Energy Management Platform for the IST Campus:

Modelling and representation of energy consumption

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Abstract

Knowing that in Europe buildings are responsible for 40% of total energy consumption, and that this sector represents large energy consumption in cities, it is of great importance to reduce this consumption. In this context, urban building energy modelling presents itself as an essential key in buildings development and energetic performance. In particular, there is also a concern about the energetic impact caused by large consumers geographically concentrated, such as hospital or university campuses, in big cities.

The present work has the objective of contributing to the development of an energy management platform for the IST Alameda campus, and in particular the energy modelling, representation and analysis of the electricity consumption of four of its buildings (which represent more than 50% of the total consumption), and taking into considerations the energy efficiency measures designed for these buildings.

In the scope of this work, various analyses referring to the four target study buildings were performed, combining using real data and results obtained from EnergyPlus models. In addition to these, analyses were also done on consumption after the lighting replacement and the implementation of photovoltaic panels as an energy efficiency measure.

Knowing that GIS visualization is an important stage in understanding and making decisions about energy consumption, this work presents a visualization of the four buildings in ArcGIS and the modelling and animated visualization of the obtained results are presented in an IST energy management platform currently under development. It was also tested the urban building energy modelling, using the CEA tool, but some challenges and simulation errors were found, so it was not possible to make a direct comparison between the two visualization tool proposals. It was also concluded that, due to the simple access of the real data of the consumption of the buildings, the proposal of real analysis and visualization in the energy management platform would be more viable in this work.

From the final results, it can be understood that the four buildings chosen are responsible for 50% of the campus' total energy consumption and that there is a high consumption associated with interior equipment and lighting, between other. Regarding the replacement of one type of lighting equipment, it allows a reduction of approximately 11% for two buildings and it is estimated that up 3.35% in total annual energy consumption of the campus. Regarding the implementation of photovoltaic panels, the conclusion was that this measure allows for a reduction of electricity consumption in approximately 9%, accounting for the four buildings and it is estimated that up to 4.44% in total annual energy consumption of the campus.

Key-words: Urban Building Energy Modelling, City Energy Analyst, ArcGIS, EnergyPlus, energy efficiency

1 Introduction

Nowadays, cities are responsible for more than 70% of global greenhouse gas emissions (GGE) (Chen and Hong, 2018). In Europe, according to the European Commission, buildings are responsible for 40% of total energy consumption (Monteiro *et al.*, 2017). Energy reduction in this sector has a special interest in reducing global energy consumption and greenhouse gas emissions, thus making part of the strategy to achieve global energy and environmental targets (Hong *et al.*, 2018). Nowadays, making neighborhoods more energy efficient is an opportunity for continuous improvement, both for emission reductions and for sustainable development (Reinhart *et al.*, 2013). Therefore, in recent years, several studies have focused on planning and evaluating retrofit strategies for buildings at the neighborhood or district scale (Hong *et al.*, 2016).

In addition to the various types of buildings, there is a concern regarding the large campus, including university campuses. This concern is to determine more effective strategies in reducing the ecological footprint (Nagpal and Reinhart, 2018), as these are a large percentage of energy consumption in cities. In 2014, the electricity consumption of the IST Alameda Campus represented 0.4% of the total consumption of the city of Lisbon (Lisboa E-Nova, 2016).

Knowing the impact that a university campus can have on a city, the main objectives of this work are the analysis of the electricity consumption of IST Campus, the assessment of the impact of the implementation of savings measures and their representation in 2D and 3D in an energy management platform in order to facilitate communication with different stakeholders. Through an intensive study about urban building energy modelling and the 2D and 3D representation of the campus, another objective is to test different UBEMs implementation tools and create an energy model for the campus for viewing all data: historical energy consumption, historical consumption after a measure of energy efficiency and relevant information of buildings. The present work focuses on the four buildings, Central, Civil, North Tower and South Tower of IST Alameda Campus.

1.1 Urban Building Energy Modelling (UBEM)

As the building sector is one of the major responsible for emissions, it is important to develop tools that help to better understand their energy consumption. Building Energy Models are an important tool for assessing energy performance. These models have been used today for the individual analysis of buildings, but it is essential to develop models at the multi-building and even urban scale, in order to analyze the impacts integrated at the city level.

The analysis of buildings energy consumption can be accomplished through two approaches, a top-down approach and a bottom-up approach (Swan and Ugursal, 2009). Top-down models use the estimation of total energy consumption as a way to characterize the characteristic consumption of buildings (Swan and Ugursal, 2009). Bottom-up models calculate the energy consumption of building groups or individually and extrapolate these results to represent a region (Swan and Ugursal, 2009). In recent decades, a new class of models has developed, the urban building energy models (UBEMs), which are based on a bottom-up approach, and represent an essential tool at the urban-scale project level (Reinhart and Cerezo Davila, 2016).

To reduce the time of modelling and computation on larger scales, one of the solutions adopted is the creation of archetypes of buildings. The concept of archetype consists of defining a unique building that represents a set of buildings with similar properties, such as age, use, climate, systems, thermal properties, and others that can be selected (Ballarini *et al.*, 2014). This division of buildings into archetypes constitutes an important step regarding the reliability of the UBEM, due to the process being typically carried out by generic assumptions. One reason for using these assumptions is insufficient access to necessary data, such as the actual energy consumption of each building and the thermal properties of buildings (Reinhart and Cerezo Davila, 2016).

There are three steps for energy modelling in UBEMs: the organization of input data for the simulation, and creation of archetypes; the creation and execution of a thermal model (definition of thermal zones); and process validation (Reinhart and Cerezo Davila, 2016).

1.2 UBEM implementation tools

Some tools can be selected for the implementation of urban building energy modelling, and many studies have been developed over the last decades. The three tools studied in this work are the following:

- ✓ UMI - Urban Modelling Interface
- ✓ CityBES - City Building Energy Saver
- ✓ CEA - City Energy Analyst

These tools are based on EnergyPlus, E+, an energy simulation program that allows to model energy consumption in buildings (such as HVAC, lighting and loads) more widely used globally (Hong et al., 2016).

In the scope of a PhD project of Francisco Pires Costa, supervised by Professor Carlos Santos Silva, an energy management platform is being developed, the **CogUBEM** platform. This platform introduces a concept called Cognitive UBEM, that evolves from the UBEM concept, with the difference that simulation is only one step in a cyclical process. This stage consists of data collection and processing, simulation and UBEM representation.

2 Methods

Regarding the method of study in the present work, two UBEM simulation proposals are presented in the figure, based on top-down and bottom-up approaches.

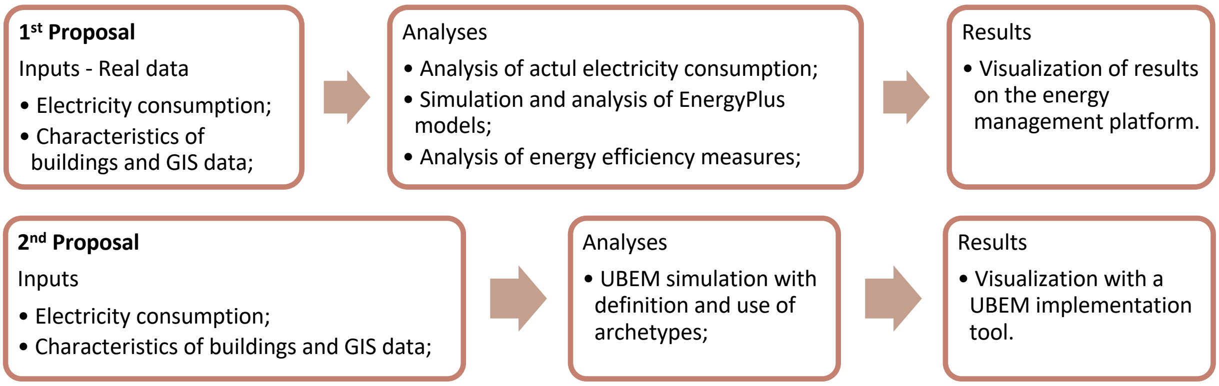

Figure 1 – Methodological proposals for the case study

2.1 UBEM implementation tools

Regarding the three tools analysed in this study, the first choice focused on the CEA tool. Although all the tools have similar characteristics and objectives, this tool has some advantages over the rest, mainly due to the ability to develop models in a single interface. In addition, the CEA works as a toolbox in the ArcGIS program, which is an intuitive program and from which there are licenses for the present case of study, so this choice presents itself as the most complete. With the ArcGIS program, it would become possible to visualize the campus and the study's target buildings, and a visual interface allows a better understanding and support for decision making. For the creation of UBEMs, several initial data are required, and the tools are capable of generating several results.

For the energy management platform CogUBEM, the base information is used to develop realistic models of the buildings and then the data is represented. For the case study of a university campus, many of the challenges associated with UBEMs they cease to exist. In particular, insufficient data of buildings and restricted access to real consumption. All these data and information are easily received to a university campus. Therefore, in the present study it is possible to analyze all the actual data and visualize on the platform.

2.2 Analysis of electricity consumption

In parallel to the creation of the energy model, it was necessary to analyze the electricity consumption of the campus. The electricity consumption data for the four buildings were ceded by the Sustainable Campus Project. The years are 2017 and 2018 were used as they are the most recent complete years.

Initially, a treatment of these data, presented with an hourly resolution, was carried out, so the monthly and annual calculations of the four buildings were performed. Subsequently, an analysis of electricity consumption profiles was performed. From these results, it becomes possible to present the information in an animated way in the energy management platform.

Through the data of the annual consumption of the campus, it was determined the impact of the target buildings of study in the total electricity consumption of the campus and thus, it is understood the need to improve the energy efficiency of these buildings.

2.3 Analysis of EnergyPlus Models

Through the EnergyPlus models of each building, given by the Sustainable Campus Project, it became possible to carry out a more detailed study for each. The models were complemented with the weather file, ". epw", that contains the climatic data of Lisbon for a typical year.

Through the simulation, results referring to the consumption of electricity and the types of energy use (energy services) were obtained and the percentage of each in total consumption, as for example regarding lighting, equipment, HVAC, and others. The visualization of results is possible at the energy management platform. With the existence of all data, it becomes possible to compare the results and validate the models. The models of the Central and South tower are calibrated until the year 2018, the remaining two are not yet updated.

2.4 Analysis of the implementation of energy efficiency measures

Taking into considerations the energy efficiency plan for 2020, an analysis was carried out in which the impact that would have on the consumption, the implementation of photovoltaic panels and the replacement of lighting of the Campus buildings was studied. And the results are represented in the energy management platform.

From the EnergyPlus models of the two buildings, Central and Civil, it is possible to change the power related to the lighting changes of each thermal zone and to perceive the impact of this measure. The values referring to the lighting used in the two buildings were ceded by the Sustainable Campus Project.

The results of the analysis of photovoltaic panels are represented in the energy management platform.

3 Results and discussion

3.1 Visualization of Energy Model for IST

3.1.1 IST Visualization in ArcGIS

With geographic data files from Lisbon, in PDF format, a .tiff file was created, which is a format for digital images. According to the ArcGIS documentation, a shapefile is a data storage format for storing the location and geographic features. After with the shapefile of the district of Lisbon, it became possible to create in ArcMap a shapefile of each building. So, it became possible the campus 2D representation in ArcMap and the 3D representation of the campus in ArcScene and each building of case study, as seen in Figure 2.

It should be noted that in the present case study, the analyzed data are only from the two towers, as seen in Figure 4. But knowing that the construction of the towers is influenced by the construction of the other base buildings, the representation in figure 3 was also created.

Figure 2 – IST Campus in ArcScene

Figure 3 – Case study in ArcScene

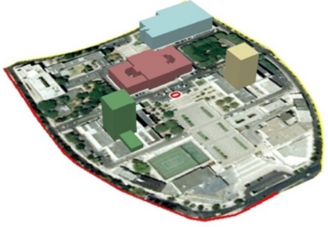

Figure 4 - Representation of towers

3.1.2 Modelling with the City Energy Analyst

CEA tool is tested with the example model, "reference-case", available online, and then changes the data by the new project data and the creation of a new shapefile and a .tiff file for the terrain. Other data are necessary for create new project, namely data regarding the architecture of buildings, the thermal loads (internal and external), the indoor comfort and HVAC systems. After entering the necessary data, create and simulate a new project are next step. This tool allows many analyses and produces many results, namely: energy consumption, photovoltaic panels and solar collectors, visualization of results with creation of plots, optimization, and others. During this study, this tool continues to be actively developed, and some modifications have been verified. One of the main ones is that the ArcGIS interface is no longer used by the programmers and there will be an interruption in monitoring for this interface. Other options to implement CEA were created and are currently being developed namely: the command line interface, the dashboard and the Rhino/Grasshopper interface.

Some challenges have been found associated with implementation through ArcGIS. Even with the possibility of continuing to use this program there are still many errors in the simulation of this tool. Therefore, with an interruption in the development and correction of the same, it ceases to be viable to use the CEA through ArcGIS, which had been the alternative initially chosen. Regarding the Dashboard, this allows an intuitive way to create a new project and also allows the simulation UBEM. The installation can be performed from the official website. In this way, it concludes that although this is a very important tool, as the results are based on defined archetypes and in this case study there are real values and models calibrated and close to the real, the actual analyses and the visualization of results through the platform would have a higher reliability in energy modelling for Campus.

3.1.3 IST Energy Management Platform

The platform with the case study is found in the figure 5. In this platform are three scenarios and referring to the results of 2018. The three scenarios are as follows: "IST Business as Usual-electricity consumption in 2018" which represents actual electricity consumption data; The "IST BAU with PV" which represents the electricity consumption data after the implementation of photovoltaic panels; The "IST BAU with PV-Savings" which represents only the savings in consumption. In each scenario it is possible to see the range of values referring to the electricity consumption of each building, the total values, the values by the sum of buildings and the type of use with the highest consumption in each building.

Selection: City Level
Number of Buildings: 4

Statistics
Number of Units: 4
Most common Building Usage Type: Interior Equipment
Average Energy Consumption: 1436154 kWh/year
Max Energy Consumption: 1605371 kWh/year

Figure 5 - Case study on Energy management Platform

It is demonstrated that the use of a platform for the representation of the energy data of a campus can be an effective tool, because it allows not only the rapid visualization of consumption, as the impact of measures of energy efficiency, as well as the observation of characteristics of each building. Anyway, the success of the visualization depends always on the models that generate the information.

3.2 Analysis of electricity consumption

Regarding the analysis of the monthly consumption of each building, in the Central building, consumption is balanced for heating and cooling, but it is possible to see a higher consumption when there are cooling needs. This may result from the existence of the data center in this building, which manages high internal thermal loads, so the cooling needs are always higher than those of heating. In the Civil building, some of the winter months have higher consumption, which reveals that there is a higher consumption in times with heating needs, although it is relatively balanced with the cooling needs. In North tower, the months with cooling needs are higher than the consumption for the months of heating, as in the north tower the heating is done through gas boilers. The South tower also has higher consumption in the months with cooling needs, in other words, in the summer months, except for the month of August, also due to the fact that the heating is made with gas boilers.

In this analysis it was found that certain variables influence the consumption. As expected, climatic conditions cause cooling or heating needs. But the most important factors are the occupancy and the occupant behavior. This variable has a high importance relatively for example to outdoor temperature. The main reason is that there are months of high temperatures, but due to the low occupation for example in the months of holidays, the consumption is not high, such as the month of August. It was also found that during the night the consumption is significantly lower than during the day due to the low occupation and use of equipment, lighting, and other aspects. Finally, there was also the impact on consumption one week day compared to a Saturday or Sunday.

Comparing the consumption of the four buildings in the year 2018, as can be seen in Figure 6, that the North Tower presents a lower consumption.

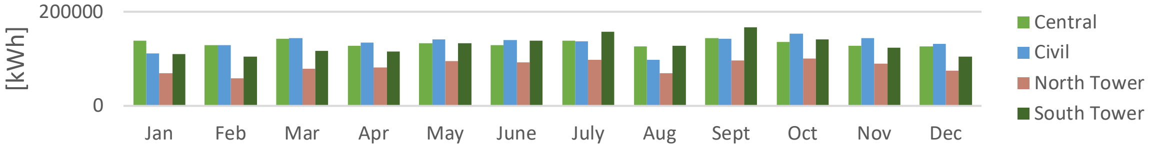

Figure 6 – Electricity consumption of the four buildings

From the annual consumption data of the campus for the year 2017, it is noticeable the high impact that these buildings have on the total consumption of the campus, verifying that they represent 50.24% of total consumption, even more knowing that the IST has a total of 26 buildings.

3.3 Analysis of EnergyPlus models

In the Central building, the equipment is the main electricity use and represent 70% of the total consumption of the building. And in consistency with the real results, the heating value is lower than cooling. Lighting shows some percentage of consumption, although not high in this case.

In the Civil building, the lighting is the higher energy use, with 35%. The equipment also presents a considerable percentage of total consumption with 28%. The heating has a higher consumption, although the percentage is similar, which is consistent with the conclusions taken from the actual data.

In the north tower it was verified that the data regarding the equipment are not all defined in the model, because it has a low percentage and the result is fragmented into several variables. In this case, the cooling has the highest percentage of total consumption with 32%. This result is very consistent with the conclusions taken from the actual data, where the months with cooling needs have higher consumption. The lighting has also a high value of total consumption with 26%. The same cannot be said of the equipment, which is not according to reality.

In South tower, the equipment has the highest percentage 42% and has high cooling values, as expected.

Regarding the validation of these models and from bibliography related to them, knowing that models were validated with errors of 6% to 39% for electricity consumption in buildings, all errors are within the values shown. It is concluded that the current models, although not updated, can be used to estimate the impact of energy efficiency measures for monthly temporal resolution analysis. The final results are in table 1.

Table 1 – Results of EnergyPlus models and comparison with real data

Building	Purchased: Facility (E+)	Total 2017 [kWh]	Error	Total 2018 [kWh]	Error
Central	1589180.75	1657772.20	4.68%	1597667.96	1.1%
Civil	1832935.82	1439591.07	27.3%	1605370.71	14.17%
North Tower	867076.84	898081.10	3.45%	1002120.52	13.48%
South Tower	1442939.62	1571763.28	8.2%	1539458.08	6.27%

3.4 Energy efficiency and savings measures

3.4.1 Lighting

This work studies the impact of the replacement of T8 tubular fluorescent equipment of 58W for LED illumination of 24W. The results regarding this analysis are shown in the table 2.

Table 2 - Savings after changes of lighting

Building [kWh]	**Lighting** Annual Consumption	**Lighting** after changes	**Savings**	**Total consumption (E+)**	**After changes (E+)**	**Savings**
Central	137601.97	110893.88	19.4%	1580180.75	1553917.18	1.67%
Civil	638655.56	297634.80	53.40%	1832935.82	1488546.52	18.80%

In the Central building the study focuses on replacing 330 of 3832 lamps. In the Civil building, it focuses on replacing 3769 of 6055 lamps.

In conclusion, this measure would represent savings of 10.9% in the total consumption of the two buildings and savings of 3.35% in the total annual consumption of the Campus. It should be noted that the change was made only in two building and only one type of lighting equipment. It becomes clear, if the changes take place in all that is desired in the efficiency plan and in all buildings planned, this measure will have viable results.

3.4.2 Photovoltaic panels

Through the power of each photovoltaic system (PV) to be installed, it became possible to understand the impact it would have on reducing consumption and its value. As expected, and can be seen in table 3, self-consumption is equal to or very close to 100%. It is estimated for the Central, Civil, North Tower and South Tower the respective savings, 14.2%, 9.3%, 5.7% and 3.7%.

Table 3 - Results of implementation of PV

Building	Number of panels	Power [kW]	Self-consumption	Self-reliance
Central	720	180	100%	14%
Civil	480	120	99%	9%
North Tower	184	46	99%	6%
South Tower	184	46	99%	4%

Regarding to the annual total consumption of the Campus, savings of 4.44% is estimated. Knowing that the four buildings represent 50% of the annual consumption of the campus, it is anticipated that the planned implementation in ten buildings could represent a significant saving in total consumption.

3.5 Visualization of results on the Platform

In the figure 7, the buildings are represented by the range of electricity consumption values.

Selection: City Level

Number of Buildings: 4

Visualisation by

Figure 7 - Electricity consumption by range of values in the first scenario

Selection: City Level

Number of Buildings: 1

Visualisation by

Figure 8 - Type of energy use with the highest consumption in each building in the first scenario

It can be verified that the Central and Civil buildings have annual consumption between 1.56 and 1.67 GWh/year, the south tower between 1.44 and 1.56 GWh/year and the North tower consumption between 0.96 and 1.1 GWh/year. In figure 8, the type of use with the highest percentage of consumption of each building is found. Note that in the platform the percentage is relative to the number of buildings selected, and not to total consumption. In Figure 9, there is a comparison between the first two scenarios, before and after the implementation of PV. As can be seen, after the implementation of PV, the South tower will become the building with the highest consumption, because the Central and Civil have higher production of photovoltaic energy.

Figure 9 – Comparison between the first two scenarios

In Figure 10, there is the third scenario that represents the energy savings originated. As can be seen, the greatest savings will occur in the Central building.

Figure 10 – Energy savings in third scenario

4 Conclusions

GIS visualization of the campus and the animation on the energy management platform of IST, referring to electricity consumption, constitutes a key to understanding the need to improve the energy performance of buildings. Through the platform it became possible this visualization and a greater understanding of the main results obtained in this work.

Regarding the proposal by creating a model with the CEA tool, some challenges have been found. Initially due to errors in the installation, subsequently by errors in the tool code, at this time already corrected. After the program was operational, all the analyses were possible to perform, but only to test with the reference model, any change to the model of this case of study originated many errors. A recently developed alternative, the CEA Dashboard, was evaluated, but due to easy access of real data in this case study, the method that involved analyses of the actual data and calibrated EnergyPlus models and the visualization on the energy management platform was selected, as previously mentioned.

From the results obtained of analysis of electricity consumption, the four buildings are responsible for 50% of the total annual consumption of the Campus. Regarding of results of the types of energy use in each building through the EnergyPlus models, the interior equipment and lighting have a considerable weight in the total consumption of buildings, and one of the main strategies of improvement on the campus goes through the change of lighting. There are also high consumptions regarding HVAC and all systems that allow for indoor comfort. It also revealed patterns regarding occupation, week days and weekends.

About the change of the lighting, only with the change of one type of equipment, savings of approximately 11% is originated in the consumption of the Central and Civil buildings. It should be noted that in the Civil building there is a high saving of 53.4% in the lighting consumption. It is estimated that this change in the two buildings yields a 3.35% savings in the total annual consumption of the Campus. According to the analysis of the implementation of PV, such as energy efficiency measure of campus, the saving in the consumption of the four buildings can be around 9%, and the total consumption of the campus can be up to 4.44%. Knowing also that in the energy efficiency plan the implementation of panels will be in ten buildings, this last percentage can increase considerably.

In this work the energy model for the case study became possible and there are some scenarios implemented in the energy management platform with the results obtained. As proposal, it allowed a greater reliability.

Reduction of buildings consumption and improving energy efficiency are the main strategies for achieving the targets associated with large cities. As such, it reveals the importance of continuing the study of UBEM, and the application of this on the university campuses.

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