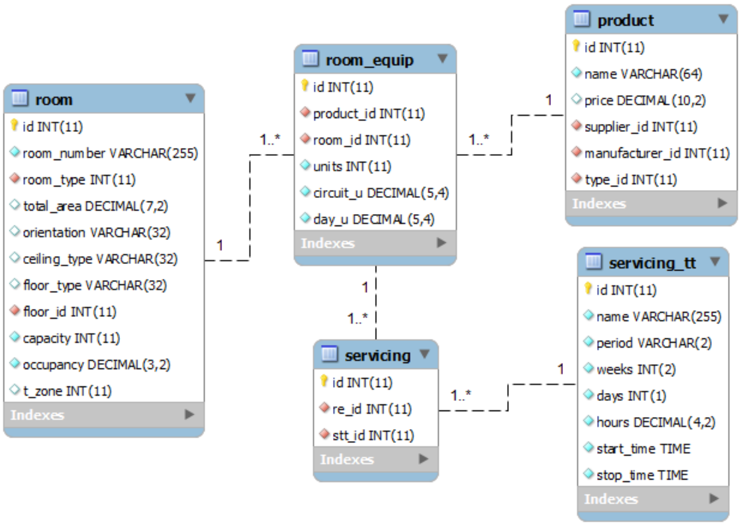


Figure 5.6: Details the room equipments related tables on both its attributes and relations.

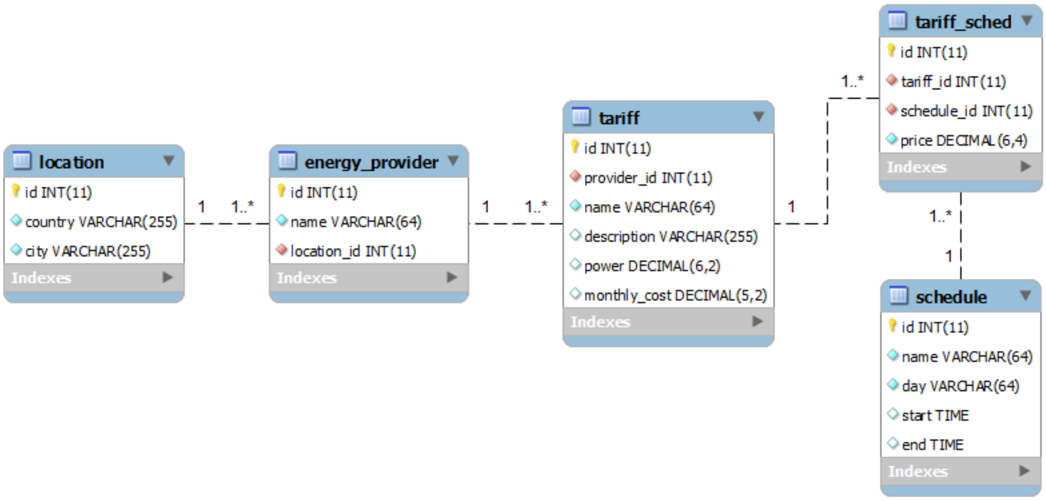


Figure 5.7: Details the Energy Provider related tables on both its attributes and relations.

it is turned on or active.

Servicing entity, see Figure 5.6, defines the working periods of each equipment. It accomplishes that by defining the number of weeks that this period is active in a year, the number of days during a week and the amount of hours through a day. Plus, in order to be able to calculate costs that change according to the time of the day, the start and end time on which each device is active must be defined. A simpler way of modelling this specific part of the system could have been done if the timetables were uniform. In this case, the servicing entity would have an association with both the room type and the product type, allowing that instead of associating it with a specific room equipment it could be paired with the room itself, reducing vastly the amount of servicing necessary to accomplish the same goal.

Energy Provider maintains the information that relates to the supply of energy according to the different

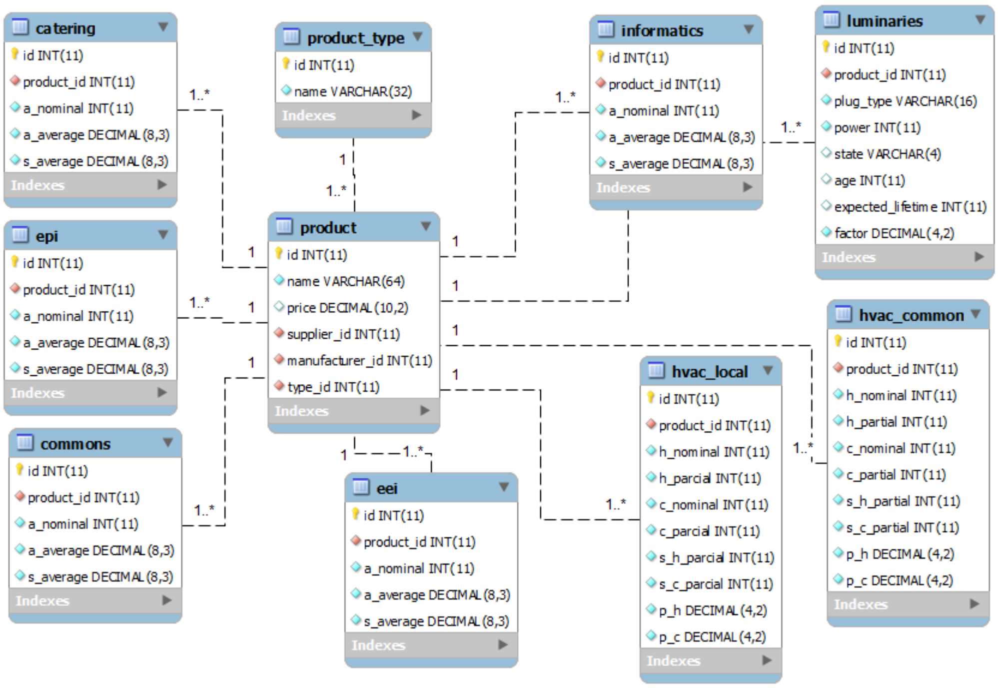


Figure 5.8: Details products related tables on both its attributes and relations.

providers, this data is vital to calculate total costs according to different time periods and to be able to present final estimations on how much the energy consumed in a certain building will cost. Multiple providers are allowed, as well as different tariffs and their related schedules, that can change according to each organization, the entities involved and their associations and multiplicity are detailed in Figure 5.7.

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, as seen in Figure 5.8. The choice to model the different product types like this relates

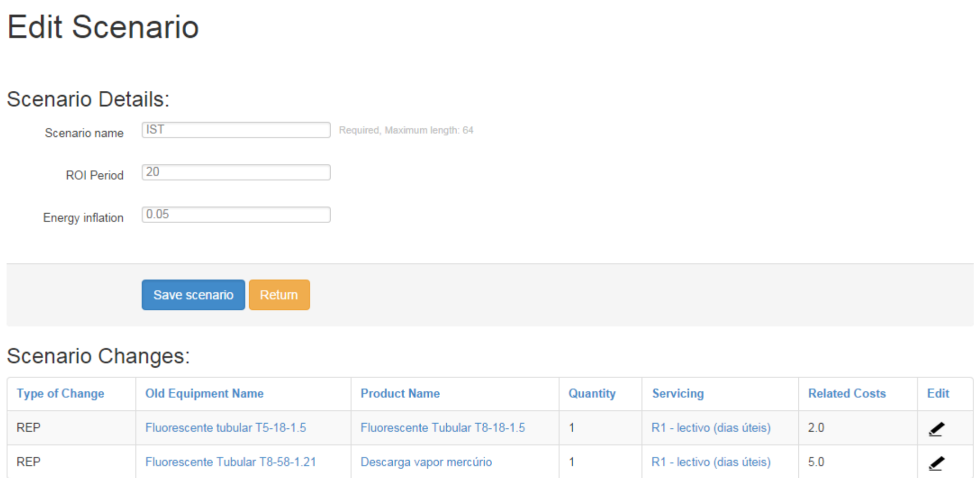


Figure 5.9: Details scenario related tables on both its attributes and relations.

Product Type	Description
commons	describes equipments that are used by the whole building, as for example elevators
catering	it's specially modelled to accommodate equipments that are present in cafeterias or other food related rooms, such as microwaves or fridges
eei	in the specific case of IST it's used to comply with equipments that are present in a research room. As an example of these equipments, we can have wind tunnels or hydraulic press machines
informatics	detail the specific informatics equipments that can present, for example desktops or laptops
epi	models all the plug-in equipments, such as televisions, printers or projectors that are connected to common use wall sockets
hvac_commons	relates to the HVAC equipments that serve several spaces
hvac_local	relates to the HVAC equipments that serve only one room
luminaries	describes all the luminary sources present in the database, these can be any kind of bulbs or emergency lights

Table 5.1: Details the existing product types and in what cases they are used.

to the fact that not all energy consumption sources share the same profile, this means that for example the attributes that determine the power consumed by a luminary are very different from the one's that define the consumptions verified in HVAC machines. The modelling of seven different product types is a consequence of how EA are conducted in our test case, Table 5.1 details what each of the product type entities relate to.

Scenario stores the possible modifications that can made to the existing building, each scenario can contain one or more changes to the current building. These scenarios can be applied to room equipments by changing, adding or removing products, and to the servicing times at which they are set to work. It is also possible to set the costs involved, for example in replacing a bulb, the ROI period and the energy price variation expected for the for the coming years. Figure 5.9 details the relations between *scenario* and *scenario_changes* and the other entities involved, as well as the attributes that define these entities.

All the attribute types, defined under each entity, were chosen taking into account the specific values they can hold. Table 5.2 give a short explanation of why these types were chosen.

5.4.2 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

Product Type	Description
VARCHAR(2)	Used to define the *servicing_tt* name. Possible choices are R1, R2, R3, R4 and R5
VARCHAR(4)	Used in scenarios to mark the type of change being made. It can be ADD, DEL or REP
VARCHAR(8)	Used for the attribute *zip_code* in multiple entities. The verification is performed in the Model layer and it should comply with the following pattern: XXXX-XXX
VARCHAR(9)	Used for the attribute *phone* in multiple entities, phones in Portugal have 9 digits
VARCHAR(16)	Used for the *plug_type* in the luminaries entity
VARCHAR(32/64/255)	Used in several attributes to characterize general strings
DECIMAL(X,Y)	Used in multiple attributes in order to specify a price, percentage or area for example. The decimal places are set according to the attribute
TIME	Used to allow the user to set hours in different entities
INT	Used in several attributes to characterize general strings

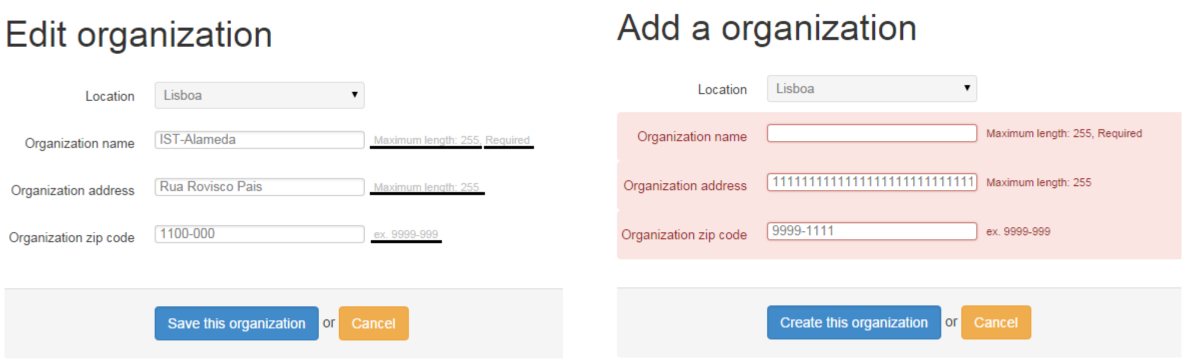
Table 5.2: Describe and explain the data types used to model the entities attributes.

application. Several constraints are used across the Model layer, we will now specify these and explain their propose.

@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.



(a) Constraint label

(b) Constraint error

Figure 5.10: (5.10a) The messages underlined in front of the text fields mean the related attribute have a constraint associated to it. (5.10b) When attributes characteristics are not respected Play automatically marks them in red.

@Constraints.Pattern(value = PATTERN) 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.

Furthermore, when editing or adding entities attributes the View layer gives an information stating that a given attribute has a restraint associated, Figure 5.10a. Also, when trying to save or add an entity in which the constraints to each attribute are not respected the Play framework presents and error message, Figure 5.10b.

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.

5.4.3 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.

List As seen in Figure 5.2, this View layer is responsible for listing all the data associated with that view, for example, the list building view his responsible for listing all the records from the building entity, and if some further information is available it will also be responsible for presenting it. Furthermore, in this view it's also possible to filter the data by name, and to order the results by any of the present attributes. Some of these views can show the consumption data for its related entity, in this case a JavaScript function is responsible for retrieving the data from it's associated entity and present it in a graphic. If no relevant data is available this graphic will be omitted. Additionally an edit button in front of each entry is, when possible, available, as well as an add button. By clicking in these buttons the auditor will be able to edit the information in the related entry or to add a new entry to this list. This view was also designed to be used as the main navigation option for the application. By selecting an attribute in an entry the auditor is often directed to another list view where the previously chosen attribute acts as a filter, as an example of this if the auditor would select the "-3" floor number a list view would present him with all the rooms in the "-3" floor.

Edit In this view the auditor can change some of the attributes of an entry, or to delete this entry, if there are not any database constraints associated with it. Some attributes are locked and it is not possible to alter their values, this is done because, for example, it wouldn't make much sense to change a whole floor from building A to B. Text fields and labels are used recurring to the Play framework, like this when the user chooses to update the data, the Play framework creates a form that is passed to the Controller layer, if the data inserted is according to the rules set in the database the user returns to the list view, otherwise an error message is showed.

Create This view is very similar to the Edit view, it follows the same logic to add data to the database, throw Play framework, and to display possible errors. In order to help the user, if when he reaches a Create view he had active filters in the List View, these will be kept. This is specially helpful when, for example, adding a new room. If the user was in a specific floor this floor will be automatically applied to the new room, if the user desires to add it to a different floor he is allowed to change this information. The user can only add new rooms if there is an existing floor,in order to help the user, every time an attribute relates to an existing entry a drop list is presented with all the possible choices.

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, Table 5.3 details all the filters that have been implemented in each of the list views.

5.4.4 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, that we will now detail.

List is responsible for asking the Model Layer the corresponding entity, and if the request is satisfied the contents are sent to the View layer to be displayed. To do this the Controller invokes a *Entity.page(page, 10, sortBy, order, [filters])* method that returns the entries that are in conformity with the given filters. Afterwords the results are sent to the View layer through a *listLocation.render(Page, sortBy, order, [filters])* call that is responsible for presenting the results to the auditor according to it's *sort_By* and *order* attributes, and any filters that are active. The attributes *sort_By* and *order* define, in that sequence, the entity attribute that is responsible for the sorting and the ordering that is being applied, ascending or descending.

Edit method asks the Model layer for the attributes of a given entry, the one being edited, and if it is successful calls the View Layer to render the result. This is done using two calls, the first one *form(Entity.class).fill(Entity.find.byId(id)*, calls the related entity and retrieves the attributes of that

View	Filter	Description
location	country	filters by country name
organization, supplier, energy_providers and manufacturer	locationid name idf	filters by location id filters by own name filters by own id
building	institutionid name idf	filters by institution id filters by building name filters by own id
floor	buildingid floornumber idf	filters by building id filters by floor number filters by own id
product	manufacturerid supplierid ptype name idf	filters by manufacturer id filters by supplier id filters by product type filters by product name filters by own id
product_type, room_type, schedule & scenario	name idf	filters by own name filters by own id
room	floorid roomnumber idf	filters by floor id filters by room name filters by own id
room_equip	roomid productid idf	filters by room id filters by product id filters by own id
hvac, luminary, informatic, catering, eei, epi and common	productid	filters by product id
servicing_tt & servicing	roomtypeid producttypeid name idf	filters by room type id filters by product type id filters by own name filters by own id
tariff_sched	tariffid scheduleid idf	filters by tariff id filters by schedule id filters by own id
tariff	providerid name idf	filters by provider id filters by tariff name filters by own id
scenariochange	scenarioid idf	filters by scenario id filters by own id

Table 5.3: Presents the filters that are used to allow the filtering of the data showed to the auditor, under each list view.

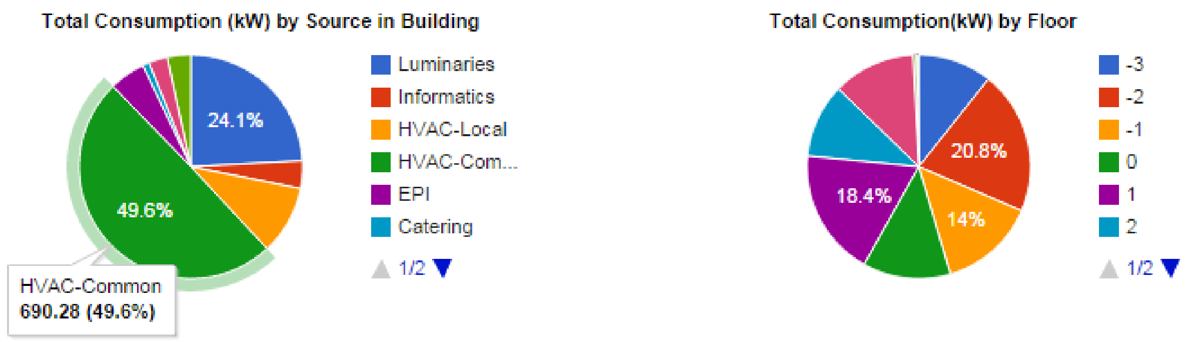


Figure 5.11: At the left side is possible to see the total consumption of the Civil building according to each type of equipment, while in the right side the results are presented by floor consumption, the level bellow building.

entry, the attributes are then inserted into a *form* and passed to the View layer throw a call to *editEntityForm.render(id, [filters])* that renders it and present the edit page to the auditor.

Update is responsible for updating an entry after an *Edit* call. The update method firstly retrieves the form *form(Entity.class).bindFromRequest()* and check it for errors *entityForm.hasErrors()*, according to the restraints defined before. If the form is filled correctly the database is updated using *entityForm.get().update(id)* and a success message is presented to the auditor. If the form contains any errors on its attributes, these are highlighted in red so the auditor can correct them.

Create is called whenever the auditor wishes to insert a new entry in the database, to do this the application creates an entity form, *form(Entity.class)*, and call the corresponding View, *createEntityForm.render(entityForm, [filters]))*. The filters are used to pre-fill some of the entity attributes, for example if the auditor desires to add a floor in the current building, the building id will be passed automatically to the form.

Save method can be called after the *create* method. In this case the Controller acts in a very similar way to when the *update* method is called but instead of updating the database it uses the *entityForm.get().save()* call. Like when performing an *update* the controller also checks for errors in the form and alerts the auditor when corrections are in need. If the form is correctly filled the auditor is directed to the *List* view where any filters active are kept.

Delete can be called after the edit method. If the auditor instead of updating a entry information wishes to erase it, the controller invokes *Entity.find.ref(id).delete()*, that returns a success message has the auditor is re-directed to the associated *List* view.

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.

Figure 5.12: At the left side is possible to see the total consumption of the Civil building according to each period, while in the right side the results are presented by consumption periods according to each product type.

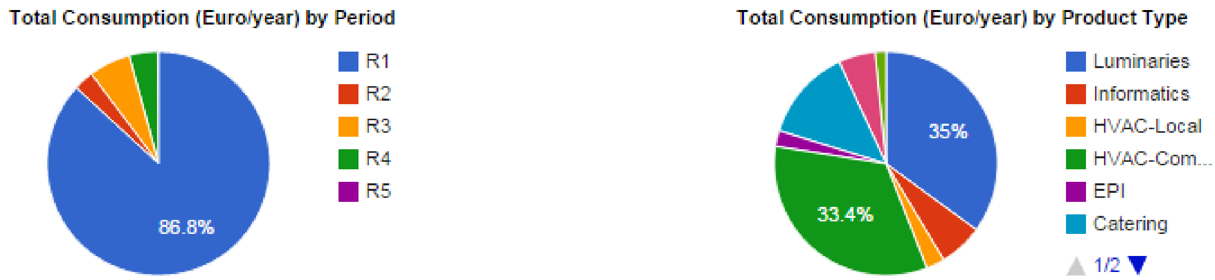


Figure 5.13: At the left side is possible to see the total consumption, in Euro, of the Civil building according to each type of equipment, while in the right side the results are presented by floor costs, the level bellow building.

5.4.5 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. These results are displayed under three main areas:

Installed Consumption Under this area the results are presented according to the watts they will consume under an one hour period. In Figure 5.11 its possible to see the total amount of watts, regarding the equipments installed, in floor number 3, in the Civil building, and its percentage regarding the whole Civil building.

Period Consumption Presents the audit report taking into account the time period the equipments are set to be active. This information is given when the auditor adds an equipment to a given room. Figure 5.12 displays the total consumption under each of the defined periods.

Euro Consumption Finally, the auditor also has the option to retrieve the audit report under Euro. This options takes into account all the relevant data each room equipment has. Further details about how the total costs were obtained are given bellow. This option displays the results under the same conditions as seen in the Wattage consumption. Figure 5.13 displays the total costs by equipment type and facility.

Plus, within each of the areas describe above, the results are presented under two main areas according to the areas described above, Figure 5.11 presents the results according to the wattage consumption:

Equipment Type This option retrieves all equipments present in the current facility and displays their consumption, grouped according to each of the equipment types that are installed in it.

Facility Consumption In this report the consumption is calculate according the level bellow the current one, the relations between entities in the building envelope can be seen in Figure 5.4. For example Figure 5.11 shows on the right the consumptions according to the floors that are available in a given building, in this case the Civil building. If the auditor would choose to enter floor number 3, the results would be given taking into account all the rooms in floor number 3.

The only view, where the consumptions are not showed under these two areas is the room equipment view. The room equipment view follows a slightly different approach because there are no levels under the room equipment. Like this the results in here are presented by Equipment Type and by Equipment, instead of Facility. Like this the auditor can have a view of what each equipment is consuming in a given room.

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.

We will now present how the total consumption of a luminary is calculated under the three main areas defined above.

Wattage Consumption For each room equipment:

- $t\_power = l.power * l.factor * re.units * re.circuit\_u$

Where *l* relates to the luminary entity and re to the *room_equip* entity.

Period Consumption For each period:

- $t\_power\_period = t\_power * re.day\_u * stt.weeks * stt.days * stt.hours$

Where *stt* relates to the *servicing_tt* entity and *re* to the *room_equip entity*.

Euro Consumption For each room equipment:

and for each period (*stt.start_time* and *stt.stop_time*) in (*sc.start* and *sc.stop*):

- $t\_power\_euro = t\_power * re.day\_u * stt.weeks * stt.days * hours\_period * ts\_price$

Where *ts* relates to the *tariff_sched* entity, *stt* to the *servicing_tt* entity and *re* to the *room_equip* entity. *hours_period* states the number of hours a given equipments works in a given tariff period.

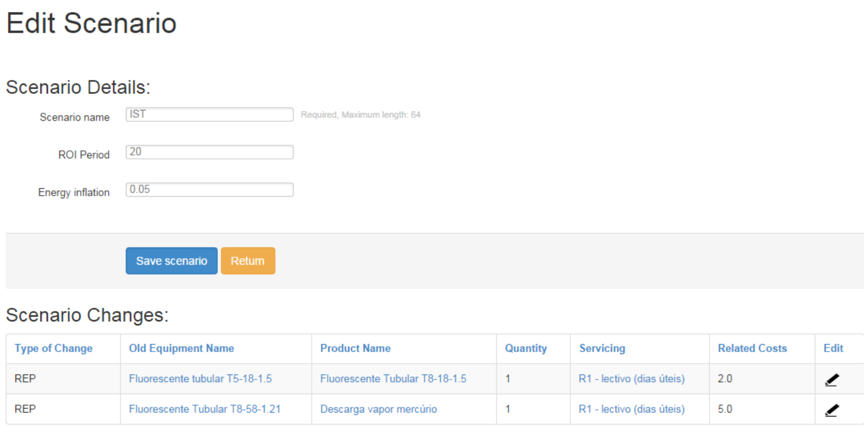


Figure 5.14: A scenario example where the changes being made are showed in a list and, on top, the details of the scenario

5.5 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, as seen in Figure 5.9, and allows the auditor to verify if changes in the current environment will result in long term saving. Figure 5.14 shows how the scenario and scenario changes are presented to the auditor. The auditor can perform three kinds of actions to current room equipments:

ADD allow the auditor to add a new equipment to a given room. The auditor will then be able to choose the equipment to add, the number if units, it's installation costs and it's servicing period.

DEL allow the auditor to delete a room equipment. This action can have associated the costs of removing the equipment. The results will only show the savings by not having this product functional in a given facility.

REP allow the auditor to replace a room equipment. With this option the auditor can choose to replace an equipment by a different one, for example a more efficient luminary, besides other values, the result will have under consideration the costs of the new products, as well as the costs associated with replacing the old ones.

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.

Chapter 6

Evaluation

To validate the implemented solution, real data, regarding Instituto Superior Técnico (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 ”Pavilhão 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.

6.1 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 6.1: Describes the total number of entries under each entity, retrieved from the audit report.

In this section we will present the data that was retrieved from the audit report. The original data source divides the products into eight different types, already presented in Section 5.4.1 and models the building envelope of ”Pavilhão de Civil” according to its floors and rooms, furthermore it defines the workings periods associated with IST. We decided to maintain the given models since they follow the concepts and the related work previously done in this field, see Chapter 2 and Chapter 3, and will help validating our solution.

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 6.1, that were loaded into our database so they could be used to validate the solution presented.

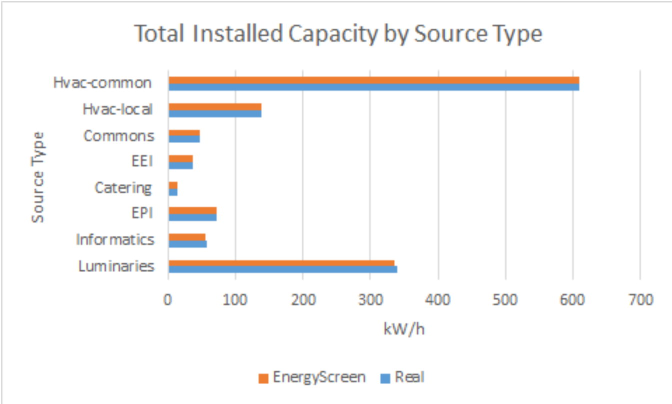


Figure 6.1: Comparison between the results of the audit report and the toll developed, taking into account the total installed power.

6.2 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.

6.2.1 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 6.1 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:

$$\frac{|X - Y|}{(X + Y)/2} \tag{6.1}$$

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

$$(1 - (\frac{|X - Y|}{(X + Y)/2})) * 100 \tag{6.2}$$

Table 6.2 shows the similarity percentage obtained by applied the above formula to the results seen in Figure 6.1. In Section 6.3 we will discuss this results.

6.2.2 Period Consumption

In this Section we applied the formulas to get the consumption under each period. Figures 6.2 and 6.3 present the relation between the results obtained with our tool, in red, and the results from the energy

Product Type	Similarity Percentage
Commons	99.9916
EEI	100
Catering	99.9773
EPI	99.58
Informatics	94.7354
Luminaries	99.0623
HVAC-Commons	99.22
HVAC-Local	98.71

Table 6.2: 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.

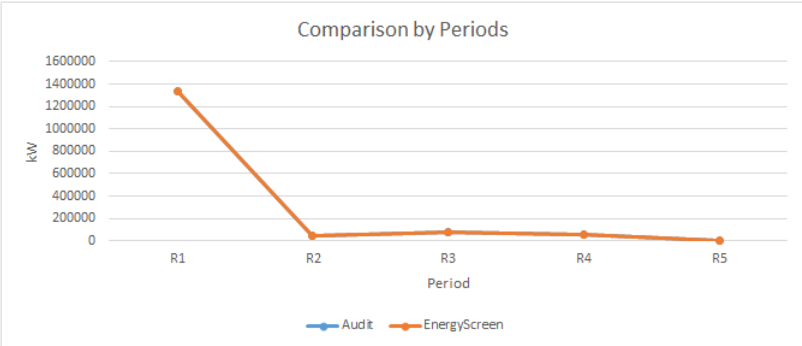


Figure 6.2: Comparison between the results of the audit report and the toll developed, divided by each of the periods modelled.

audit, in blue, by period and source type, correspondingly. It is possible to see that the lines overlap throw the results, with only the informatics source type having a slight difference.

Period	Similarity Percentage
R1	99.89
R2	99.31
R3	98.30
R4	97.40
R5	100

Table 6.3: 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 period.

In Tables 6.3 and 6.4 we present the the similarity percentages of the results presented in Figures 6.2 and 6.3.

Figures 6.4, and 6.5, and 6.6, and 6.7 and 6.8 present the relation obtained, when the results from above, are depicted accordingly to the period. In Table 6.5 we present the similarity percentage obtained for each of these cases.

6.3 Discussion

Considering the data retrieve from the audit report and taking into account the results obtained and presented in Section 6.2, we can conclude that the proposed model completely copes with the objective

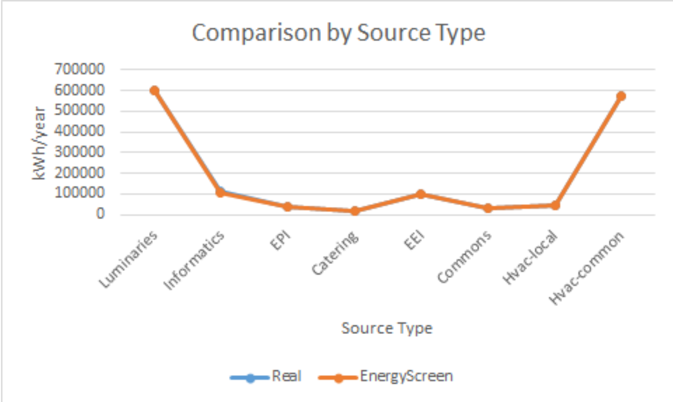


Figure 6.3: Comparison between the results of the audit report and the toll developed, dividing the results according to the product type.

Product Type	Similarity Percentage
Commons	100
EEI	100
Catering	95.63
EPI	94.33
Informatics	97.47
Luminaries	99.98
HVAC-Commons	99.89
HVAC-Local	99.23

Table 6.4: 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.

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 6.2, 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.

It is also possible to see, in Table 6.3, that after applying the time periods servicing on each of the room equipments, the results obtained also prove to be under an acceptable deviation, with all the similarity percentages being above 97%.

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

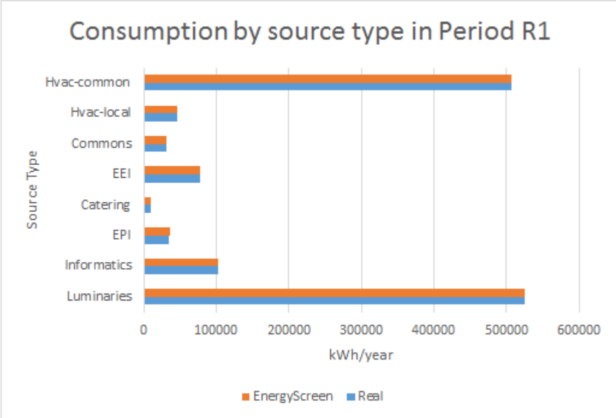


Figure 6.4: Comparison between the results of the audit report and the toll developed, dividing the results according to the product type.

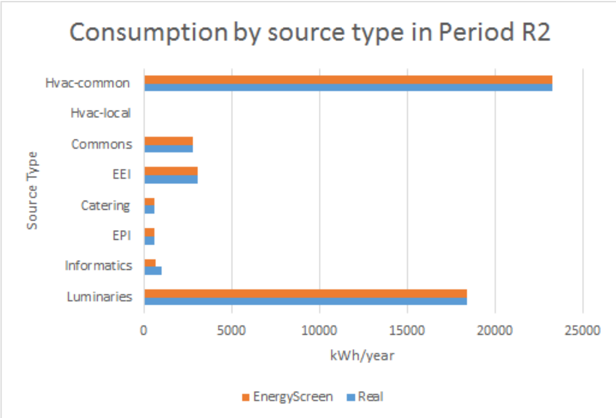


Figure 6.5: Comparison between the results of the audit report and the toll developed, dividing the results according to the product type.

them into the periods set previously. It is possible to observe in Table 6.5 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.

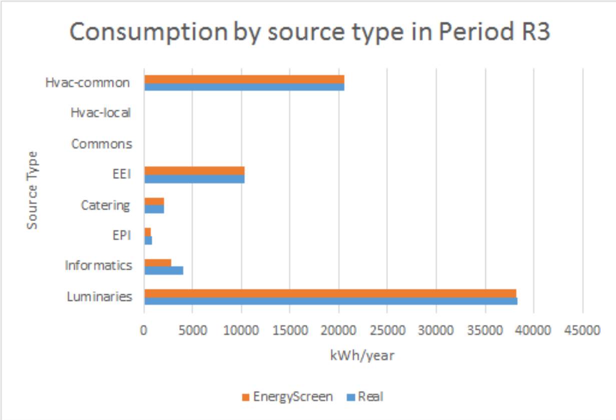


Figure 6.6: Comparison between the results of the audit report and the toll developed, dividing the results according to the product type.

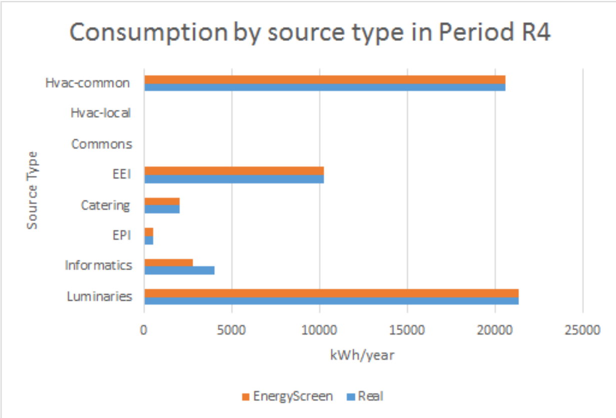


Figure 6.7: Comparison between the results of the audit report and the toll developed, dividing the results according to the product type.

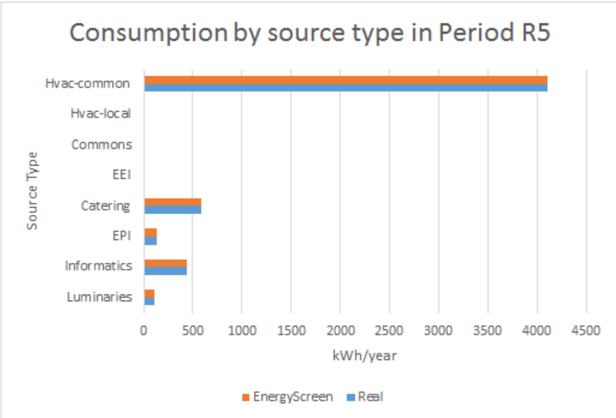


Figure 6.8: Comparison between the results of the audit report and the toll developed, dividing the results according to the product type.

Product Type	Similarity Percentage by Period				
	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
Informatics	99,94	60	64,77	64,77	100
Luminaries	100	100	99,84	100	100
HVAC-Common	99.89	100	100	100	100
HVAC-Local	99.21	99.68	100	100	100

Table 6.5: 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.

Chapter 7

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.

7.1 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 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.

7.2 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:

A compilation of the existing work and notions 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.

7.3 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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