Energy Management Platform for Army Buildings

Jóni André Santo Bernardo
joni.bernardo@tecnico.ulisboa.pt
Instituto Superior Técnico, Universidade de Lisboa, Portugal
March 2021

Abstract: The year 2020 was, and is, marked by the global impact that the COVID-19 pandemic had on the way we managed and lived our day-to-day lives. This pandemic caused a huge health and economic shock that will have global repercussions at an economic, social and political level. This catastrophe has the potential to accelerate the process to change the world on a sustainable path, as well as having the opposite impact and delaying all the processes and efforts that have been carried out so far in pursuit of that goal.

The scope of this work consists of a study-project to manage consumption and increase the energy efficiency of the buildings of the Portuguese Army, having as object of study the campus of Academia Militar-Amadora. This study is divided into 2 phases, the first of which consists of building an urban energy model in the City Energy Analyst on the campus and performing a dynamic simulation through EnergyPlus to verify its consumption and verify measures to increase efficiency campus energy. The second phase consists of the construction of an energy model in DesignBuilder, using EnergyPlus as one of the buildings on the campus as a dynamic simulator to analyse electricity consumption, propose energy efficiency measures and simulate the potential for reducing electrical costs and of a building that represents about 12.5% of campus needs. To improve the energy efficiency of the building, an audit and a design study of several systems, equipment and measures were carried out simultaneously to reduce the costs arising from the building and the economic viability of implementing these changes.

Key-words: Military Installations, Electricity Consumption, Energy Efficiency, *City Energy Analyst*, Dynamic Simulation, *UBEM, Design Builder*.

Introduction

Framework

The year 2020 was, and is, marked by the global impact that the COVID-19 pandemic had on the way we managed and lived our day-to-day lives. According to BP CEO Bernard Looney, the coronavirus pandemic could be the biggest tragedy that many of us will experience throughout our lives. This pandemic caused a huge health and economic shock that will have global repercussions at an economic, social and political level. This catastrophe has the potential to accelerate the process to change the world on a sustainable path, as well as having the opposite impact and delaying all the processes and efforts that have been carried out so far in pursuit of that goal.

One of the sectors that suffered a major upheaval with the impact of the pandemic was the energy sector, more specifically its consumption. As expected, energy consumption has been increasing over the last few years, with 2019 having grown 1.3% compared to 2018 in global primary energy consumption.

Climatic changes resulting from pollution of the environment are nothing new in the 21st century, and the attempt to reduce carbon emissions started around the 1980s and became official in global terms through the Kyoto Protocol in 1997. It was based on this protocol that the European Commission (EC) published in 2018, correcting the directive of 2010/31 / EU and 2012/27 / EU, directive 2018/844, also known as EPBD, Energy Performance of Buildings Directive, which aims reverse this paradigm, focusing on energy efficiency and energy performance of buildings. With this directive, a series of strategic packages emerges that aim to reduce at least 40% of greenhouse gas (GHG) emissions in 2030 compared to 1990, increase the proportion of renewable energy consumed, save energy according to the ambitions of the EU and improve the EU's energy security, competitiveness, and sustainability. Based on these objectives, intermediate steps were created divided into the short-term (2030), the medium-term

(2040) and the long-term (2050), all stipulated in the RNC 2050.

In this context, and to achieve the objectives stipulated in RNC 2050, the Plano Nacional de Energia e Clima 2021-2030 (PNEC 2030) was developed, made official with DL nº64 / 2020, whose main function is to be an instrument national energy and climate policy for the 2021-2030 decade with the intention of achieving a carbon neutral future.

To assist the PNEC 2030, a Long-Term Strategy for the Renovation of Buildings (ELPRE) was elaborated in Portugal, which at the end of the 1st semester of 2020 is in the final stage for later approval and should be concluded in 2021, and which the measures are not only aimed at improving energy efficiency but also to bring benefits in terms of occupant health, labour productivity and asset appreciation, in which all together end up covering investment in infrastructure.

As such, this dissertation at the beginning has an intensive and complex analysis of the energy consumption of one of the units of the Portuguese Army, the Military Academy in Amadora (AMA), in which energy consumption is studied and observed on campus, the implementation of savings measures and is represented in 3D on an energy management platform to facilitate the understanding and change of measures.

After the general study of the campus, an intensive study is made on one of the buildings on the campus, the building of the 3rd and 4th Company of Students, with the aim of the dissertation being to reduce electrical and thermal costs and increase the energy efficiency of this same building and apply the data obtained at CEA, and then follow as a guide for sustainability and energy efficiency for the units of the Portuguese Army.

Literature Revision

Legal Framework

Portugal's task and mission to reduce its carbon footprint, and even reach its neutrality, has been a long-talked about and debated objective, and everything started with the 1997 Kyoto Protocol, which was defined as the first legal agreement international with strict measures / tasks to counter global warming by reducing and limiting GHG emissions from developed countries [1]. Based on this treaty, Europe, which uses 40% of its energy in the buildings sector, 27% in the residential sector and 13% in the services sector, defined that a good part of the measures to be taken to reduce GHG emissions is the increase energy efficiency in the real estate sector. In view of this fact, the EC enacted Directive 2002/91 / EC, also known as EPBD, Energy Performance of Buildings Directive, which was later amended by Directive 2010/31 / EU and, subsequently, by Directive 2018/844, this being, to date, the current one in force.

Portugal in response to the EPBD, and to make the plans defined in the PNEC 2030 official, enacted DL nº64 / 2020, defining the PNEC 2030 as a national strategic plan, serving as support for the RNC2050. For the PNEC 2030 to achieve its objectives, a long-term strategy was created for the buildings sector, taking into account that in Portugal this sector is responsible for the consumption of 30% of the final energy, this strategy consists of ELPRE, Long Term Strategy for the Renovation of Buildings, in which its main objective is to make buildings more energy efficient by acting in terms of building surroundings, replacing existing systems with more efficient ones and promoting the use of energy from renewable sources [2]

ECO.AP Program

The ECO.AP program was launched in the Resolution of the Council of Ministers no. 2/2011 of 12 January, in which the objective is to increase the level of energy efficiency of 30% in public administration bodies and services by 2020 without increasing public expenditure. , focusing efforts on reducing energy consumption in services and organizations, reducing GHG emissions, combating waste and inefficiency in the use of energy in all its aspects and developing a legal framework for the conclusion of efficiency management contracts energy that stimulate the economy.

Within the ECO.AP program, a computer tool was created and made available to the Public Administration that aims to characterize, compare and publicly disclose the energy performance of services, thus allowing to calculate the thermal quality of the surroundings, the energy efficiency of buildings based on data from the Public Administration and allows Local Energy Managers, GLE, to quickly and approximately determine the measures to be implemented to improve energy efficiency in buildings.

City Energy Analyst – CEA

Methodology UBEM

Cities currently consume more than 2/3 of primary energy on average and produce more than 70% of global GHGs [3]. In view of this enormous energy consumption, Portugal adopted strategic plans to increase the energy efficiency of buildings and reduce GHG emissions, with the PNEC 2030 and ELPRE being the strategic plans in force.

To manage where energy is used and to reduce GHG emissions, cities need to understand which buildings cause GHG emissions, but also what future impact will have measures to be taken in reducing these same gases and energy consumption. This analysis is done through energy models in buildings, designated as BEM or UBEM when applied to an urban scale, these allow individual analysis of buildings, such as energy balance, mass balance, atmospheric conditions of the interior and periphery, consumption of energy, among others.

These models are divided into 2 groups, top-down and bottom-up, with the bottom-up models being the most adopted in simulators.

The creation of a building in a UBEM model consists of modelling the building's geometry and building systems, however entering this individual information for each building is a time-consuming and complex process and as such archetypes were created, these are elaborated in 2 phases, the first being the segmentation and the second the characterization in which we place the information of a typical building of a certain category. After having defined the archetypes, thermodynamic simulation is initiated, this simulation is usually performed using only one archetype zone in transient regime, to simplify calculations, which can also be performed in dynamic regime, according to criteria established in accordance with ASHRAE 90.1, ISO 13790 and ISO 13780.

Transient simulations are preferable for the analysis of systems with a high need for heating, however, dynamic thermal simulations, such as EnergyPlus, DOE2, TRNSYS and IDA-ICE, are the most suitable for analysis of buildings with a great need for cooling [4].

City Energy Analyst

The CEA consists of a combined simulation between urban plans, energy systems and engineering processes to obtain the effects, trade-offs and synergies between energy infrastructure projects and plans [5]. The CEA allows the construction and modelling of parametric models of buildings in 3D and export and execute them in EnergyPlus, allowing their analysis according to sunlight, life cycle and the variation of spatial and temporal scales.

The generic functionality of CEA then consists of storing, analysing and visualizing information on urban energy models in time and space scales, analysing energy services in buildings, their power needs, solar radiation on building surfaces, shading phenomenon own, interaction of the building under study with its neighbourhood, its own characteristics due to its geometry and surroundings and several HVAC systems and energy services.

In terms of the operating structure of the CEA, it uses predictable urban project scenarios as input georeferenced data to calculate the hourly power requirements and the temperature required in the buildings' energy systems. For this purpose, 2 bottom-up methods are used to calculate the requirements, one being the statistical method and the other the analytical method, in which the databases on which the two are based are on the stipulated archetypes of the respective buildings. After having obtained the result of the 2 methods, these are combined and complemented by actual measured data. Finally, to reduce the processing time of the simulation and the analysis of consumption patterns, algorithms from the same “family” are grouped, which can be simplified, to obtain results with low processing and good results accuracy. consumption. The results are then displayed via a 4D interface [5].

Energy Audit

The energy audit consists of a detailed analysis of all consumption in relation to consumption and energy use in relation to heating, cooling, DHW, lighting, ventilation, equipment, among others.

It aims to acquire information on energy consumption, account for energy consumption, have data to decide, act to optimize and control situations [6] to achieve economic, environmental and social benefits

As such, the preparation of an audit is carried out in four steps, being the preparation of the audit, intervention at the installation site, treatment of the information collected and finally the preparation of the energy audit report.

To achieve the stipulated objectives, the audit may assist in the use of consumption recording equipment or dynamic simulators that acquire consumption values close to reality and are permissible if the CVRSME is less than 25% for electrical consumption in relation to a month and less than 35% if it is for a year or more [7].

An example of a dynamic building simulator is the EnergyPlus energy simulation software, the purpose of which is to generate a program that generates an energy model of a building based on information about its surroundings, energy systems integrated in the building that provide , store, distribute and consume energy, hourly profiles of the various systems and the climatic data of the building's occupation area, which then compiles and organizes the information in order to be able to calculate and forecast the desired data.

However, the EnergyPlus interface presents a certain complexity and does not allow an easy insertion and visualization of the data to be inserted for the simulations, and to overcome this problem, DesignBuilder arises, a software developed based on EnergyPlus that allows defining construction models of in a simple and intuitive way, which in the end uses EnergyPlus as a simulator.

Energy Certification and the SRI

The attribution of the Energy Certification is governed by the SCE legislation and is classified according to the performance of the building on a predefined scale of 8 classes, A + to F.

Regarding the SRI, Smart Readiness Indicator, it consists of an assessment of the building or construction unit's capacities to adapt its operation to the needs of the occupants and the network to improve its energy efficiency and overall performance.

Case Study

The case study of this dissertation is divided into 2 phases, the first of which is consumption management and energy data for the AMA campus as a whole, taking into account all AMA buildings as well as their consumption in general and data processing in the CEA in order to increase the energy efficiency of the campus. The second phase consists of the management of consumption and energy data of the barracks building of the 3rd and 4th year of AM students, which after the acquisition of the respective data, the consumption and energy efficiency measures in the DesignBuilder will be simulated.

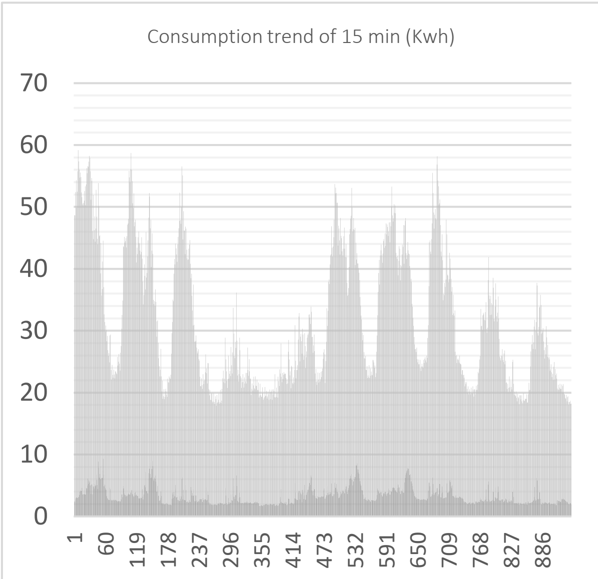

Figure 1 *– Consumption of AMA and of the building in study*

To obtain the data to carry out the intended simulations, an audit and characterization of the building's spaces, its equipment and respective nominal powers was carried out. A study was made of the space occupation profiles, the installed power in lighting, equipment and the HVAC system, in which it was concluded that the building in question has a consumption equivalent to 12.5% of AMA's consumption. AMA's annual electrical consumption corresponds, on average, to 970.225 MWh and its electrical tariff to € 0.11871 / KWh, which corresponds to € 115 175.41 / year. Regarding the building under study and considering that most of the expenses are on nightly rates, it has an annual electric consumption, on average, of 120.987 MWh and its electric tariff of 0.12019 € / KWh, to € 14 541.42 / year.

Regarding thermal consumption, in this case the consumption of natural gas, AMA has approximately an annual consumption, on average of 654.195 MWh, with a tariff of 0.0362 € / KWh, which corresponds to 23 681.86 € / year. With regard to the natural gas consumption of the building under study, it has a consumption of approximately 327 MWh, which corresponds to 11 837 € / year.

CEA campus Energy modelling

Using the CEA, an energy model that represents the AMA was elaborated. The first phase of the modeling consisted of drawing the 2D plan of the building. This modeling was done directly on the Open Street Map servers using the area and building design tool in the official OSM page.

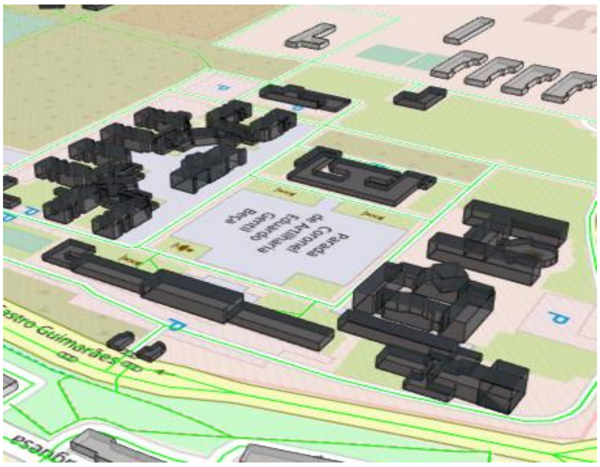

Figure 2 *– Modelling AMA in CEA*

Then, in the CEA, the values of the respective buildings present on the campus were assigned, firstly the respective heights and number of floors of the buildings were assigned, then the category and typology to which each building belongs was stipulated based on the ISO13790 standards and occupation style. After stipulating the categories, information about the building's surroundings was recorded. Finally, data on internal gains, comfort and adjustment temperatures, the HVAC and DHW systems present in each building and their respective power sources for each type of energy were added.

After recording data, several simulations were carried out to obtain solar irradiation, annual consumption and the potential of installing solar panels in buildings and in which their applicability would be more efficient.

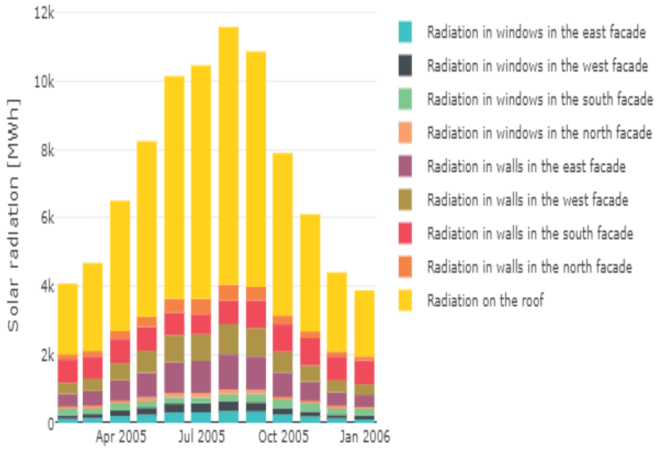

Figure 3 *– Solar radiation emitted on all facades of buildings in the countryside*

Building Energy Modelling in DesignBuilder

Using the DesignBuilder, a geometric BEM model was created that represents the building of the barracks of the 3rd and 4th Company, building that houses students of the 3rd and 4th year of AM. After the geometrical modeling was done, the data was inserted, which regardless of the electric or thermal energy supply system would always be the same, as such the data was inserted in relation to its surroundings, profiles of occupation times, lighting and equipment and systems ventilation and infiltration defined.

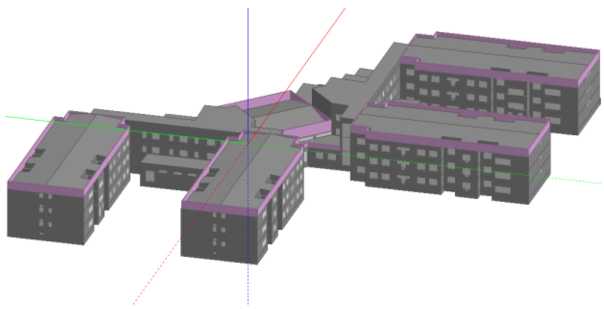

Figure 4 *– Geometric Building Model*

After the insertion of the common data, 4 energy models were made in which the structure of the HVAC system and that of the DHW differs, being defined as:

Simulation 1 - Space heating system using electric fan heaters and DHW heating through condensation boilers fed with natural gas;

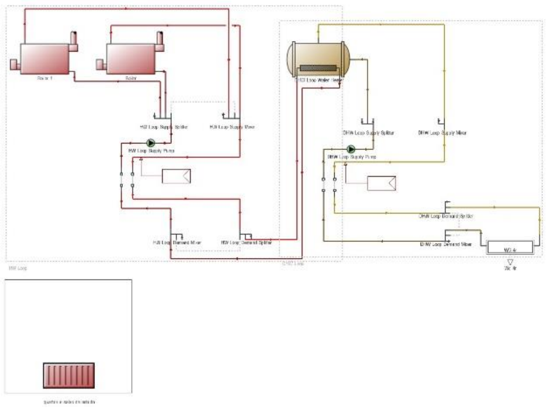

Figure 5 *- Simulation 1 HVAC System*

Simulation 2 - Space heating system using water radiators and DHW heating through condensing boilers fed with natural gas;

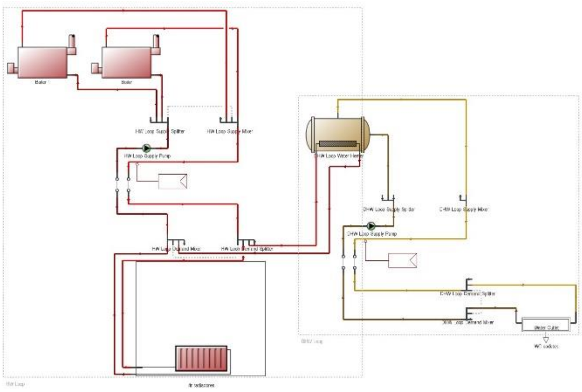

Figure 6 *- Simulation 2 HVAC System*

Simulation 3 - Space heating system using water radiators and DHW heating mainly through solar thermal panels and one as an aid to condensing boilers fed with natural gas, which are the main sources of water heating to be injected into the radiators;

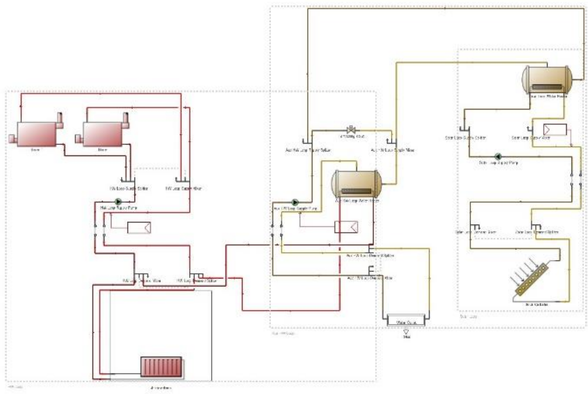

Figure 7 *- Simulation 3 HVAC System*

Simulação 4 – Sistema de aquecimento do espaço através de radiadores a água e aquecimento de AQS através de uma bomba de calor industrial, sendo a fonte de energia elétrica proveniente da rede e de um sistema de painéis solares fotovoltaicos com uma potência de instalação de 56,7 KW, instalada no telhado do próprio edifício.

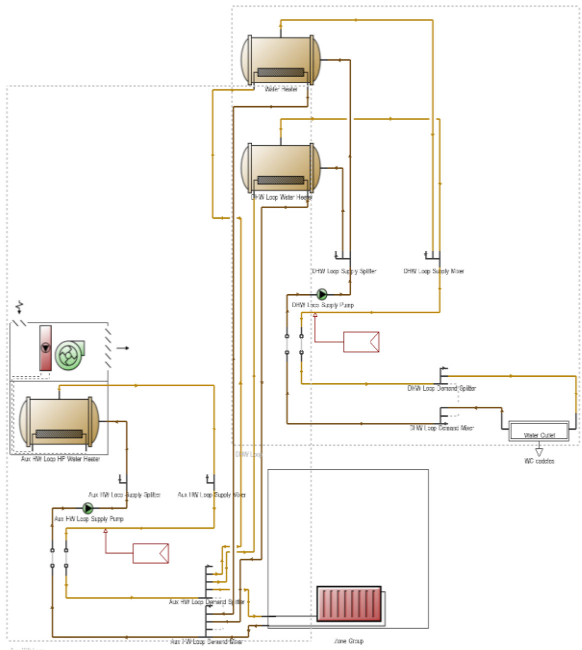

Figure 8 *– Simulation 4 HVAC System*

Results and discussion

Simulation on CEA

After assigning the necessary data to the CEA archetypes, simulations of solar radiation and consumption on the campus were carried out, which allowed us to observe that the building with the highest consumption in electrical terms, consists of building A, the building of offices, laboratories , classrooms, library and servers.

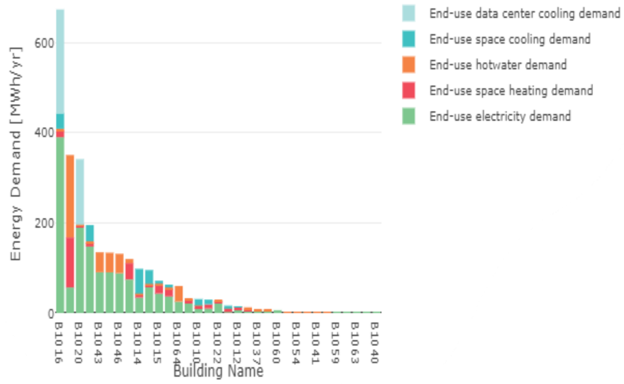

Figure 9 *– Useful Energy of AMA buildings*

Regarding the one with the greatest potential for the installation of photovoltaic panels based on the gross area occupied by the building and taking into account that for each square meter it is possible to produce an average of 54.68 KWh / year, totaling a maximum of electricity production in the July of 2 168.9 MWh with the panels installed on all AMA roofs.

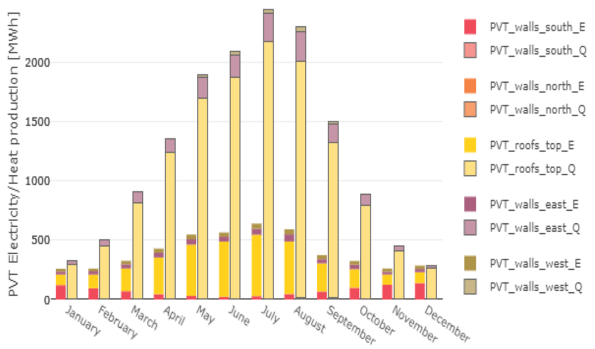

Figure 10 *- Electricity produced through PV panels*

Since this type of information is possible to obtain in detail for each building of the AMA, as well as the potential of installing solar thermal panels, sewage regeneration, heating or cooling network, geothermal energy, use of heat from lakes, as well as studying the annual, monthly and daily consumption of buildings and check the optimizations to be applied to buildings.

Simulation on *DesignBuilder*

As mentioned, this model presents a high degree of complexity as it presents all the spaces and divisions that the building has, from offices, bedrooms, bathroom, laundry, study rooms, storage room and others.

The different floors are interconnected as a single thermal zone through the areas of the stairs, and the doors and windows of each room are represented with their respective blinds and window frame thickness. Different hourly profiles for the use of equipment, lighting, hot water and occupation were stipulated, taking into account national holidays and weekends, as well as the period of military exercises, which normally take place outside the AMA.

The dynamic energy simulation was developed by EnergyPlus and the different simulations to be carried out with different energy sources were considered.

Therefore, for simulation 1, an annual electric consumption of 111 474.79 KWh and an annual natural gas consumption of 391 835.54 KWh were obtained, and taking into account the tariffs applied to AMA in electricity and natural gas consumption, annual payment of € 27 567.45. In terms of annual validation, this simulation obtained a CVRMSE of 4%.

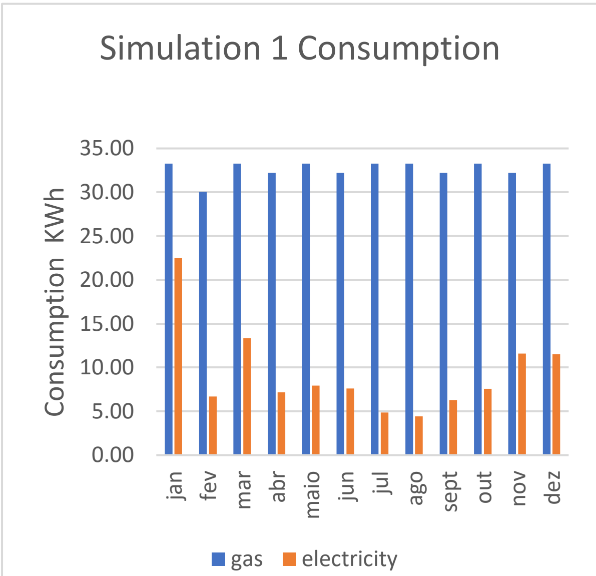

Figure 11 *– Monthly Consumption in Simulation 1*

For simulation 2, an annual electrical consumption of 71 893.57 KWh and an annual natural gas consumption of 402 868.94 KWh were obtained and, considering the tariffs applied to AMA, an annual expense of € 23 209.26.

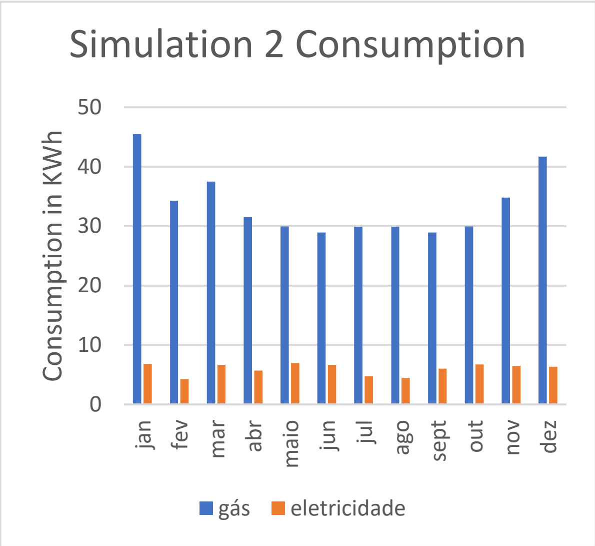

***Figure 12** - Simulation 2 monthly consumption*

For simulation 3, an annual electric consumption of 77 207.69 KWh and an annual consumption of natural gas of 346 700.75 KWh were obtained and considering the tariffs applied to AMA, an annual expense of 21 816.81 €.

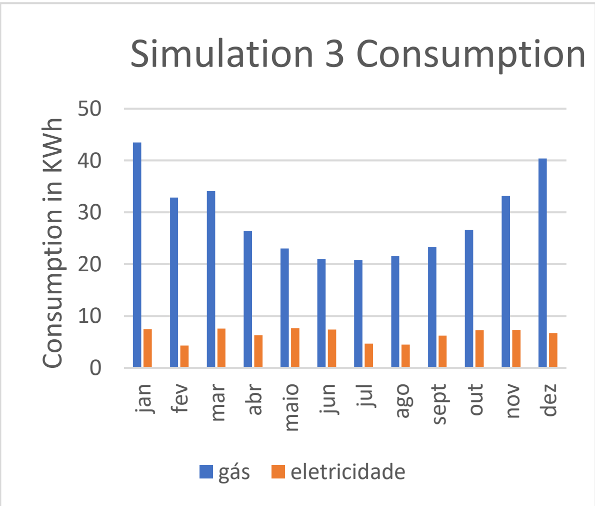

***Figura 13** - Consumos mensais da Simulação 3*

For simulation 4, an electrical consumption of 304 696.48 KWh was obtained, and due to the installation of photovoltaic panels they contribute to 30% of the building's consumption, totaling an electrical consumption extracted from the grid equal to 210 755.74 KWh, which makes a total cost of € 25 330.68 assuming the rates that AMA is subject to.

It should be noted that the panels installed and used in the DesignBuilder consist of an LR4-60HPH panel, with 350W power and 19.2% efficiency. An installation of 56.7 KW was assumed, corresponding to 162 panels, occupying an area of 295.1 m2 of the roof with an inclination of 5º. It was assumed the installation of a power of 56.7 KW so that when applied the temperature coefficient of the power of the photovoltaic module and the slope coefficient, it is possible to extract a maximum power of 50 KW in optimal conditions.

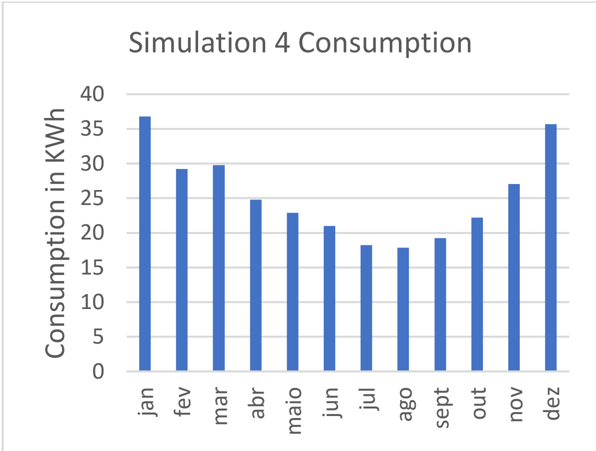

***Figura 14** - Simulation 4 monthly consumption*

Conclusion

Bearing in mind the panorama and the current situation in the armed forces, the common term for all branches is cost containment and resource rationalization. In this context, efficiency in the use of resources and resources plays a vital role in the fulfilment of the assigned missions.

To be able to act with discretion and effectively in the process of reducing energy consumption and its efficiency, it is essential to know when, where and how much electricity is consumed. According to the results of the analysis of the simulations and by comparing the consumptions measured using an electrical energy monitoring equipment in the general picture of the building of the 3rd and 4th Company, it was possible to measure the consumptions and compare the values in relation to the campus and calculate the fraction affected to the building. Thus, it can be concluded that the building is responsible for about 12.46% of the total annual consumption of the campus, which represents about € 14 362.81.

Through the geometric modelling and dynamic simulation of the building mentioned above, it was possible to verify that the modality adopted in simulation

1, which corresponds to what AMA currently adopts, corresponds to the most expensive measure, because if AMA adopts the measure suggested in simulation 2 for the two barracks, that is to say for the 4 Companies, AMA manages to save € 8 716.38 per year if it opts for heating the rooms through the use of radiators and natural gas as a source of heating of DHW waters and radiators.

However, the measure that, through the simulations, is the most economical in terms of maintenance and comfort costs, consists of simulation 3, the adoption of solar thermal panels and that if adopted for the 4 Companies saves € 11 501.28 annually

The question of cost reduction due to simulation 4 is not very significant, since the installation is a low power considering the consumption of the building and even the campus, since simulation 4 is the most viable in in terms of self-support and energy efficiency, however, it requires the installation of a large power of photovoltaic panels in order to fill the power required by the heat pump to heat the waters. Finally, and using the primary simulation in DesignBuilder, a summary extraction of the general and specific consumptions of the building is made and the same data is inserted in the CEA archetypes, this measure being the easiest to implement to obtain accurate and consumption of different categories such as those of the Portuguese Army.

This dissertation allowed us to demonstrate that the Armed Forces and the Army must lead by example and demonstrate to the country that energy efficiency is achievable and profitable in reducing costs and GHG emissions.

References

[1] Agência Portuguesa do Ambiente, “Protocolo Quioto,” 1997. [Online]. Available: https://apambiente.pt/index.php?ref=16&subref=81&sub2ref=119&sub3ref=500.

[2] DGEG, “Diretiva do Desempenho Energético dos Edifícios.” [Online]. Available: https://www.dgeg.gov.pt/pt/areas-setoriais/energia/eficiencia-energetica/diretiva-do-desempenho-energetico-dos-edificios/diretiva-dos-edificios/

[3] Y. Chen and T. Hong, “Impacts of building geometry modeling methods on the simulation results of urban building energy models,” Appl. Energy, vol. 215, pp. 717–735, 2018, doi: 10.1016/j.apenergy.2018.02.073

[4] C. F. Reinhart and C. Cerezo Davila, “Urban building energy modeling - A review of a nascent field,” Build. Environ., vol. 97, pp. 196–202, 2016, doi: 10.1016/j.buildenv.2015.12.001

[5] CEA, “The City Energy Analyst,” 2020.

[6] J. A. Fonseca, “Energy efficiency strategies in urban communities: modeling, analysis and assessment,” p. 89, 2016, doi: http://dx.doi.org/10.3929/ethz-a-010639933

[7] J. S. Haberl, D. E. Claridge, and C. Culp, “ASHRAE’s Guideline 14-2002 for Measurement of Energy and Demand Savings: How to Determine what was Really Saved by the Retrofit,” Fifth Int. Conf. Enhanc. Build. Oper., no. June 2015, pp. 1–13, 2005.