DEPARTMENT OF
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RAQUEL OURIVES DA SILVA
Bachelor of Science in Mechanical Engineering

TESTING THE USE OF THE PRIORITEE DECISION SUPPORT TOOL IN PORTUGAL TOWARDS DESCAR-BONISED PUBLIC BUILDINGS

MASTER IN RENEWABLE ENERGY ENGINEERING

NOVA University of Lisbon
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NOVA SCHOOL OF SCIENCE & TECHNOLOGY

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To Maria do Rosário Ourives, the one who taught me to dream.

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"Espero que a derrota que tracei venha a ser o meu rumo."

ABSTRACT

In the European region, more specifically in the Mediterranean area, most of the public authorities need to enhance their institutional capacity in the field of Energy Efficiency (EE) and use of Renewable Energy Sources (RES) to contribute to the Energy Performance of Buildings and the Energy Efficiency Directives, developing solutions adapted to various regional contexts. In the national context, there is a clear pressure for energy independence and decarbonization, which inevitably pass through the increase of ambition regarding the target for Energy Efficiency.

The work developed within this dissertation focuses on the collection and application data belonging to the buildings of LNEG (State Laboratory of Energy and Geology), Arruda dos Vinhos Municipality, and AREANATejo (Regional Energy and Environment Agency). For this analysis, 22 public buildings were selected to identify the priority interventions to improve energy efficiency and optimize energy uses, evaluating their effectiveness in terms of energy savings, reduction in CO_2 emissions, and return on in-vestment (ROI). The goal, after testing the tool, was to support the definition of a local action plan that could support the drafting of the city's Sustainable Energy and Climate Action Plan.

This study is framed with the follow-up project – *PrioritEE PLUS,* recently funded by INTERREG MED, whose focus is the testing of the *PrioritEE* Decision Support Tool (DST). The data to be inserted in this tool comes from the buildings' Energy Performance Certificates, encompassing a diversity of end users from local authorities.

Given the results of the prioritization analysis of improvement measures suggested by the DST, the most recommended renovations to be implemented, resulting from the savings felt by the decision makers as well as from the energy performance of the buildings, are the substitution of the floors, as well as the replacement of the windows.

The results allow to understand which type of buildings have more energy performance deficiencies within the clusters under analysis and, through this sample, to give municipalities this sectorial knowledge to integrate into their Energy and Climate Action Plans, which in many situations is required to apply for funds and funding.

Keywords: Energy Performance Certificates, Commercial and Service Buildings, Energy Efficiency Measures, Building Typologies, *PrioritEE PLUS*.

RESUMO

Na região da Europa, ao nível do mediterrânio, grande parte das autoridades públicas necessitam reforçar a sua capacidade institucional no domínio da Eficiência Energética e da utilização de Fontes de Energia Renováveis, por forma a contribuir para o Desempenho Energético dos Edifícios Públicos, bem como das Diretivas de Eficiência Energética, desenvolvendo soluções adaptadas aos diversos contextos regionais. Existe, no contexto nacional, uma pressão clara para a independência energética e para a descarbonização, que passam inevitavelmente pelo aumento da ambição relativa à meta para a eficiência energética.

O trabalho desenvolvido nesta dissertação foca-se no recolhimento e aplicação dos dados pertencentes aos edifícios do LNEG (Laboratório Nacional de Energia e Geologia), edifícios pertencentes à municipalidade de Arruda dos Vinhos, e os edifícios pertencentes à AREANATejo (Agência regional de Energia e do Ambiente). Para esta análise, foram selecionados 22 edifícios públicos de forma a identificar as principais intervenções a serem priorizadas por forma a melhorar a eficiência energética, e a otimizar a utilização da energia, avaliando a sua eficácia em termos de economia de energia, redução de emissões de CO_2 e retorno sobre o investimento. O objetivo, após a ferramenta ser testada, é o de dar suporte à criação de um plano de ação local que possa ser convertido a um porterior Plano de Ação para a Energia Sustentável e Clima.

Este estudo enquadra-se na extensão do projeto recentemente financiado pelo INTERREG MED, denominado PrioritEE Plus Project, cujo principal foco é a utilização da ferramenta Decision Support Tool (DST). Os dados a serem inseridos nesta ferramenta advém dos Certificados Energéticos de cada edifício e, neste sentido, terá de existir do utilizador uma prévia análise e extração de informação do mesmo.

Como resultado da análise de priorização de medidas de melhoria sugeridas pela ferramenta DST, as renovações mais recomendadas a serem implementadas, decorrentes das poupanças sentidas pelos decisores bem como pelo desempenho energético, são as interveções associadas ao pavimento bem como a substituição dos vãos envidraçados.

Desta forma, perante os resultados obtidos, é possível entender-se que tipo de edifícios apresentam mais carências de performance energéticas dentro dos clusters em análise e, através desta amostra dar aos municípios este conhecimento sectorial para integrar os Planos de Ação de Energia e Clima, que, em muitas situações são necessários para concorrer a fundos e a financiamento.

Palavras-Chave: Certificados Energéticos, Edifícios de Comércio e Serviços, Medidas de Eficiência Energética, Tipologias de Edifícios, *PrioritEE PLUS*.

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ABREVIATIONS AND ACRONYMS

AREANATejo - Regional Agency for Energy and Environment of North Alentejo and Tagus

CAC - Commission for Climate Change

CCP – Public Contract Codes

CELE - European Commerce of Emissions Licenses

CIMAA - Intermunicipal Community of Alto Alentejo

COP21 - United Nations Conference of the Parties

DST - Decision Support Tool

EPBD - European Directive for Energy Performance of Buildings

EE – Energy Efficiency

EU- European Union

IEA - International Energy Agency

GHG - Greenhouse Effect

LNEG - National Laboratory for Energy and Geology

MPBs - Municipal Public Buildings

NZEB - Nearly Zero Energy Building

PNAC - Nacional Program for Climate Change

PNAEE - National Action Plan for Energy Efficiency

RES - Renewable Energy Sources

RNBC - Nacional al Low Carbon Roadmap

RNC2050 - Roadmap for Carbon Neutrality 2050

ROI - Return on Investment

SDG - Sustainable Development Goals

SEAP - Sustainable Energy and Action Plan

1. INTRODUCTION

Buildings are responsible for approximately 40% of energy consumption and 36% of CO_2 emissions in the European Union [1]. About 35% of the buildings are over 50 years old and 75% of the overall stock is energy inefficient [2]. Additionally, commercial buildings are more energy-intensive than residential ones.

Despite all the efforts made to make citizens worldwide aware of the need for higher energy efficiency in buildings, there are still several flaws. It is notorious that despite all the information that exists in an easy way to reach, not many people understand the concept of energy efficiency and the weight it has in our world for energy consumption and greenhouse gas reduction.

The European Union directives underline the path of decarbonizing energy systems in response to the climate challenges set by the Paris Agreement, adopted by the United Nations Conference of the Parties COP21 in 2015 and ratified in November 2016 by 187 parties, which aims to restrict global warming to 2ºC and encourages a further limitation to 1,5ºC.

Enhancing adaptive and mitigate capacity to deal with climate change is a pressing challenge for cities across the planet and is among the United Nations Sustainable Development Goals (SDGs). A specific analysis of 885 cities in the EU has highlighted the need for local authorities' capacity building in Europe [3] [4].

A recent assessment by the International Energy Agency (IEA) regarding the status of the global building sector according to the SDGs identifies that "emissions from buildings appear to have risen again in 2018 for the second year in a row" due to "several factors, including extreme weather that risen energy demand for heating and cooling" and that "enormous potential remains untapped due to the widespread use of less-efficient technologies, a lack of effective policies and insufficient investment in sustainable buildings" [5].

A range of sustainable solutions already exist; however, these are not always well understood or available to local decision-makers. In most cases, public authorities have insufficient knowledge of building features, energy consumption, and the knowledge of most potentially effective options for improving buildings' energy performance. Bridging this gap is important while tapping greenhouse gas emissions and local authorities' energy bills.

To resolve those issues, many computer-based models and tools have already been developed to perform an energy analysis of buildings models and the building energy systems to support energy planning and analyze the integration of renewable energy into energy systems.

However, most of these models and tools are very complex and remain unknown to municipalities and local governments, hindering their utilization in supporting strategic decision-making.

It is, therefore, necessary to strengthen the institutional capacities of local public bodies in the sustainable management of public buildings. One example of this kind of initiative is addressed by the project *PrioritEE* Project “Prioritize energy efficiency measures in public buildings: a decision support tool for regional and local public authorities” [6] [7], financed by INTERREG MED program and with the main goal the planning towards implementation of more energy efficient solutions in municipal public buildings in five Europe countries - Croatia, Italy, Greece, Portugal, and Spain.

The present work was developed in the context of a follow-up of this research project (i.e., *PrioritEE* Plus), and the main objective is to explore the DSTool in order to prioritize and select the energy efficiency measures in the public administration buildings under study. To this end, it is essential that the following detailed objectives are achieved:

- To explore the use of the Decision Support Tool in the Portuguese context, selecting a set of case study buildings.
- To collect the information present in the Energy Performance Certificates.
- To analyze the renovation solutions for public buildings resulting from the simulation.
- To understand the national framework of public energy policies, to find out how we can advise the public entities that own the buildings.

1.1. Context and Motivation

Today, energy efficiency in buildings has become increasingly important due to the large portion of energy consumption that buildings account for. Finding solutions to this issue is a major goal for the scientific community, particularly in renewable energies and building construction. As a result, a strong collaboration between these two areas is crucial and necessary. The advancement of this collaboration is also driven by the growth of the concept of Near Zero Energy Building (NZEB).

Despite the driving force that has been felt to leverage energy efficiency at European and national levels, there are still many unknowns regarding Portuguese public buildings. In this sense, at the national level, several goals were set to face the economic recovery and the climate transition that public administration entities must go through.

Among the objectives outlined for energy policy in the national public buildings, "energy efficiency must be given priority", as mentioned in Council of Ministers Resolution n.º 2/2011, of January 12, [8], which marked the approval of ECO.AP programme. In this sense, it is necessary to improve the energy efficiency of public buildings. However, this challenge is not easy to achieve since one of the major difficulties centers on the fact that the data available on the energy certificates of public buildings do not distinguish between government buildings and private sector buildings. Even so, regardless of the building's typology, the core of the problem is centered, most of the time, on lacks of the building's constructive elements, such as Investment in insulation and poor quality of the windows.

It is known through the ECO.AP 2020, which are the objectives and challenges facing public buildings: by 2030 achieve reductions of 40% in primary energy consumption, 20% in water consumption, and 20% in material consumption, as well as achieving 10% self-consumption based on renewable sources and an annual rate of 5% for building renovation. In this way, it is important to develop decision support tools by the public administration which prove to be easy to understand and use so that they can be tested even by those who do not have knowledge about the topics associated with promoting energy efficiency of a building. These tools, contrary to many other existing energy simulation programs, present results focused on the plan and not on a detailed perspective of the performance of each building so that decision-making becomes a less complex process.

A pioneering example of these cases is the *PrioritEE* DSTool decision support tool, developed within the framework of the European project *PrioritEE*, funded by *INTERREG MED*[1], which helps to prioritize energy efficiency measures in local public administration. This tool allows the local entity decide, based on the portfolio of buildings in the municipality, which should be the focus of attention. Second, now with a more detailed analysis, helps to find opportunities for improvement and to select the most appropriate and impactful measures depending on the objective. Finally, it allows combining different indicators to assess the financial impact and impact on emissions, also considering the building area and number of users impacted. By introducing an environmental indicator into the analysis, the tool also helps to balance the arguments for investing in passive measures - wall and roof insulation ad window replacement.

The bottom line of this work is based on the importance of the awareness of making a cost-effective renovation of the Municipal Public Buildings (MPBs) to reduce both CO_2 emissions, energy consumption, and the bill of a local council.

As mentioned before, this work developed within this dissertation focuses on the collection and application of the DSTool to the Portuguese buildings on the case studies of regions of LNEG, Arruda dos Vinhos, and AREANATejo. For this analysis, 22 public buildings were selected to identify the priority interventions to improve energy efficiency and optimize energy uses, evaluating their effectiveness in terms of energy savings, reduction in CO_2 emissions, and return on investment (ROI). The goal, after testing the tool, was to support the definition of a local action plan that could support the drafting of the city's Sustainable Energy and Climate Action Plan (SECAP) that the city administration could implement starting from the previous Sustainable Energy and Action Plan (SEAP). [9]

1.2. The *PrioritEE* Project Framework

Making Public Buildings smarter and more energy efficient requires tailored solutions to overcome the barriers to implementing sustainable technology options in a large variety of building types.

The *PrioritEE PLUS* Project which the core is: "*Prioritize energy efficiency measures in public buildings: a decision support tool for regional and local public authorities*", was developed is parallel

[1] https://prioritee.interreg-med.eu/

with the present dissertation. This project aimed to support more efficient energy management of MPBs in five Mediterranean countries (Croatia, Italy, Greece, Portugal, and Spain). The core of the approach is the development of a comprehensive and generally applicable set of tools (which constitutes the *PrioritEE* toolbox) aimed at professionals and experts from different levels, including energy managers, energy planners, and decision-makers.

As it was mentioned before, one of the main objectives of this project was to create and test a toolbox to support the management of energy use in municipal public buildings. The development of the *PrioritEE* DST was driven by the following main requirements outlined by the city governments and local stakeholders that were involved since the early stages of the project: i) easy and user-friendly Interactions; ii) free online availability of both the English version and translated version In the languages of the partner countries; iii) focus on building project development and implementation evaluation; iv) flexibility in data input (limited key data but the ability to apply more extensive data, If available); v) ranking of EE measures and RES solutions under several key performance indicators.

The DST allows a tailored approach where users can provide numerous assumptions and database Information and quantify different technical and financial parameters for their specific buildings. As it will be described in chapter

3.3. The *PrioritEE* Decision Support Toolof the present dissertation, using the tabs, users can select the building typology, insert information about energy consumption and relevant energy cost, specify the current state of the building envelope analysed and the parameters for its technical systems. In addition, users can select the desired level of energy renovations, such as the new preferred technical systems, the desired options for the building envelope, and the inclusion/exclusion of certain measures from the calculations. In a dedicated input tab (calculation operations), users can modify the calculation processes that have the greatest influence on financial parameters (energy costs, investment value, return of Investment). This means that users directly influence the results-the more detailed the inputs, the more accurate the results. In the case of buildings with an Energy Performance Certificate (EPC) it is possible to use this information to obtain a detailed characterization for inclusion in the DST. Otherwise, if users are unable to provide certain information, the calculations are based on average values for each country contained in the database, which were derived during the project from national EPC, standards, and reports from each pilot case. The geographical location of the buildings added to the DST application is represented on a map, which provides an overview of all the buildings that have been entered and their respective basic information (energy class and expected energy saving potential).

Once the data entry phase is completed, the calculation module allows the computation of the main impacts of the selected EE and RES interventions per each of the MPBs analysed. The DST calculates energy savings and costs for interventions, e.g., improving the building envelope, replacing heating, cooling and hot water systems with more efficient and/or RES-based systems (among those selected by users), and replacing lighting devices with more efficient LED ones. Among RES technologies, solar thermal collectors and PV panels are the main options included in the DST.

The next step is the analysis of the results. Results are provided as indicators per building and per type of measure and allow a customized ranking (and prioritization) of EE and RES interventions in each MPB as well as in the entire stock of MPBs under analysis. This customization is undertaken through a dynamic sorting of the list of measures, based on different criteria, namely: annual energy savings (kWh), annual primary energy savings (kWh), annual energy cost savings (€), investment (€) and annual reduction of CO_2 emissions (tons/year). Calculation options can be changed quickly, and different measures can be easily included/excluded so that the total values for a single building are automatically updated. Finally, the results are also presented through a set of indicators relevant to the benchmarking of different MPBs, before and after the selected buildings. Apart from calculations, the *PrioritEE* DST also allows the exportation of a report for a single building or for more selected buildings providing an overview of input and results.

In summary, this interactive online calculator provides users with a relatively easy and quick calculation of energy and financial savings in public buildings by applying different EE measures and RES interventions. Users can create their accounts which allow them to enter an unlimited number of buildings, to use the large database available for countries Involved in the *PrioritEE* project and identify the buildings with the highest potential of energy (and financial) savings.

1.3. Approach and Contributions

There were several works that served as the basis for the construction of this study. Since the main objective of this dissertation is to test the DST, it is important to highlight the contributions that served as the basis for the use of the tool. In the first stage it was necessary to collect the energy certificates belonging to the different buildings. This directive focuses solely on local administration buildings, based on the analysis and treatment of data present in the energy certificates of the 24 buildings to be analyzed here.

Through the obtained data, it was mainly intended to identify which information was important to be placed in the tool. After inserting the data in the tool, some inconsistencies were detected, which were later made known to the support team that created the tool so that these flaws could be suppressed, and the calculations could be optimized.

This work was developed in parallel with the *PrioritEE* PLUS project, and in this sense, it was also possible to extract several outputs, namely associated with awareness raising activities. Regarding the Portuguese project, it is important to highlight the workshop given to the municipalities associated with the project, where the advantages of the tool were explained and how it should be used. At an international level, a Technical Visit was made for the partners of the project. The place of the meeting was the Solar XXI building, which is part of the LNEG campus in Lisbon. On this visit, it was possible to get to know a building that was conceived with the implementation of strategies that optimized the building envelope by reducing thermal loads, as well as the implementation of passive solar systems (heating and cooling) and active (photovoltaic and thermal). Also, during this partners' conference, the latest developments that each entity had achieved as a result of the *PrioritEE* Plus project were made known, in addition to promoting interpersonal links between partners.

Moreover, awareness-raising initiatives and capacity-building activities were carried out throughout the project to involve key target groups, familiarize them with the *PrioritEE* toolbox, and ensure it was suitable for application in the five local pilots. One relevant feature of the *PrioritEE* toolbox is that it focuses explicitly on several types of public service buildings (e.g., cultural buildings, health centers, sports centers, schools) and office buildings. This progresses current literature a step further, where previously, it has mainly focused on office buildings [6].

1.4. Work Organization

This dissertation is organised into five chapters, which reflect distinct phases of its development. In this sense, the structure of the dissertation is presented as follows:

Chapter 1 - Introduction and contextualization of the theme under study and description of the main and specific objectives of the work and its structure.

Chapter 2 - Description and characterization of the state-of-the-art energy consumption in general and in specific for the buildings sector, presentation of the energy efficiency and renewable energy sources in public buildings, presentation of the overview of European regulations and Portuguese plans, programs, and instruments for the promotion of energy efficiency.

Chapter 3 - Description of the methodology used for preparing the sample and data treatment for obtaining the results, namely the DST Tool, as well as the presentation of the buildings included in the case study.

Chapter 4 - Presentation and discussion of the results obtained, with the purpose of characterizing the current situation and providing detailed information about the buildings under analysis.

Chapter 5 - Description of the renovation measures to be prioritized for the Implementation of public buildings under analysis.

Chapter 6 - Presentation of the main conclusions drawn from this work and the main limitations encountered in its development.

2.
STATE OF THE ART

Energy is fundamental to produce industrial, commercial, and social wealth, and most countries, and consequently many human activities, depend on the combustion of fossil fuels, such as oil, coal, and natural gas [9].

In the EU, according to existing records on primary and final energy consumption, which can be seen in Figure I.1 of Annex I, from the 1990s to 2006, there were progressive increases in these consumptions, with the peak of energy consumption having been recorded in 2006, with consumption of primary and final energy of approximately 1.723 Mtoe and 1.194 Mtoe, respectively. From 2006 to 2014, there seems to be a drop in these consumptions, highlighted only by the exception that occurred in 2010, where both energy consumptions increased again but never reached the maximum values reached in 2006. From the year 2014 to the most recent records dating from the year 2016, it is possible to verify that the consumption of primary and final energy in the EU increased again.

Also analyzing the European context, according to the records of final energy consumption by sector for the year 2020, presented in Figure 2.1, the energy consumption by the buildings sector is notorious, characterized jointly by the residential sector and the services sector. In the EU, buildings represent around 30% of final energy consumption, with a predominance of electricity (24.8%) and natural gas (31.7%), as the main forms of energy used in this sector [10]. The transport sector is also prominent as an energy consumer, as it represents around 18.8% of final energy consumption.

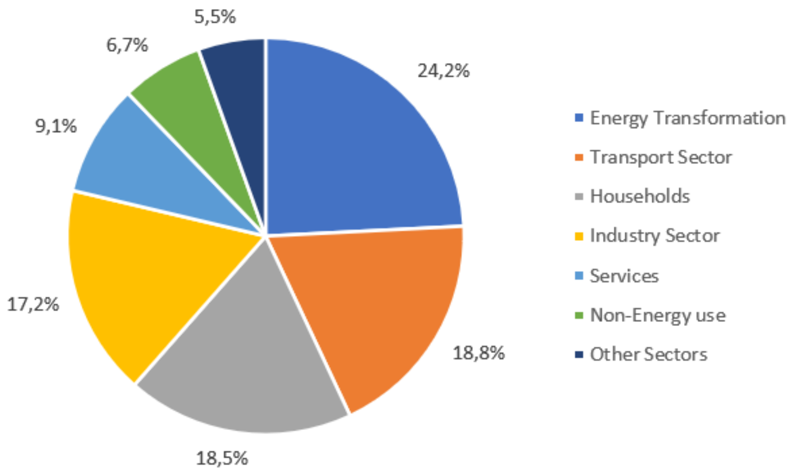


Figure 2.1 - Final energy consumption by sector, in the European Union, for the year 2020. Source: adapted from Eurostat [10].

Bearing in mind that the present study focuses on the buildings sector, particularly on commercial and service and State buildings, it is relevant to analyze, at the European level, individually what happens with the Services sector, which encompasses this type of buildings. It is a fact that at the European level, as can be seen in Figure 2.1, buildings represent approximately 30% of final energy consumption, with this consumption being mostly attributed to the residential sector, with a representation of 18.5%. However, despite the lower expression of the services sector, which represents around 9.1% of final energy consumption, this sector is not overlooked and assumes equal importance in the development of work on energy efficiency.

Contrary to the evolution of total final energy consumption recorded over the years in the EU, in the services sector, and as shown in Figure 2.2, this consumption grew progressively from 1990 to 2010, with the maximum energy consumption final recorded precisely in 2010, with a value of around 158 Mtoe.

Looking with more detail at the final energy consumption within the non-residential building sector in the European Union, this sector can be divided by the different types of buildings in Offices (26%), Commerce (28%), Education (12%) Hotels and Restaurants (12%), Hospitals (10%), Sports (6%) and Others (6%) [10].

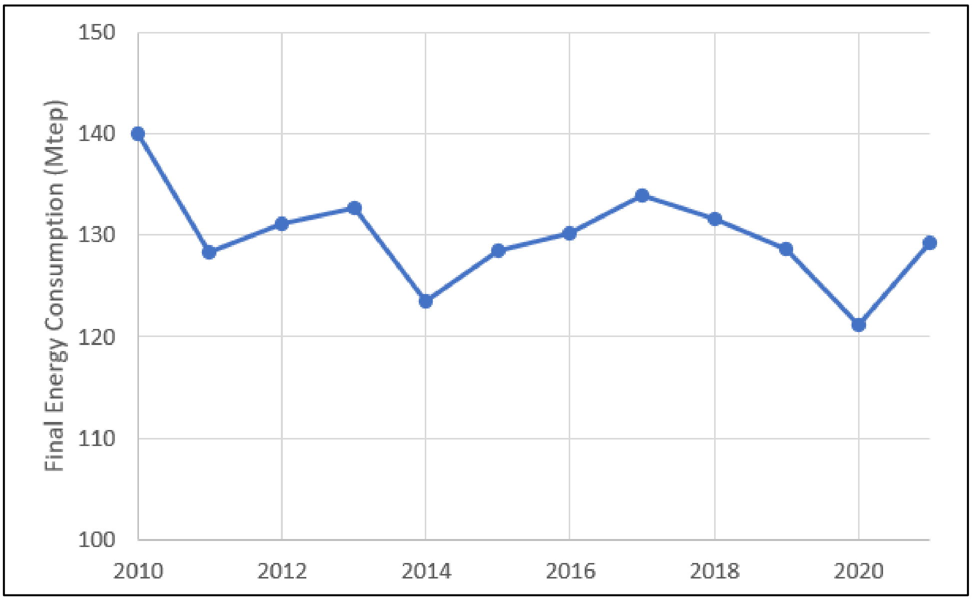


Figure 2.2 - Final energy consumption for the Services sector, in the European Union, between 2010 and 2020. Source: adapted from Eurostat [11].

Considering that the present study focuses on public buildings in the Portuguese context, it is relevant to analyze in detail the energy consumption of these types of buildings. However, it is difficult to find data on the energy consumption of public buildings and services, especially for local administration, since this same information is often scarce or non-existent, or is not accounted for correctly, or is dispersed by various departments or locations [15].

On the other hand, statistics on energy consumption of services, when they exist, are not available for most countries or are aggregated for the public sector, with no breakdown of consumption by the main factors, which translates into the scarcity of information presented, for instance, in the Odyssee-Mure database [16].

According to superficial data made available by the Odyssee-Mure database [16] referring to 2015, it is possible to define a pattern of electricity consumption by the different categories of services. Through the Figure 2.3, it is possible to observe electricity consumption in the EU and Portugal, for the education, hotel and restaurant, health, public and private offices, and wholesale and retail categories. In the EU, it is in wholesale and retail trade, as well as in public and private offices, that more electricity is consumed, with values around 34.1% and 32.6%, respectively. Hotels and restaurants (13.8%), health (13.5%), and education (5.9%) follow the two categories, in descending order of electricity consumption recorded for the services sector.

In Portugal, electricity consumption for the different categories follows the trend registered in the EU for the hotel and restaurant categories (13.3%), health (6.7%), and education (2.3%), as the least consuming categories. However, at the national level, the highest consumption of electricity is attributed to public and private agencies (48.3%), followed by wholesale and retail trade (29.5%), with both categories responsible for the highest electrical consumption in the service sector.

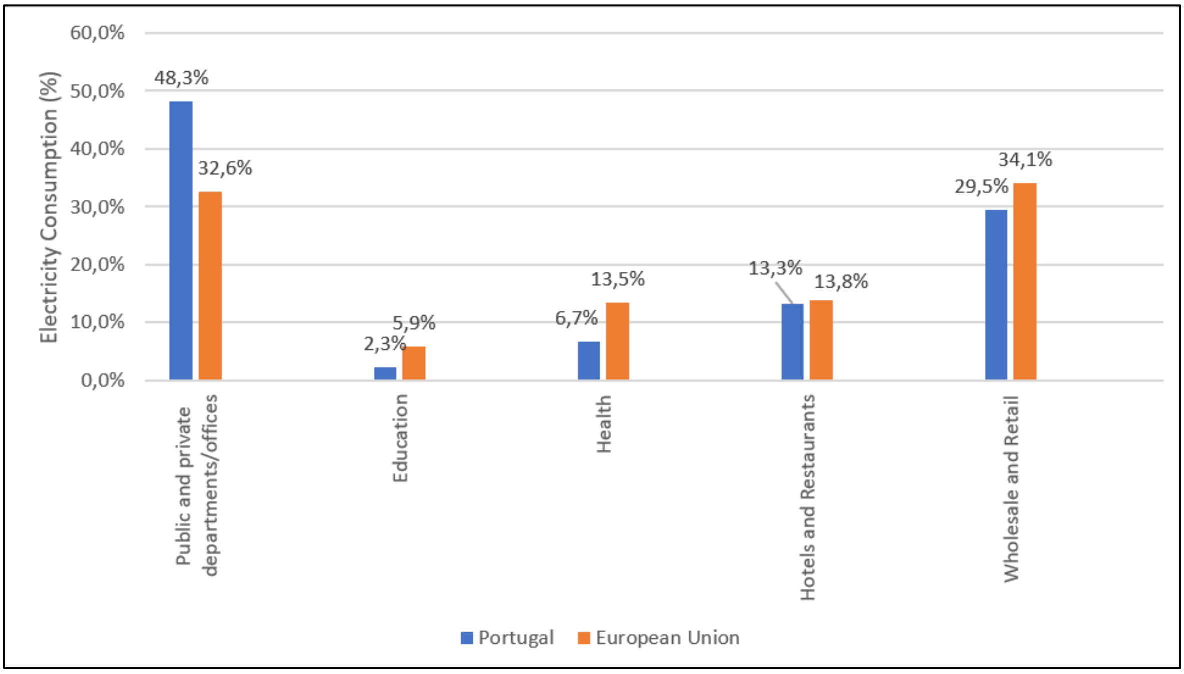


Figure 2.3 - Electricity consumption by category, for Portugal and the European Union, in 2015. Source: adapted from Odyssee-Mure [16].

Due to the energy consumption recorded for the buildings sector, both at European and national levels, it is essential to focus on energy efficiency in this sector, since in the EU the potential for energy savings is quite significant and can reduce around 50% of energy consumption is reduced with the application of energy efficiency measures. Therefore, this decrease in energy consumption translates into an annual reduction of 400 Mt of CO_2, almost the entire EU commitment under the Kyoto Protocol [17]. It is also important to bet on greater use of energy from renewable sources to the detriment of that from fossil sources, since in the EU in 2016, the contribution of renewables in gross final energy consumption represents only about 17%. In turn, the contribution of renewables to electricity production represents around 30%, while heating and cooling account for a share of 19% (Eurostat, 2023d). In Portugal, due to its characteristics and location, according to 2016 data, the contribution of renewables in gross final energy consumption was around 28.5%, with heating and cooling being one of the main causes of energy consumption in buildings, this contribution was approximately 35% [18].

2.1 Energy Efficiency and Renewable Energy Sources in Public Buildings

Analyzing the final energy consumption by type of fuel, which can be found in Figure 2.4, it is possible to observe that the consumption of electricity and gas are the main forms of energy used in this sector, similarly to what happens with the other sectors of activity. It is important to note the significant increase in electricity consumption in non-residential buildings in the EU, which is compatible with the technological advances that have taken place over the last few decades, where there has been a growing penetration of smart technologies, air conditioning systems, among others [13].

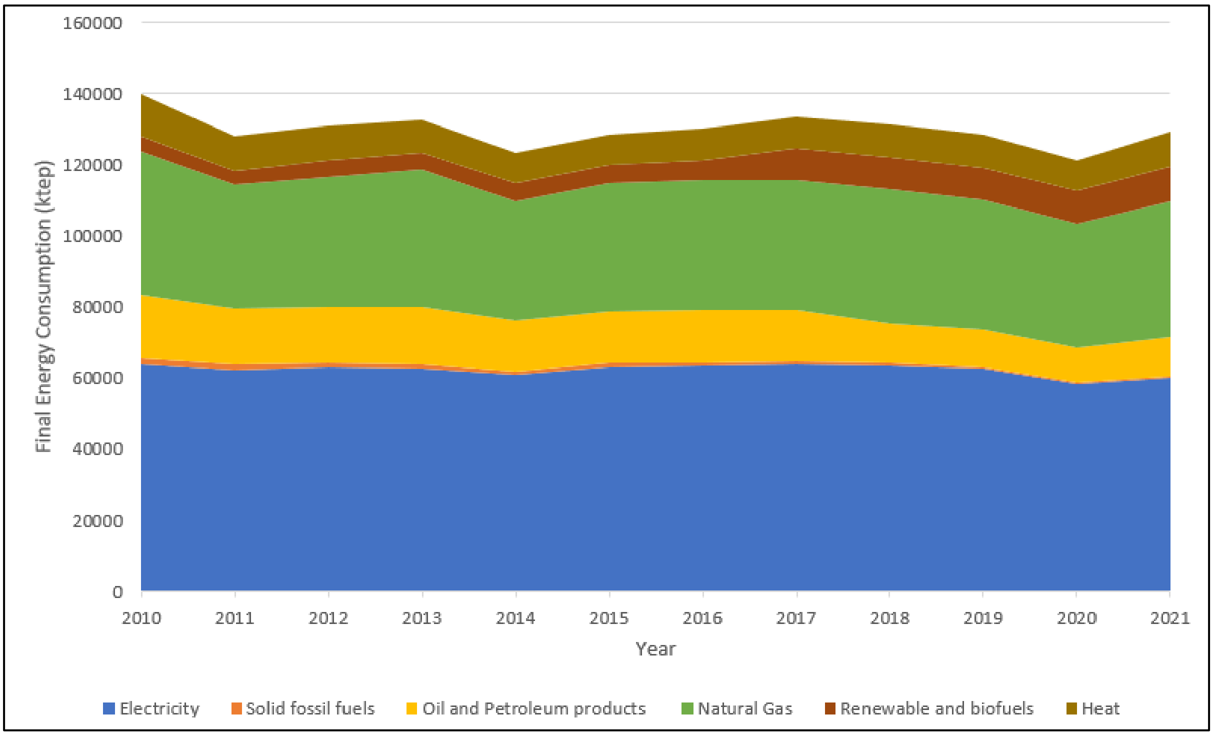


Figure 2.4 - Final energy consumption of the Services sector by fuel, in the European Union, for the period between 2010 and 2021. Source: adapted from Eurostat [10].

Energy efficiency, or energy sustainability, is directly associated with how energy is produced or used. This fact can be seen from a macro point of view, regarding the way renewable sources produce the electricity that is needed to supply buildings, as well as from a micro perspective related to the measures to be applied to buildings to make them more efficient. energetically.

This work will only analyze the measures to be implemented in buildings since how renewable electricity is produced is outside the scope of this work. Regarding the measures to be implemented in buildings, in this study we will divide them into two aspects, active measures and passive measures. Regarding active measures, these involve implementing equipment in buildings that encourages the production of renewable energy, such as aerothermal energy, to promote people's comfort. Passive measures, on the other hand, are related to how unwanted thermal exchanges are avoided by implementing solutions with better energy performance such as windows, and insulation, among others.

Over the years and because of the increasing energy consumption recorded in the EU, public administration of EE and RES measures in the Mediterranean area is characterized by a wide variety of administrative requirements, sometimes presenting a barrier to the implementation of these measures. This administrative process presented the most significant challenge in the development of the *PrioritEE Plus* Toolbox.

2.2 European Regulatory Overview

With the adoption of the Paris Agreement 2015, it was agreed that it is possible to overcome the challenge of climate change and stop global warming on the planet, just 2ºC above pre-industrial levels.

As a result, the European Commission has created a series of strategic packages to respond to this global challenge in different areas. Among them, we can highlight the Climate 2030 Energy Package, the Clean Mobility Package, and the Clean Energy Package for all Europeans.

In this global context, the inevitability of the energy transition is recognized, given the climate urgency and the need to change the economic paradigm about fossil fuels.

At this moment, the benchmarks are necessarily those resulting from European policies regarding the energy efficiency of buildings. Member States have been promoting a set of measures intending to boost the improvement of energy performance and the comfort conditions of buildings, by Directive 2002/91/EC, of 16 December [19], Directive 2010/31/EU, of 19 May – European Directive for Energy Performance of Buildings (EPBD) [20] – both European Parliament and of the Council, concerning the energy performance of buildings.

Following the implementation of the Energy Union Strategy [21], one of the main advances was the adoption of the Commission proposal, in 2016, of the Clean Energy Package, as mentioned before, which included eight legislative proposals. In this context, in 2018, the EPBD was amended by Directive (EU) 2018/844 [22] of the European Parliament and the Council, to accelerate the renovation of EU buildings, namely accelerating the renovation of existing buildings until 2050 and supporting the modernization of all buildings with smart technologies and a clearer relationship with clean mobility.

The EPBD recast changes, create a clear trajectory to reach a housing stock with reduced or zero emissions in the Union by 2050, supported by national roadmaps with indicative targets and indicators of internal progress, as well as by public and private financing and investments. Long-term national renovation strategies with a solid financial component, in line with the requirements of Article 2A of the EPBD recast, are needed to ensure the renovation of existing buildings, converting them into buildings with nearly zero energy needs – nZEB.

Public Building Stock

When developing a building stock inventory, it is necessary to find a good balance between collecting enough information to support the purpose of the building stock inventory and reducing the efforts needed to collect and analyze the data. Therefore, the recommendation for categorization and sub-categorization of buildings in the building stock inventory is based on Annex I of the EPBD and EUROSTAT. In most countries, in existing or drafted building regulations, the building categorization is close or like what is used by EUROSTAT. Consequently, the following categorization and sub-categorization are recommended for non-residential buildings (Table 2.1). This sets the scene for the selection of typologies and buildings to be targeted in *PrioritEE PLUS* activities.

Table 2.1 - Categorization and sub-categorization are recommended for public building stock.

Category	Subcategory	Description
Offices	----	Buildings used as places of business, or clerical and administrative purposes, e.g., banks, post offices, municipal offices, government department offices, conference and congress centers, law courts, parliament buildings, etc.
Educational buildings	Kindergartens	Buildings used for pre-primary education.
	Schools	Buildings used for primary and secondary education (e.g., nursery schools, primary schools, secondary schools, colleges, grammar schools, technical schools, etc.), formal education schools, vocational training schools.
	Universities/High Schools	Buildings used for higher education and research; research laboratories; higher educational establishments.
Health care facilities	Hospitals	Sanatoria, long-stay hospitals and nursing homes, psychiatric hospitals, dispensaries, maternity facilities, maternal and child welfare centers. Institutional buildings with combined residential/lodging services and nursing or medical care for the elderly, for disabled people, etc. Buildings used for thermal treatment, therapy, functional rehabilitation, blood transfusion, breast milk collection, veterinary medicine etc.
Hotels and restaurants	Hostels	Hotels, motels, inns, pensions, and similar lodging buildings, with or without restaurants, detached restaurants and bars.
	Other short-stay accommodation buildings	Youth hostels, mountain refuges, children's family holiday camps, vacation bungalows, holiday and rest homes, other lodging buildings for holidaymakers, not elsewhere classified.
Sport facilities	----	Buildings used for indoor sports (basketball and tennis courts, swimming pools, gymnastic halls, skating or ice-hockey rinks, etc.) providing facilities for spectators (stands, terraces, etc.) and for participants (shower and changing rooms, etc.)
Wholesale and retail trade service buildings	----	Shopping centers, shopping malls, department stores, detached shops and boutiques, halls used for fairs, auctions and exhibitions, indoor markets, service stations etc.
Other types of energy-consuming buildings	----	The following building types defined in EUROSTAT and can thus be considered: •Buildings and installations of civil and military airports, rail stations, bus stations and harbor terminals, cable car, and chairlift stations. •Radio and television broadcast buildings, telephone exchange buildings, telecommunication centers etc. •Garages (over or underground) and roofed car parks •Industrial buildings. •Cinemas, concert halls, opera houses, theatres etc. •Meeting halls and multi-purpose halls mainly used for public entertainment.

		•Casinos, circuses, music halls, dance halls and discotheques, bandstands, etc. •Museums, art galleries, libraries, and resource centers. •Farm buildings and storage buildings used for agriculture farming, e.g., cowsheds, stables, pig. •Houses, sheep-folds, studs, kennels, industrial hen-houses, granaries, hangars and agricultural outhouses, cellars, wine-making plant, wine vats, greenhouses, agricultural silos, etc. •Churches, chapels, mosques, synagogues. •Historic or protected buildings of any kind not used for other purposes. •Penitentiaries, prisons and remand centers, barracks for armed forces, police or fire services.

2.3 Portuguese Energy Efficiency Strategic Plans, Programs, and Instruments

This sub-section provides an overview of the Portuguese building's energy consumption agenda, and national plans in place that drive changes in the building stock, improved energy efficiency, energy consumption reduction, and increased integration of renewables. Figure 2.5 shows, in a summarized form, the scheme of building legislation development up to the present day.

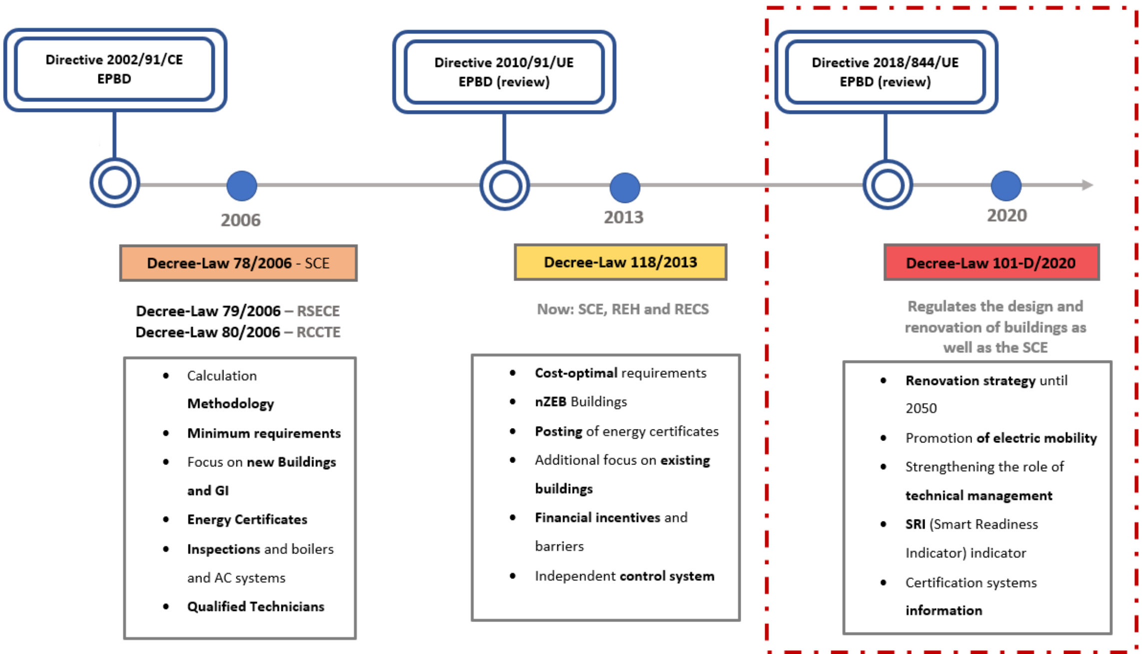


Figure 2.5 - Diagram of the legislative evolution of performance and energy efficiency policies in buildings in Portugal. Adapted from SCE.pt.

Therefore, Portugal has a vision of reaching the commitment established in the Kyoto Protocol, creating for the first time in 1998 the Commission for Climate Change (CAC). It was in 2004 that the first Portuguese strategic package called the Nacional Program for Climate Change (PNAC) appeared, approved by RCM n.º 119/2004, of July 31st [23]. This program sought to quantify the emission mitigation effort required to fulfill the commitments assumed by Portugal, identifying the sectorial responsibilities, and presenting a set of policies and measures and respective instruments that would allow an integrated intervention with the objective of mitigation emissions. In 2006, the PNAC was revised, and a new version was approved. The 2006 PNAC extended the scope of the effort to comply with the Kyoto Protocol by adopting domestic measures in sectors not covered by the European Commerce of Emissions Licenses (CELE), such as transport of the residential sector, highlighting the revision of the regulation for the management of energy consumption, among others.

In comparison to PNAC 2004, the PNAC 2006 defined a new set of measures and additional policies sectorial implementation among which the mandatory preparation of action plans for each measure stands out. It determines, accordingly, that for each measure presented in the PNAC, the proposing ministry must present an action plan containing the actions to be developed and the respective calendar; the means, the expected results, the indicators, the body responsible for monitoring and the focal point, and progress should be reported every six months [5].

Later, RCM n.º 93/2010, of November 26, approved PNAC 2020, for the period between 2013 and 2020, and RCM n.º 56/2015, of July 30, approved the new and the most recent PNAC for the period between 2020 and 2030. As described in this last action plan, the PNAC is a compilation of other existing instruments and constitutes a dynamic reference framework for the identification and definition of sectorial policies and measures in the field of low carbon, sustained through sectorial policy documents, such as the National Action Plan for Energy Efficiency (PNAEE).

The National Low Carbon Roadmap (RNBC), published in 2012, and the Roadmap for Carbon Neutrality 2050 (RNC2050), announced in 2018 were key plans pushing the country's overall decarbonization agenda. The RNBC represents an important instrument of national energy policy. It began to be elaborated in 2010, following the publication of RCM No. 93/2010, and was framed within the strategic orientation of the European Low Carbon Roadmap and in line with the European Union's objective of reducing gas emissions of Greenhouse Effect (GHG) in 2050 (APA & Commission for Climate Change, 2012). However, currently, the term low carbon has fallen into disuse, starting to use of the concept of carbon neutral. In this sense, at the end of 2018 the RNC2050 was announced, which aims to support the political objective of carbon neutrality, within which the Portuguese Government, in line with the ambition of the Paris Agreement, committed to reducing its GHG emissions, so that, in 2050, the balance between emissions and carbon sequestration from the atmosphere is zero (APA et al., 2021).

In 2019, the Government recently presented the National Integrated Energy and Climate Plan (PNEC) whose main objective is to achieve carbon neutrality in 2050 through the decarbonization of the economy and the energy transition in the 2021-2030 horizon. This plan, which is the result of an imposition by the European Commission on the Member States, is being developed in coordination and articulation with the RNC2050, ensuring coherence between policies in the areas of energy and climate for the achievement of the various goals by 2030. Thus, this new plan, whose final version is scheduled for mid-2019, sets national targets for GHG emissions, energy efficiency, and renewable energies, among other matters, replacing the national plans currently in force, namely the PNAER, PNAEE, and PNAC.

3. METHODOLOGY

The methodology adopted in this work follows the development stages of the *PrioritEE Plus* project and considers the following steps:

- Study the national and international framework of goals outlined for the Energy policies.
- Description of the public entities participating in the project and owners of the buildings in study.
- Description of the DSTool, (data input/introduction; data base; levels of renovations, type of analysis-building level, cluster level, benchmarks).
- Results and discussion of the renovation solution for public buildings under study.

The Figure 3.1 represents the summarized scheme of the methodology adopted for the present dissertation.

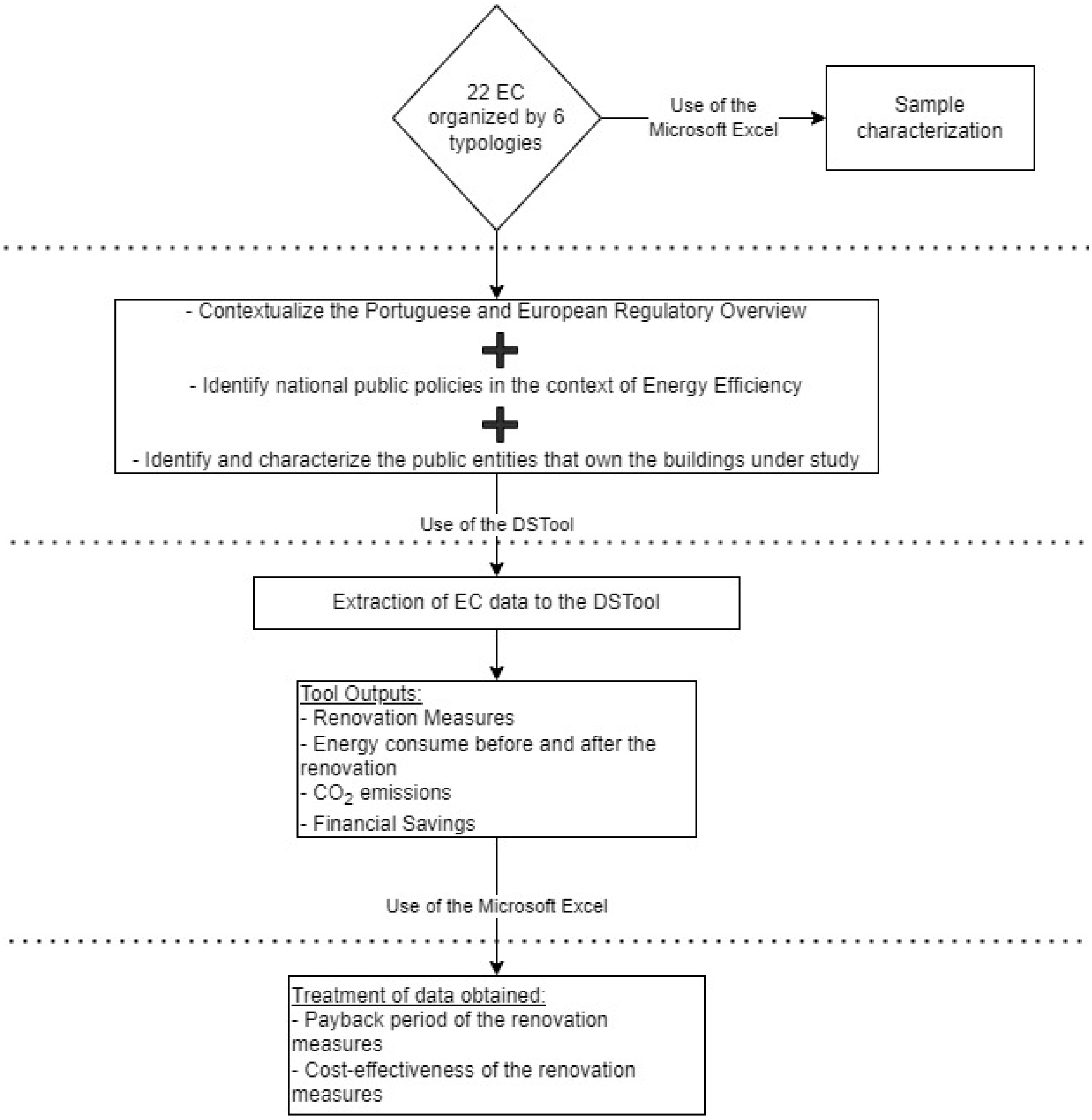


Figure 3.1 - Methodological scheme used in data processing to obtain the results of this dissertation.

3.1 Portuguese public entities and public building cluster under study

The Portuguese public buildings clusters under study in the *PrioritEE PLUS* project, are related to three different entities representing the Portuguese partners: LNEG (State Laboratory of Energy and Geology), Arruda dos Vinhos Municipality and AREANATejo (Regional Energy and Environment Agency). The geographical distribution of the buildings clusters is illustrated in Figure 3.2 and a brief description of the cases and geographical location is presented in this section.

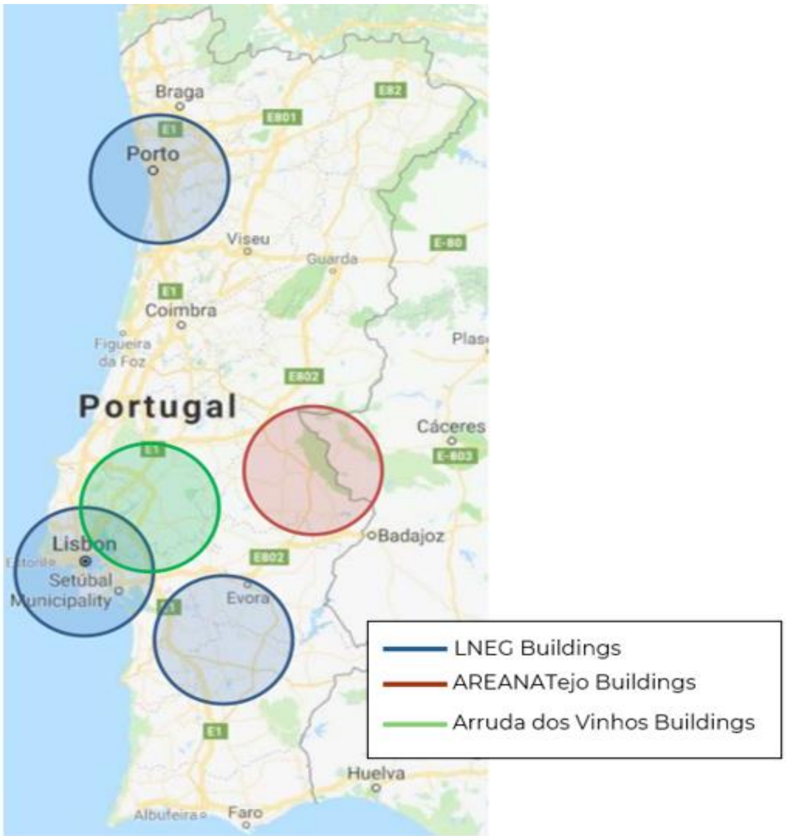


Figure 3.2 - Geographical distribution of the case study buildings.
Source: own authorship.

LNEG – National Laboratory for Energy and Geology

The National Laboratory for Energy and Geology (LNEG) is a state energy and geology laboratory of the Ministry of Environment and Climate Action that develops R&D oriented to the needs of society and enterprises. Investing in sustainable research, along with international best practices, ensures that its areas of expertise allow an adequate response to the needs of the business sector.

LNEG is the first Portuguese institution awarded by the European Commission with the Logo "R Excellence in Research" LNEG was certified according to the NP EN ISO 9001:2015 for knowledge transfer activities in Energy and Geology and with the NP 4457:2007 for the System of Research, Development, and Innovation. LNEG's mission is to promote technological innovation, science and technology-oriented for the environment and climate action, energy transition, and economic development. LNEG develops R&D activities in the following areas: Renewable Energy; Energy Efficiency; Energy Recourses and Economic Analysis; Innovative Strategic Technologies; Geological Hazards and Environment; Geology for Territorial Enhancement. LNEG's network of laboratories includes the Laboratory for Biofuels and Biomass; Laboratory of Mineral Science and Technology; Laboratory of Solar Energy; Laboratory of Materials and Coatings.

This institution is a partner of the *PrioritEE Plus* project and consists of four different poles located from north to south of the country, with four also different buildings. These buildings are in São Mamede de Infesta (North of Portugal, council of Matosinhos), Lumiar and Alfragide (Lisbon, Center of Portugal), and Aljustrel (Alentejo, South of Portugal). There is also one more building associated with LNEG, the Geological Museum, but will not be analyzed in this work (Figure 3.3).

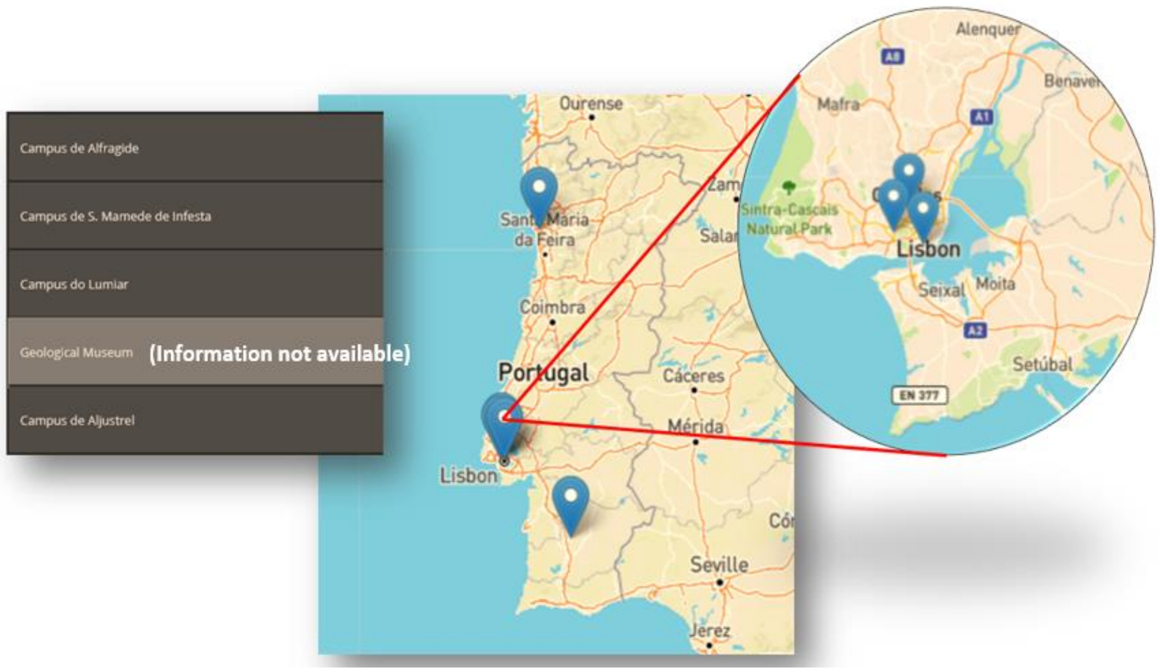


Figure 3.3 - LNEG Associated Buildings. Source: own authorship.

Municipality of Arruda dos Vinhos

The council of Arruda dos Vinhos is located about 30km north of Lisbon, with a total area of approximately 77.7 km^2. This locality belongs to the district of Lisbon, belonging to NUTS 3 – West of the Region of Lisbon and Vale do Tejo. According to the 2010 COS (the most recent available), the municipality's artificialized territories are around 616 ha, out of its 2636.4 ha of gross area, representing less than 8% of the country's area.

Regarding its socio-economic and cultural system, the municipality of Arruda dos Vinhos presents an exceptional situation in terms of population growth, with a population variation of 29.4% in the period between 2001 and 2011. This growth stands out considering the national and regional behavior, as the population variation in the Western Region corresponds to 7%. The resident population in the municipality of Arruda dos Vinhos in 2011 consisted of 13391 inhabitants, of which more than half reside in the parish of Arruda dos Vinhos (8656 inhabitants) [29]. Preliminary data from the 2021 Census [30] report a population growth of 4.4% with 13983 inhabitants.

AREANATejo – Reginal Agency for Energy and Environment of North Alentejo and the Tagus

Most of the buildings targeted by *PrioritEE PLUS* Portugal in the study are in Alentejo (linked to associated partner AREANA TEJO); which is mainly a rural area with a strong agricultural sector but also industrial and services. Situated in the north of Alentejo experiences a warm and temperate climate, with more rainfall in the winter than in summer. The average temperature is 16.5°C, and the average annual rainfall is 700mm. In August, the warmest month of the year is August, with an average temperature of 22.5°C, and the coolest is January, with 11ºC. The Regional Agency for Energy and Environment of North Alentejo and Tagus (AREANATejo) has the mission of contributing to energy efficiency and the better use of endogenous energy resources, developing projects and methods, and disseminating the best techniques and procedures with a view to the rational use of energy and resources and the preservation of the environment, to promote sustainable local development, specifically, to obtain greater energy efficiency and better environmental performance of the associated Municipalities.

This public entity results from the joint effort of the municipalities belonging to the current Intermunicipal Community of Alto Alentejo (CIMAA), to promote the use of endogenous resources and renewable energies, ensuring the development of the region. Currently AREANA Tejo associates with CIMAA, the Municipal Councils of Alter do Chão, Arronches, Avis, Campo Maior, Castelo de Vide, Crato, Elvas, Fronteira, Gavião, Marvão, Monforte, Nisa, Ponte de Sor, Portalegre and Sousel, a EDP Distribution (E-REDES) and NERPOR – Business Association of the Portalegre Region.

3.2 Buildings Energy Performance Certificates data analysis

For the development of the dissertation, the energy performance certificates were collected from the partners related to their clusters of buildings. Around 22 Energy Performance Certificates were provided referring to the typology of commercial and service buildings, under the supervision of the public administration of the three different poles, organized by 6 different typologies. All these certificates are in accordance with the new SCE, which is legislated under DL n.º 118/2013, of 20 August, and were issued in the period between 21 January 2015 and 25 of February 2021. All the EC, that are emitted in Portugal, are identified according to the predominant type of use in the building or fraction in question. Since in the tool to be analyzed here, there are only 6 distinct categories, there was previously a refinement based on the criterion of proximity or similarity of the activity developed in the building or fraction target of energy certification. In this sense, all buildings were assigned to one of these typologies, which are distributed among: “Social Centers”, “Office Buildings”, “Cultural Buildings”, “Educational Buildings”, “Sports Facilities”, and “Swimming Pools”.

In this way, it is important to make an analysis of the constructive solutions of these buildings, in this case, using the information collected and necessary for the energy certification. Thus, for the sets of constructive elements characterized by roofs, walls, floors, doors, single windows, and double windows, the types of solutions found, their locations (interior, exterior, buried or ground floor) were accounted for, as well as the total area and the total average area of each element were calculated. The fact that the envelope had or had not already been intervened was also analysed, as well as the correlation between the existing constructive solutions and the energy classes of the buildings.

The existence of technical systems in these buildings, as well as the types of equipment present in them, the function for which they are intended, and the energy source they consume, correspond to another topic examined in this study. In this analysis, it was intended to know about the equipment commonly used in these buildings and the form of energy consumed, namely the types and the expression that renewables assume in the technical systems of these buildings. Thermal and photovoltaic solar panels were subject to an individual and more detailed analysis, where information such as the average total area per collector, the total area of each type of collector, the average productivity of each type of collector, and, based on these two last indicators, the indicator alluding to the total energy production by each system was calculated.

The CO_2 emissions were also analyzed, namely the emissions of each type of building use. Something that was not analyzed, since it did not result in added value to the tool, were the improvement measures suggested in the certificates.

The information extracted from the certificates was necessary to be treated via Microsoft Excel, in order to gather the information on the 22 Energy Performance Certificates in a more succinct way, and so that there was a comparison between the various certificates. Although the analysis carried out on the certificates was careful, the data available in the certificates do not always meet the needs of the DST; in this sense, difficulties were felt, when there were cases in which there was a lack of information in the certificates, namely regarding the lighting of buildings, which is not always well described in the certificates.

3.3. The *PrioritEE* Decision Support Tool

The *PrioritEE* DSTool available online [27], allows local and regional authorities to calculate energy and financial savings achievable by applying different energy efficiency measures In Individual public buildings and for the whole building stock. The DSTool Is being used by local administrations in the Mediterranean (MED) region, e.g. in Italy [30], to manage energy consumption In municipal public buildings, to assess the cost-effectiveness of a predefined set of EE and RES measures and alternatives, and to prioritize investments. A comprehensive set of key indicators is an integral to the decision support tool. It allows for comparing different scenarios of interventions and monitoring energy consumption, assessing the effects of proposed strategies.

The DSTool is built in a flexible manner and designed to be used with building-specific data or average pre-filled information for typical buildings in the MED region. To prioritize Energy Efficiency measures, it has a structure divided into nine areas focus: external walls, external windows, roof, ventilation system, heating and cooling system and integration of renewable energy. The DSTool provides an overview of results ranked by savings, investment costs, and return on investment costs, and return on investment for each building and building typology, allowing the evaluation of different combinations of Energy Efficiency measures. Users can either fill only "basic inputs" section, which will be supplemented with a list of country/region-specific assumptions from the toolbox's database, or fill-in also "advanced inputs" for more accurate results.

The DSTool is available in a user-friendly online software application. Each building can be evaluated separately, and/or the building stock or group of buildings can be compared in benchmarking mode. The DSTool results are indicative and representative of the MED countries ‘buildings and should not be used as a replacement for an energy audit or an energy certificate. To be a user-friendly web application, tutorials in six languages (English, Portuguese, Spanish, Greek, Italian and Croatian) are available, which should serve as a great explanation of the Input data, methodology and filling in process. In Figure 3.4 architecture of the tool is presented.

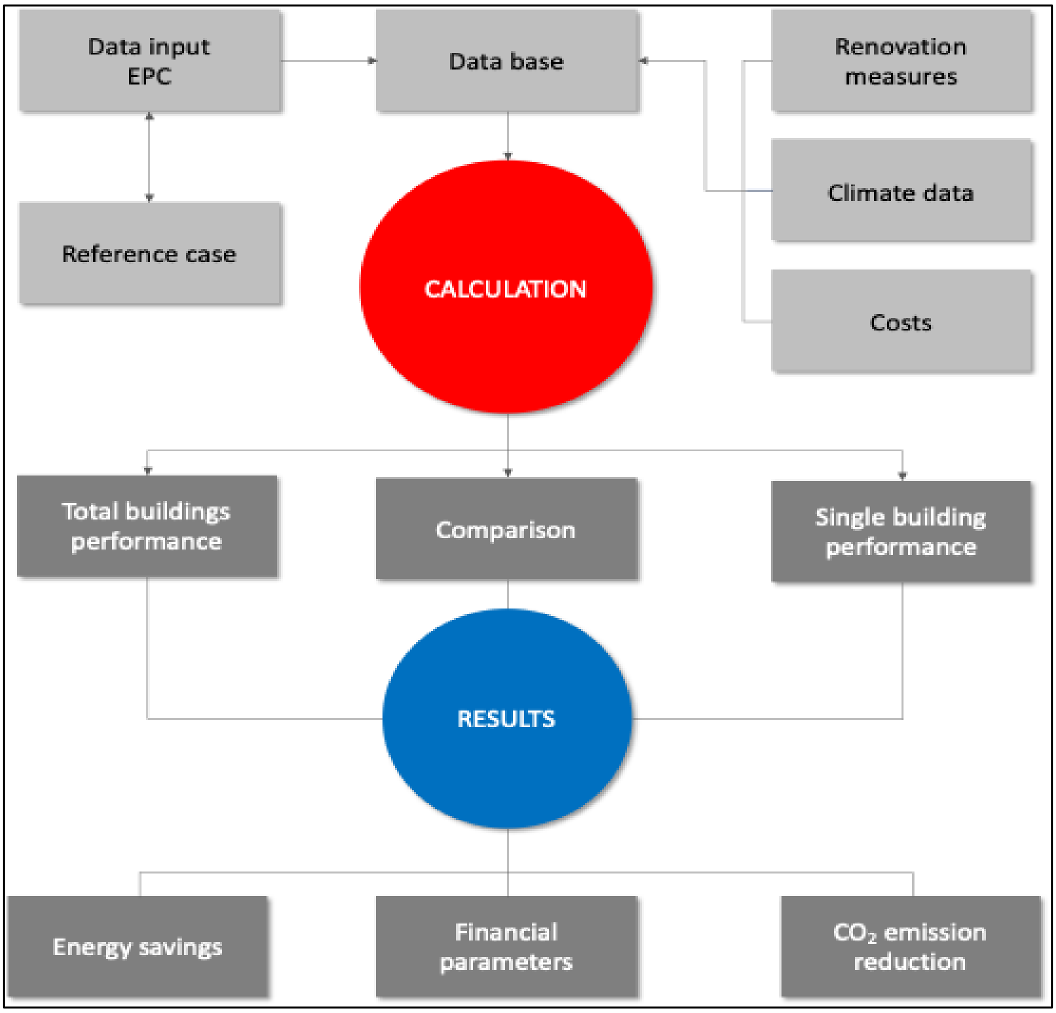


Figure 3.4 - *PrioritEE* DSTool architecture. Source: adapted from SDEWES 2022 [30].

3.3.1. DST Database

The database of the DSTool was developed through the collaboration of different MED countries to represent the different energy indicators of each country/region. Only administrators can make changes to the DSTool database, manage registered user permissions (only for the administrator's country), edit the translation, as well as upload and edit tutorials.

This database brings together technical, financial and climate data that may be on a National, or Regional and Municipal scale. To improve the accuracy of the calculation results, all Project partners modified and updated the national database of their respective countries. Subsequently, in order to obtain more specific results, the possibility of inserting regional and/or municipal average data was foreseen. In this way, users have the possibility to select which set of data they want to use in the calculation to better characterize the geographic area in which the buildings are located.

In the following, the description of the tool is presented.

First, the administrator is asked, in the section -> "General", the main data of the region, such as the name of the region, the annual irradiation, VAT, and the price of water - Figure 3.5.

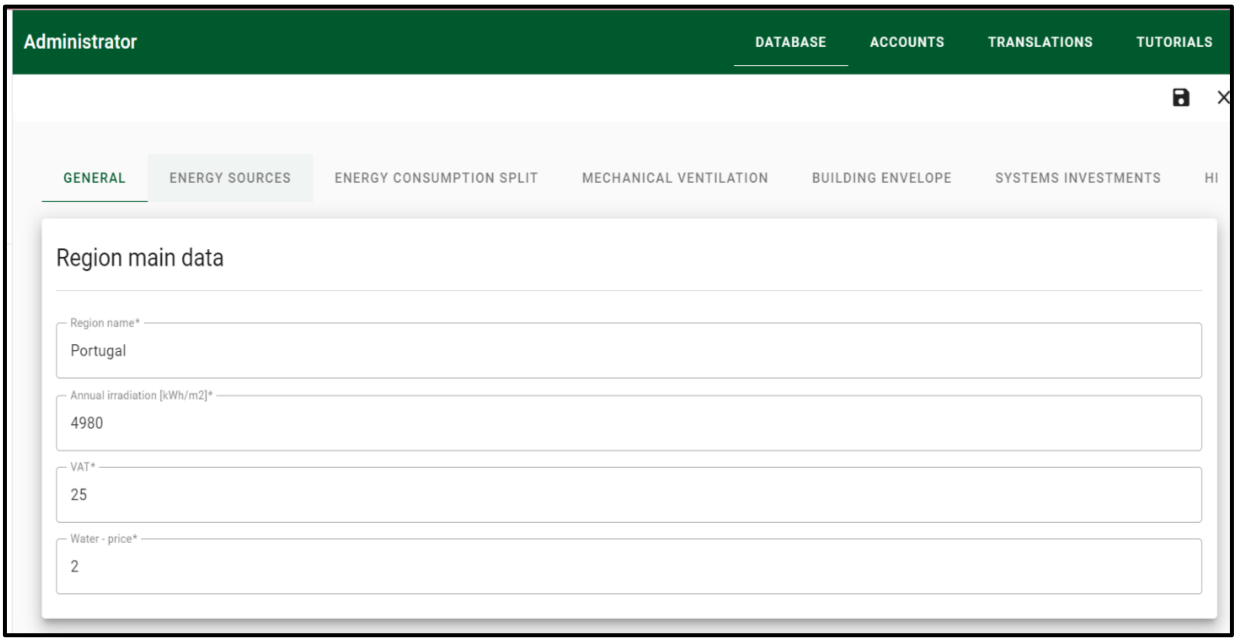


Figure 3.5 - Database: Region Main Data. DSTool

Next, there is the "Energy Sources" section - Figure 3.6 - for the different energy sources presented, it is possible to define indices such as the "CO_2 emission factor".

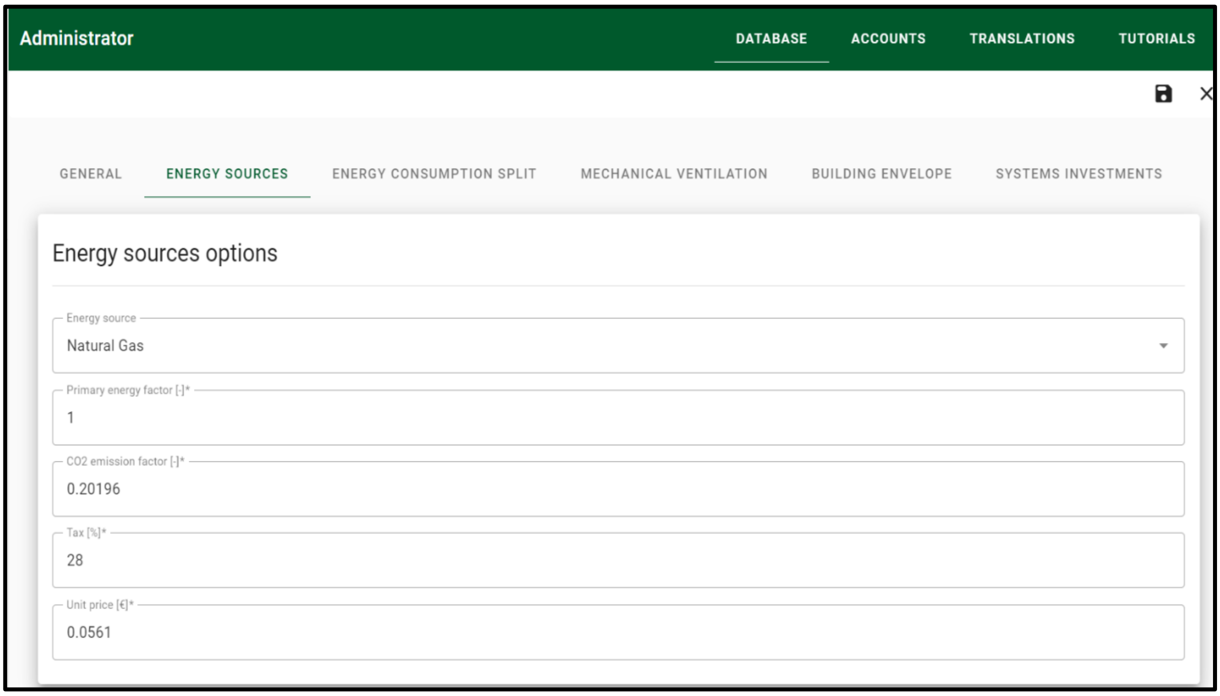


Figure 3.6 - Database: Energy Sources. DSTool

In the "Building Envelope" section - Figure 3.7 - he thermal transmission coefficients (U-Value) of the building envelope are requested for each rehabilitation level (Low, Medium, or High).

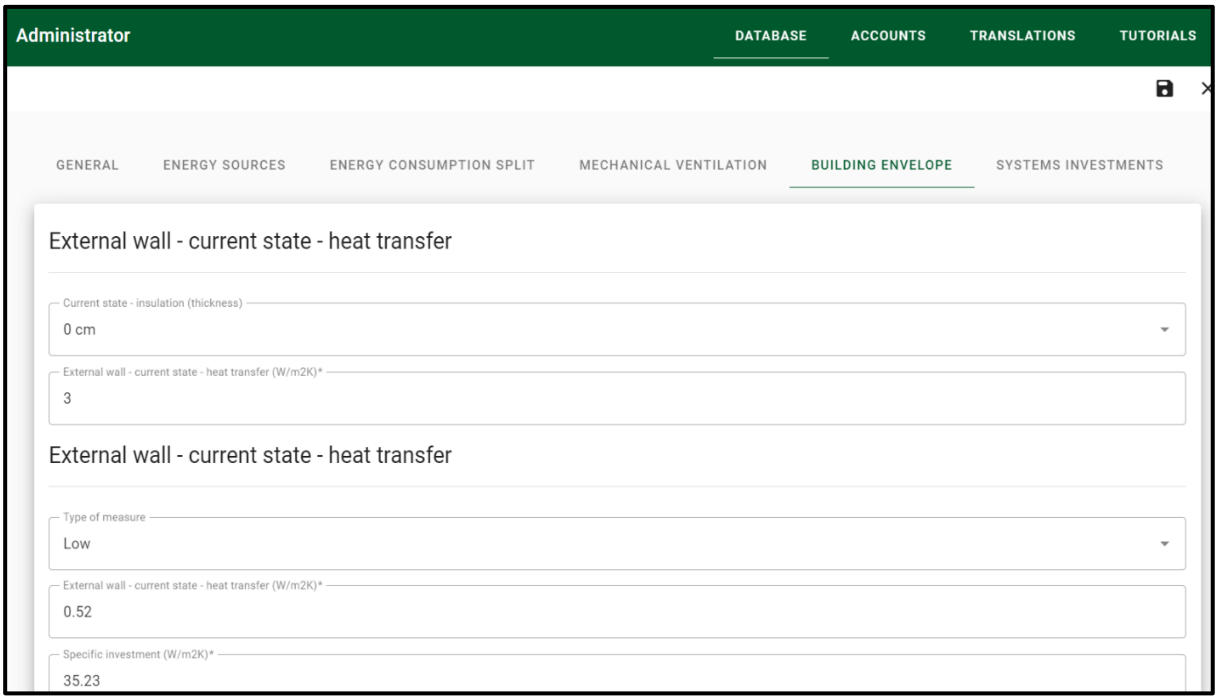


Figure 3.7 - Database: Building Envelope. DSTool

Finally, it is also important to be inserted, by the administrator, the investment price of the different systems (lighting, heating systems) by measure in the section called "Investment in Systems", as illustrated in Figure 3.8.

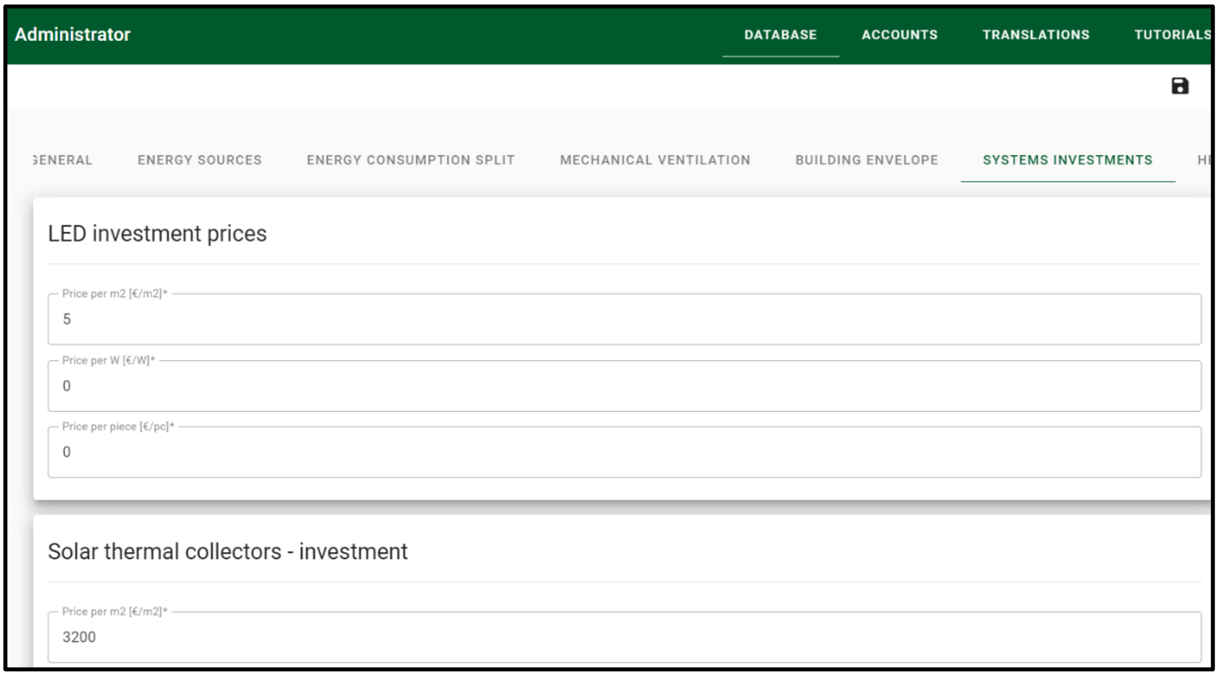


Figure 3.8 - Database: Systems Investment. DSTool

3.3.2. EC Data Input

As mentioned before the Decision Support Tool allows for characterizing the overall set of MPBs, selecting the ones to be renovated, identifying the appropriate technical interventions, and evaluating the potential investment opportunities in terms of different parameters.

In the initial phase of filling in the tool data, it is important to read the tutorials that summarize how the DSTool works. Nevertheless, after examining these tutorials, it is important to understand how to extract the key elements to place them in the appropriate fields of the tool. In the Annex V, the Energy Certificate from the Loja do Arruda dos Vinhos will be used as an illustrative example of data to be placed in the tool.

3.3.4. Levels of Renovation and associated costs

In the "Measures" section, after adding the building characteristics, the different renovation measures that can be adopted by the decision-maker can be verified. In this section, the user can find the summary of all measures including energy savings, financial savings, investment, payback period, and associated CO_2 reductions. These measures can be divided into passive renovation measures, associated with constructive elements, and active renovation measures, associated with technical systems, lighting and the implementation of renewable systems. Figure 3.9 illustrates the schematic of the section referring to the "Measures" of the Alfragide Campus belonging to LNEG.

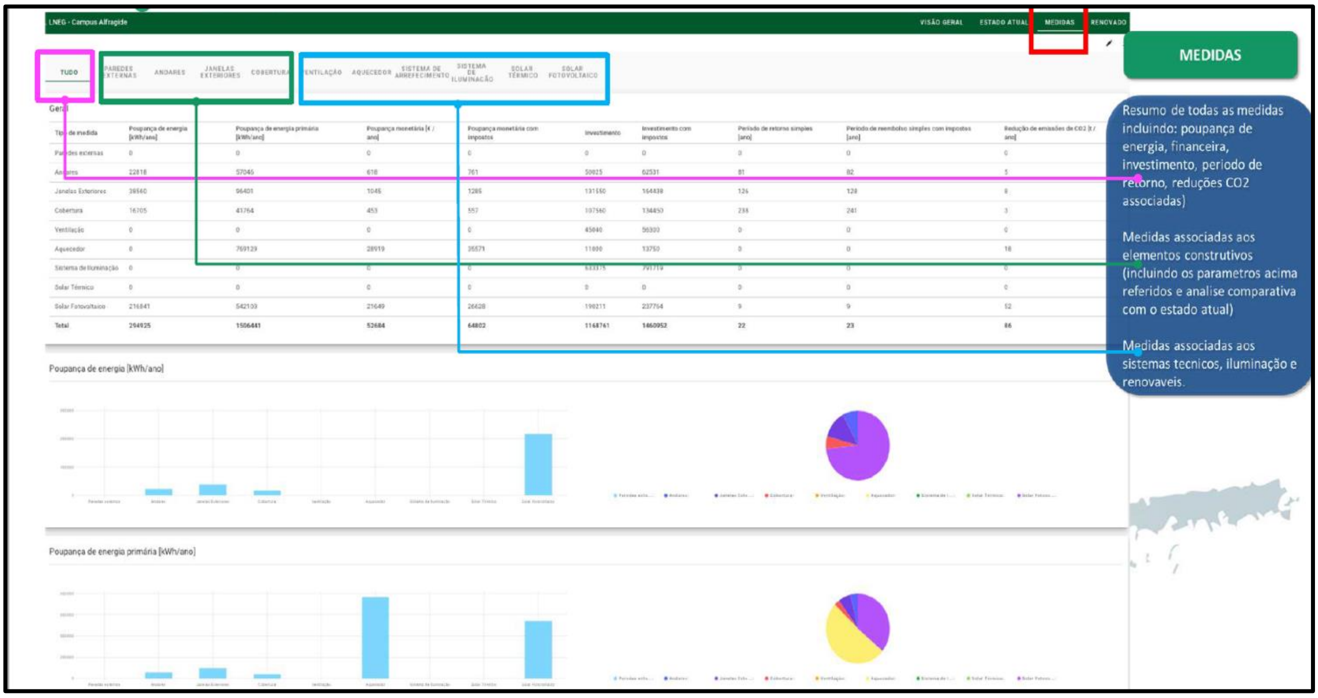


Figure 3.9 - Schematic of the section referring to the "Measures" of the Alfragide - LNEG

For the parameters of passive constructive renovation, different levels of renovation were adopted, so that the user can understand whether it is feasible in each renovation measure to invest more or less capital, since investing more in a given renovation measure does not always imply an increase of proportional energy efficiency.

Table 3.1 to Table 3.4 present the different values that were considered for the different levels of renewal by passive measure.

Table 3.1 - Different levels of external walls renovation

External Walls		
Type of measure	**Price [€/m^2]**	**U-Value [W/m^{2}k]**
Low	25	0.6
Medium	30	0.4
High	40	0.25

Table 3.2 - Different levels of external windows renovation

External Windows		
Type of measure	Price [€/m^2]	U-Value [W/m^{2}k]
Low	150	0.6
Medium	200	0,4
High	350	0.25

Table 3.3 - Different levels of roof renovation

Roof			
Type of measure	Roof type	Price [€/m^2]	U-Value [W/m^{2}k]
Low	Flat roof	40	0.4
	Sloped roof	30	0.4
Medium	Flat roof	40	0.3
	Sloped roof	30	0.3
High	Flat roof	40	0.2
	Sloped roof	30	0.2

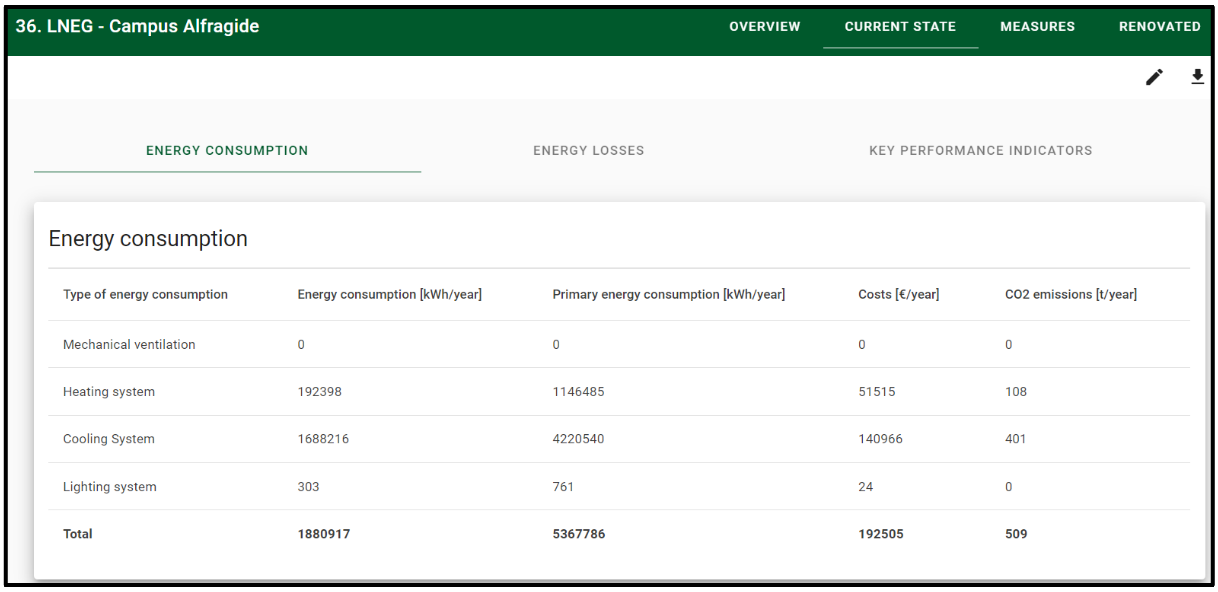
Table 3.4 - Different levels of external floor renovation

External Floor		
Type of measure	Price [€/m^2]	U-Value [W/m^{2}k]
Low	25	0.6
Medium	30	0.4
High	40	0.25

3.3.5. Analysis: Single Buildings and Benchmarking

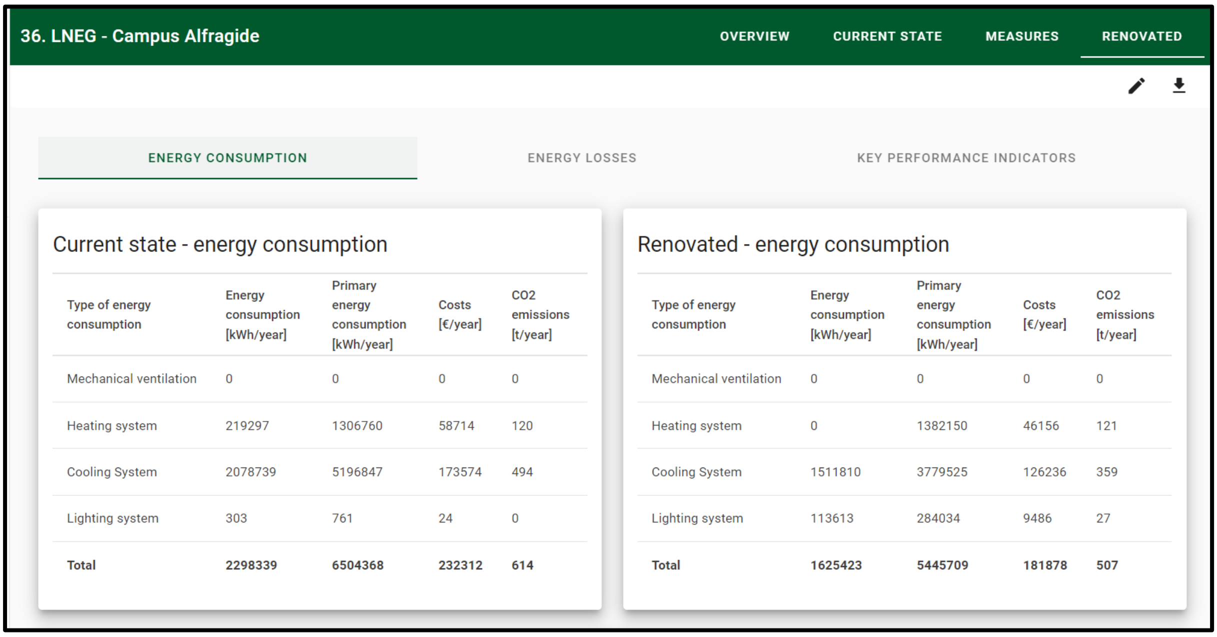
In the Decision Support Tool, the analysis can be carried out through the outputs of a single building, or through the aggregation of buildings (cluster) of the same typology and/or category that will be analyzed together through the Benchmarking option.

Regarding the analysis of only one building, after inputting its data, we have the option of checking the values of the current state of the building and/or checking the values after its renovation in different tabs, as illustrated in Figure 3.10 and Figure 3.11 relating to the Alfragide Campus belonging to LNEG. The "Renovated" section, as illustrated in Figure 3.10, presents the total energy consumption by measure/energy system before and after the renovation, as well as its graphical comparison. Also, in the "Renovated" section it is possible to see a graphic comparison of energy losses by type of measurement/part of the building envelope before and after renovation. Still in this section, there is another tab corresponding to the "KPIs" that demonstrates the main performance indicators of the selected buildings. Here too, values are calculated for the current status and after renewal, while changes are displayed in percentage.



Type of energy consumption	Energy consumption [kWh/year]	Primary energy consumption [kWh/year]	Costs [€/year]	CO2 emissions [t/year]
Mechanical ventilation	0	0	0	0
Heating system	192398	1146485	51515	108
Cooling System	1688216	4220540	140966	401
Lighting system	303	761	24	0
Total	**1880917**	**5367786**	**192505**	**509**

Figure 3.10 - Representation of the "Current State" of the LNEG - Campus Alfragide



Current state - energy consumption

Type of energy consumption	Energy consumption [kWh/year]	Primary energy consumption [kWh/year]	Costs [€/year]	CO2 emissions [t/year]
Mechanical ventilation	0	0	0	0
Heating system	219297	1306760	58714	120
Cooling System	2078739	5196847	173574	494
Lighting system	303	761	24	0
Total	**2298339**	**6504368**	**232312**	**614**

Renovated - energy consumption

Type of energy consumption	Energy consumption [kWh/year]	Primary energy consumption [kWh/year]	Costs [€/year]	CO2 emissions [t/year]
Mechanical ventilation	0	0	0	0
Heating system	0	1382150	46156	121
Cooling System	1511810	3779525	126236	359
Lighting system	113613	284034	9486	27
Total	**1625423**	**5445709**	**181878**	**507**

Figure 3.11 - Representation of the "Renovated" section of the LNEG - Campus Alfragide

In the "Current State" tab, there is an overview of the parameters calculated for the state in which the building is found before renovations. Here, you can see how much energy is lost through the building envelope and how much energy is consumed by all systems within the building. In addition to these factors, it is also possible to verify the Performance Indicators - KPIs of this state of the building. Associated with these tabs, it is possible to have a graphical overview of the factors already mentioned, such as primary energy losses, CO_2 emissions related to energy losses and energy costs related to energy losses, energy consumption primary, among others.

After analyzing the current state of the building, it is possible to verify all possible measures to be implemented in the building under study. For each measure, factors that will influence the analyzer's decision-making are observed. Among them are, as mentioned earlier: energy savings, primary energy savings, financial savings (including taxes), investment, investment (including taxes), simple payback period, simple payback period (including taxes), and reduction of CO_2 emissions. All these factors can also be visualized, for a better perception, in the form of a graph.

In the Benchmarking option, the user must select a certain set of buildings whose analysis he wants to compare, and the tool suggests the aggregation of up to 10 buildings per analysis. The values obtained in this section are the values after the intervention in the buildings and, for the selected buildings, three types of results can be seen for total values relative to the sum of the cluster under analysis.

The Figure 3.12 demonstrates the table that gives a graphical overview of the total/summarized energy consumption and energy losses for all the selected buildings.

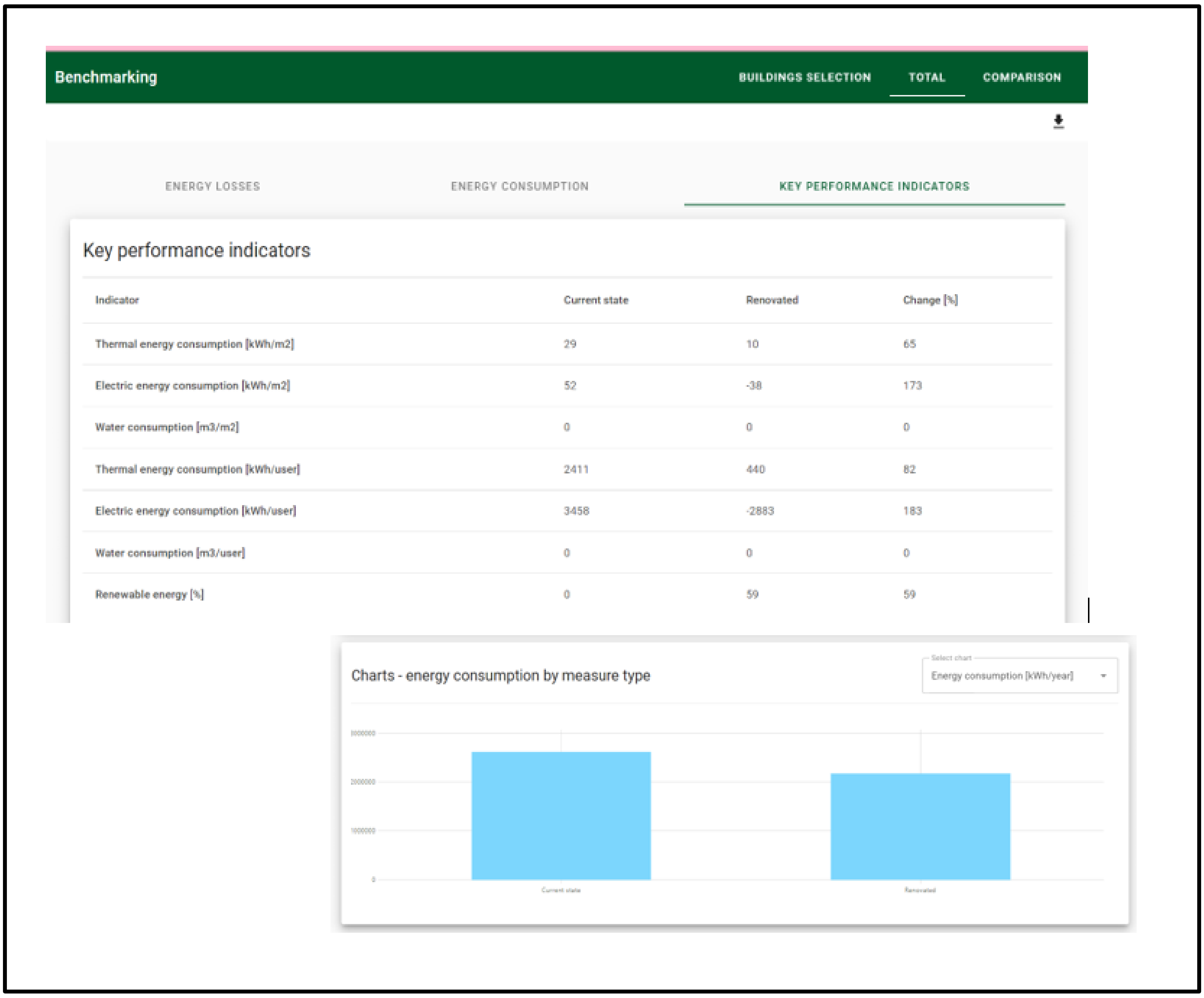
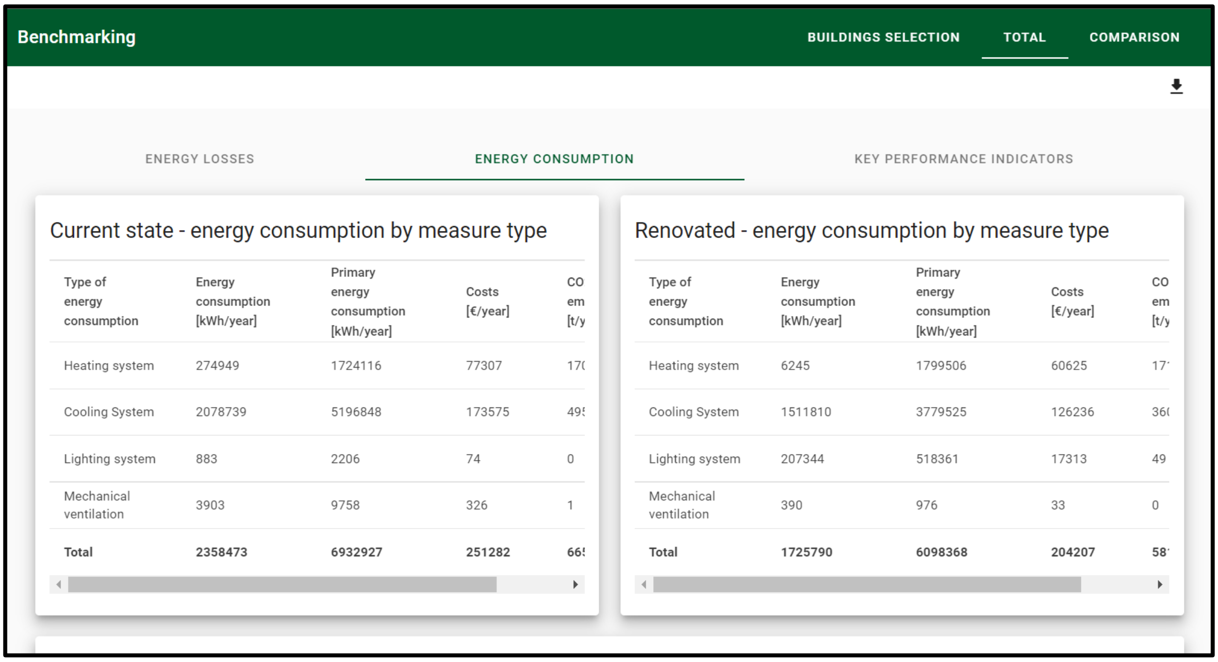


Figure 3.12- Overview of the total/summarized energy consumption and energy losses for all the selected buildings

Finally, in this section we also have the "Energy Consumption" section that presents the energy consumption for each building and its comparison (summary of analyzes of individual buildings), as well as, again, a graphical view of the comparison of energy losses for each building - Figure 3.13.



Current state - energy consumption by measure type

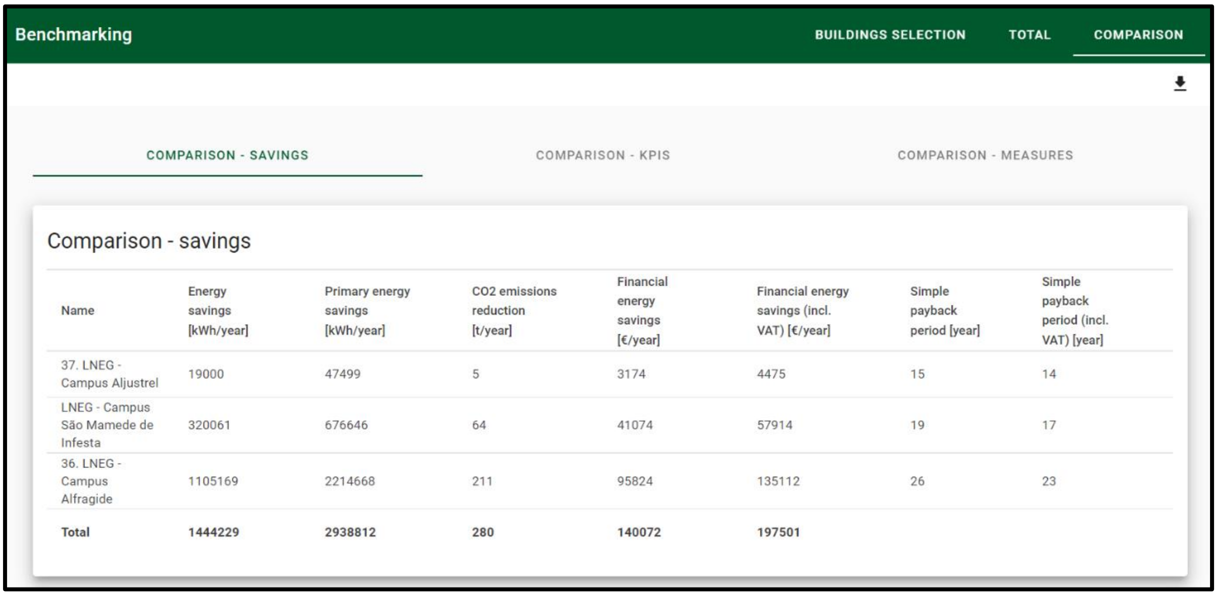
Type of energy consumption	Energy consumption [kWh/year]	Primary energy consumption [kWh/year]	Costs [€/year]	CO em [t/y
Heating system	274949	1724116	77307	17(
Cooling System	2078739	5196848	173575	49!
Lighting system	883	2206	74	0
Mechanical ventilation	3903	9758	326	1
Total	**2358473**	**6932927**	**251282**	**66!**

Renovated - energy consumption by measure type

Type of energy consumption	Energy consumption [kWh/year]	Primary energy consumption [kWh/year]	Costs [€/year]	CO em [t/y
Heating system	6245	1799506	60625	17
Cooling System	1511810	3779525	126236	36(
Lighting system	207344	518361	17313	49
Mechanical ventilation	390	976	33	0
Total	**1725790**	**6098368**	**204207**	**58**

Figure 3.13 - Overview of the comparison of energy consumption with energy losses for each building

Finally, within Benchmarking we also have the "Comparison" option, Figure 3.14, where buildings are compared to each other to identify the best and worst cases. This tab comparison gives an overview of the current state differences and renewal results for the measures the user selects. Also, the KPIs are compared in this tab where you can have a view of the differences of the current state and renewal results for selected measures. Finally, benchmarking gives users the opportunity to "manually" select certain measures.



Name	Energy savings [kWh/year]	Primary energy savings [kWh/year]	CO2 emissions reduction [t/year]	Financial energy savings [€/year]	Financial energy savings (incl. VAT) [€/year]	Simple payback period [year]	Simple payback period (incl. VAT) [year]
37. LNEG - Campus Aljustrel	19000	47499	5	3174	4475	15	14
LNEG - Campus São Mamede de Infesta	320061	676646	64	41074	57914	19	17
36. LNEG - Campus Alfragide	1105169	2214668	211	95824	135112	26	23
Total	**1444229**	**2938812**	**280**	**140072**	**197501**		

Figure 3.14- Representation of the "Comparison" section of the DST

3.4. Case Study - Public Buildings cluster under study in Portugal

The present case study was based on the work developed by the author within the scope of the study of analytical tools to support the energy transition and decarbonization in public buildings. This work originated the article "Exploring analytical tools to support the energy transition towards decarbonized Public Buildings" [31], where the *PrioritEE* tool was tested in three sets of buildings belonging to different public entities and located in different climate zones of Portugal.

The three local pilots serving as a testbed for the development and use of the *PrioritEE* DSTool, National Laboratory of Energy and Geology (LNEG), Municipality of Arruda dos Vinhos and the municipalities of Energy and Environmental Agency of North Alentejo and Tejo (AREANATejo), are very diverse in size, number of inhabitants, climate and type of buildings, patterns and levels of consumption, allowing for significant testing of the adaptability and transferring potential of the DSTool for other regions and countries [30].

As already mentioned earlier in this research, the LNEG's group of buildings consists of three office buildings located in São Mamede de Infesta (North of Portugal, Matosinhos council), Lumiar and Alfragide (Lisbon, Center of Portugal) and Aljustrel (Alentejo, South of Portugal). The buildings can be seen in Figure 3.15 [31]:

Figure 3.15 - LNEG buildings case studies [31].

The second group of buildings used in this case study is in Arruda dos Vinhos, and several typologies were considered: cultural, sports, educational and office buildings. In Figure 3.16 it is possible to observe the buildings of Arruda dos Vinhos [31]:

Figure 3.16 - Arruda dos Vinhos case studies [31].

The third and last set of buildings included in this case study belong to AREANATejo, located in Alentejo, where several typologies were included: sports, cultural, educational and office buildings. These buildings can be observed through the analysis of Figure 3.17 [31].

Figure 3.17 - AREANATejo case studies [31].

The planning objectives of the local governments and public institutions where the tool was tested were: renovation of the public buildings, adoption of packages of renovation including energy efficiency measures and renewable energy integration, promotion of good practices in passive, bioclimatic solutions and renewable integration towards nZEB, use simplified tools for achieving rapidly for the best renovation solutions in public buildings and capacity building and communication with public administration technicians towards the effective renovation of public buildings [31].

These objectives are planned to lead to the following expected results: improve the public buildings' energy efficiency, increase the use of renewable sources; enhance thermal comfort in buildings; reduce the expenditures related to energy consumption; disseminate good practices; reduce time for building renovation solution calculation through the utilization of simplified tools, and provide technical support to non-skilled public authorities on EE decisions. In Table 3.5, an overview by typology of the public buildings targeted in the *PrioritEE* DSTool is presented [31]:

Table 3.5- Main characteristics of the Portuguese case study buildings [30].

Build. ID	Typol.	Ene. Class	RES Tech. [Y/N]	Net cond.area [m^2]	Annual gas and other fuels consumption [MWh/year]	Annual electricity consumption [MWh/year]	Energy data sources
AREANA TEJO Cluster							
AR1	Sport	B -	Y	924	59.84	44.06	EPC (n.a.)
AR2	Office	B -	N	1127	-	76.36	EPC (2017)
AR3	Sport	A	Y	1049	-	70.34	EPC (n.a.)
AR4	Cultural	C	N	1815	-	65.03	EPC (2015)
AR5	Cultural	D	N	712	-	29.37	EPC (2017)
AR7	Edu.	C	N	238	5.67	17.95	EPC (n.a.)
AR8	Office	D	N	937	-	127.28	EPC (2020)
AR9	Office	B	N	5208	543.40	393.94	EPC (2015)
AR10	Sport	C	Y	774	68.73	120.21	EPC (2021)
AR11	Sport	C	N	2887	520.34	315.34	EPC (2016)
AR12	Office	B -	N	1456	-	97.03	EPC (2019)
ARRUDA DOS VINHOS Cluster							
AV1	Office	B-	N	398	-	35.578	EPC (2015)
AV2	Edu.	B	Y	907	11.53	98.98	EPC (2015)
AV3	Office	C	N	997	-	74.81	EPC (2018)
AV4	Social	C	N	167	-	16.64	EPC (2020)
AV5	Sport	C	N	432	-	47.96	EPC (2020)
AV6	Cultural	C	Y	1104	-	66.94	EPC (2018)
AV7	Office	C	Y	1104	-	114.62	EPC (n.a.)

LNEG Cluster							
LEG1	Office	C	N	8445	143.13	555.052	EPC (2017)
LEG2	Office	B	Y	301	-	21.34	EPC (2020)
LEG3	Office	D	N	4120	-	319.42	EPC (2018)

The main results will be presented below.

4. RESULTS

In this section the renovation measures resulted from the simulation with DST are presented and analyzed. The results provided by the DSTool after the application of renovation measures can be analysed at the building level or group of buildings and according to different geographic distributions or building typologies.

As previously mentioned, for some parameters (walls, roofs, floors, windows, mechanical ventilation) DST consider 3 level of renovation according with different characteristics and for other parameters (heating and cooling systems, renewable) only one level of renovation. The renovation solutions corresponding to the best performance are Identified In the following and correspond to the results presented in terms of energy savings, CO_2 emission reduction, and financial savings.

The renovation solutions were considered as follows:

- Thermal insulation for the external walls, roofs and floors of about 10 cm, resulting in a U-value of 0.25 W/(m^2.K) and triple-glazed windows with argon, resulting in a U-Value of 0.825 W/(m^2.K).
- Replacement of the current lighting systems with LEDs.
- Mechanical ventilation with heat recovery systems.
- Heat pumps for heating and cooling.
- Solar Photovoltaic panels, for some of them.

In this dissertation, cumulative results are presented for each cluster and the main identified parameters: energy savings, CO_2 emission reduction and financial savings. This kind of incremental analysis is expected to support the local administration in the decision and planning of building intervention.

The results are presented for 3 Portuguese clusters of buildings under study, and we will analyze each cluster of regional buildings individually.

4.1. LNEG - National Laboratory for Energy and Geology

The three studied buildings of LNEG have the same typology – Offices – therefore, the analysis will be carried out together. First, the data taken from the Benchmarking (Annex II) will be analyzed - Table 4.1 and Table 4.3. In the first table, it is possible to find the current reference scenario of each building belonging to LNEG, while in the second table, the renovation scenario after the tested energy efficiency measures are applied is presented.

Table 4.1 - LNEG Buildings Reference Scenario.

Reference Scenario			
Building Name	**Energy consumption [kWh/year]**	**Primary energy consumption [kWh/year]**	**CO_2 emissions [t/year]**
Alfragide Campus [LNEG1]	1880926	5367798	516
Aljustrel Campus [LNEG2]	6293	46956	4
São Mamede de In-festa Campus [LNEG3]	53834	381597	36
TOTAL	2358473	6932927	665

Table 4.2 - LNEG Buildings Renovation Scenario.

Renovation Scenario			
Building Name	**Energy consumption [kWh/year]**	**Primary energy consumption [kWh/year]**	**CO_2 emissions [t/year]**
Alfragide Campus	1625424	5445715	518
Aljustrel Campus	7595	50210	5
São Mamede de In-festa Campus	92771	602443	57
TOTAL	1725790	6098368	581

The results provided by the DSTool after the application of renovation measures can be analyzed at the building level or group of buildings and according to different geographic distribution or building typologies.

The renovation solutions were considered follows:

- Thermal insulation for the external walls, roofs, and floors of about 10 cm, resulting a U-value of 0.25 W/(m^2.K) and triple glazed windows with argon, resulting a U-value of 0.8 W/(m^2.K);
- Replacement of the current lighting systems with LEDs;
- Mechanical ventilation with heat recovery system;
- Heat pumps for heating and cooling;
- Photovoltaic panel, for some of them (Table 4.3).

Table 4.3 - Overview table of the buildings for LNEG.

	LNEG
Number of buildings	3
Number of typologies	1
Primary Energy Savings (MWh/year)	3252
Co_2 emission reduction (tCO_2e/year)	310
Financial Savings (€)	217.523

This cumulative analysis is advantageous to serve as a guide so that stakeholders can have a full view of the improvements that can be achieved if the solutions are implemented in all buildings belonging to the cluster in question. Figure 4.1 depicts the primary energy savings, Figure 4.2 the CO_2 emissions reduction, and Figure 4.3 the financial savings.

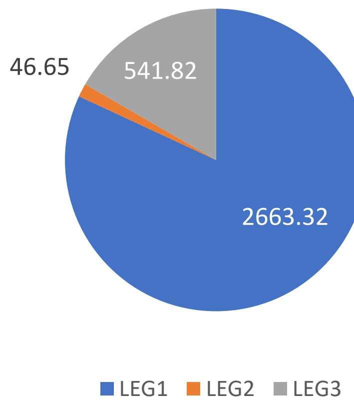


Figure 4.1 - Primary Energy savings LNEG, in MWh/year.

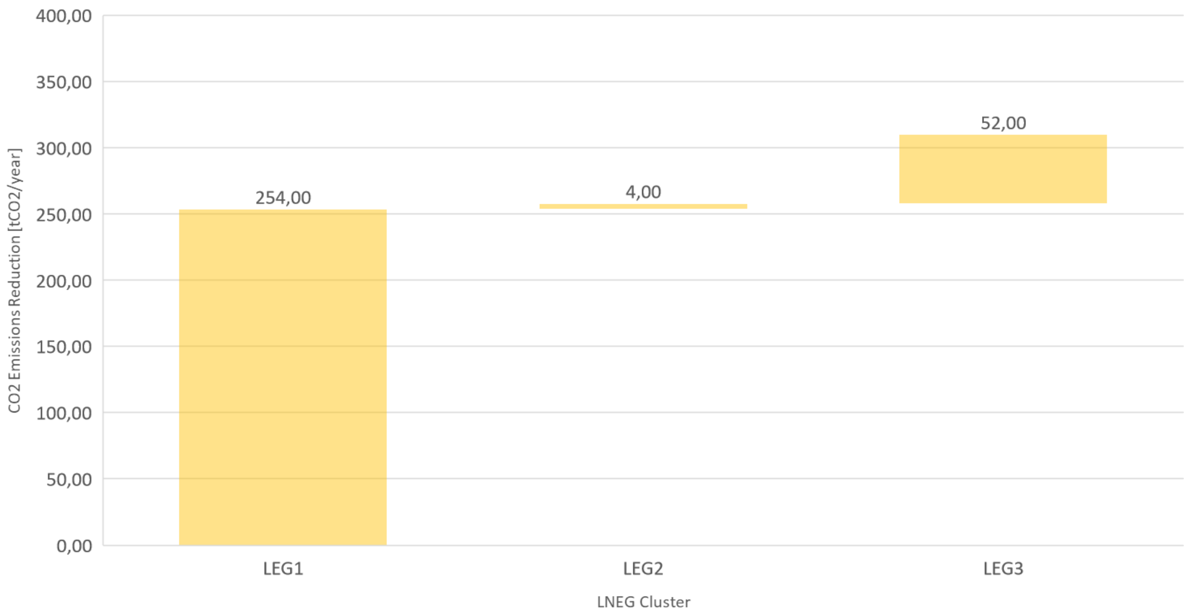


Figure 4.2 - CO_2 emission reduction LNEG.

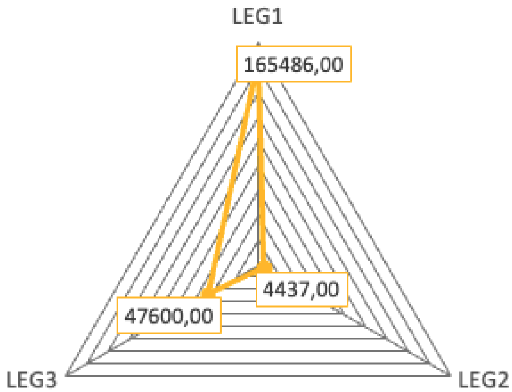


Figure 4.3 - Financial savings LNEG, (incl. VAT) [€/year].

However, most of the time, public entities, have budget limits to implement renovation measures. As such, in most cases it is not possible to choose to implement all (and the most efficient) measures to improve energy performance. Furthermore, in this sequence, it is also important to identify which buildings will be most advantageous for the first renovations/investments. For these reasons, a more in-depth analysis of the data that can also be extracted from the DSTool is necessary.

As previously mentioned, for some parameters (walls, roofs floors, windows, mechanical ventilation) DST consider 3 levels of renovation according with different characteristics and for other parameters (heating and cooling systems, renewable) only one level of renovation. In the following analysis, the payback period and cost effectiveness are presented first for the parameters with 3 renovation levels for all LNEG buildings and after for the parameters with one renovation level, for all LNEG buildings.

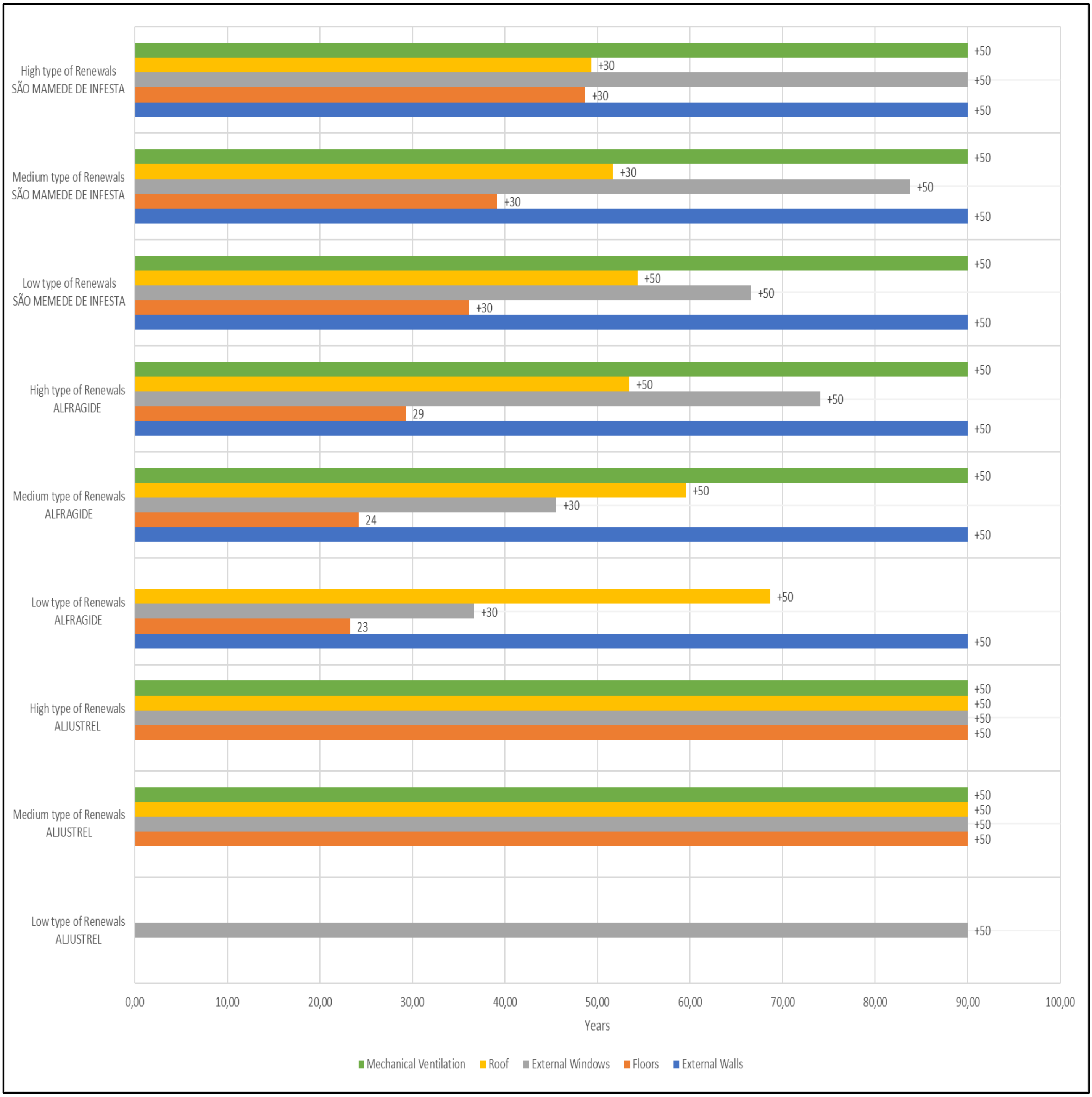


Figure 4.4 - Payback Period of the implementation of 3 renovation levels parameters.

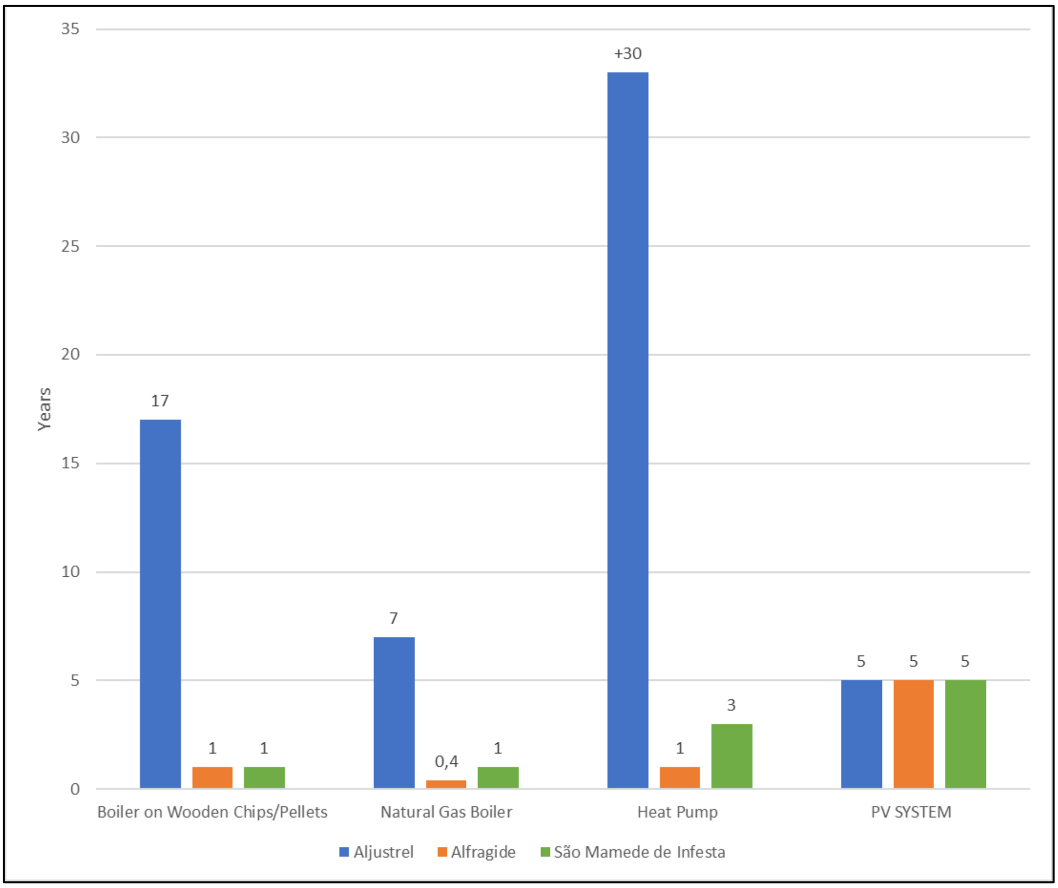


Figure 4.5 - Payback period of the Implementation of 1 renovation levels parameters.

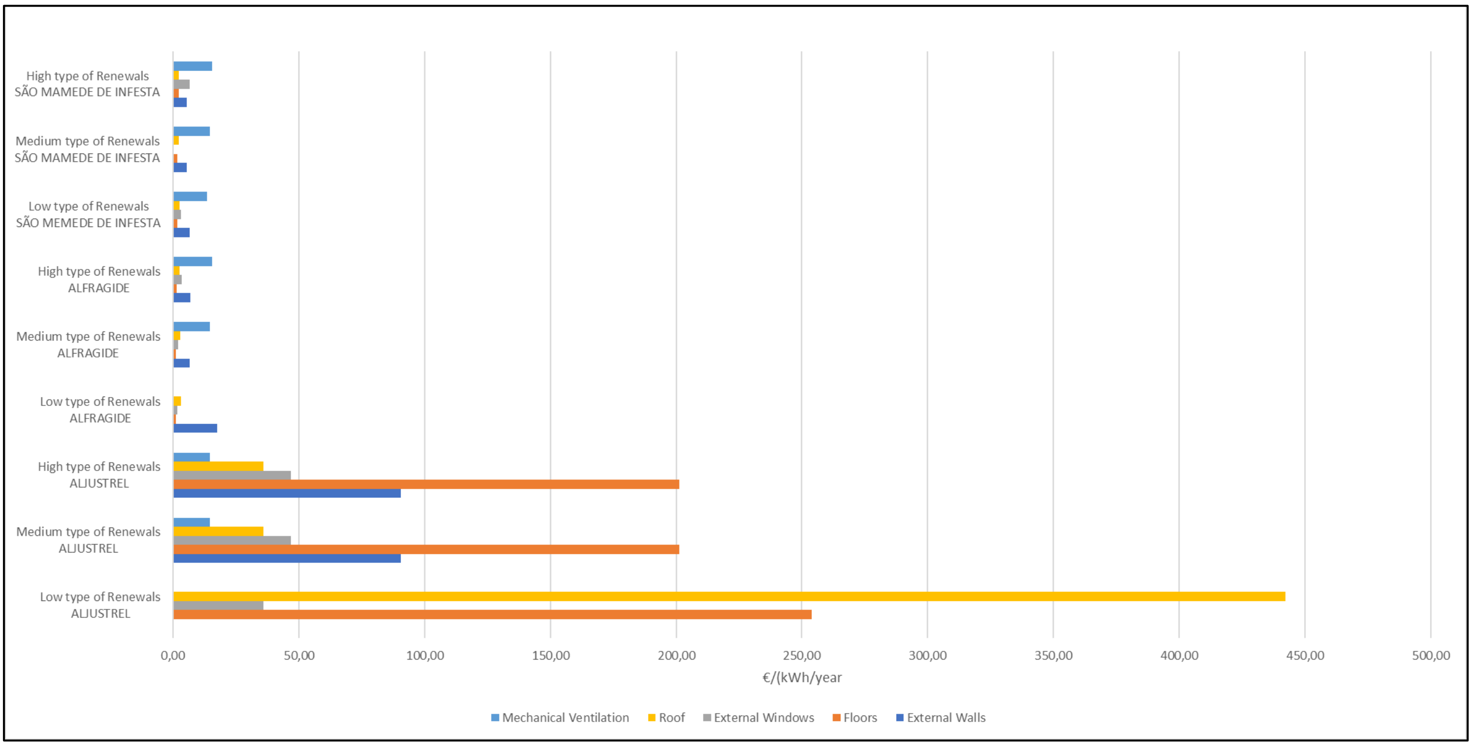


Figure 4.6 - Cost-Effectiveness of the implementation of 3 renovation levels parameters.

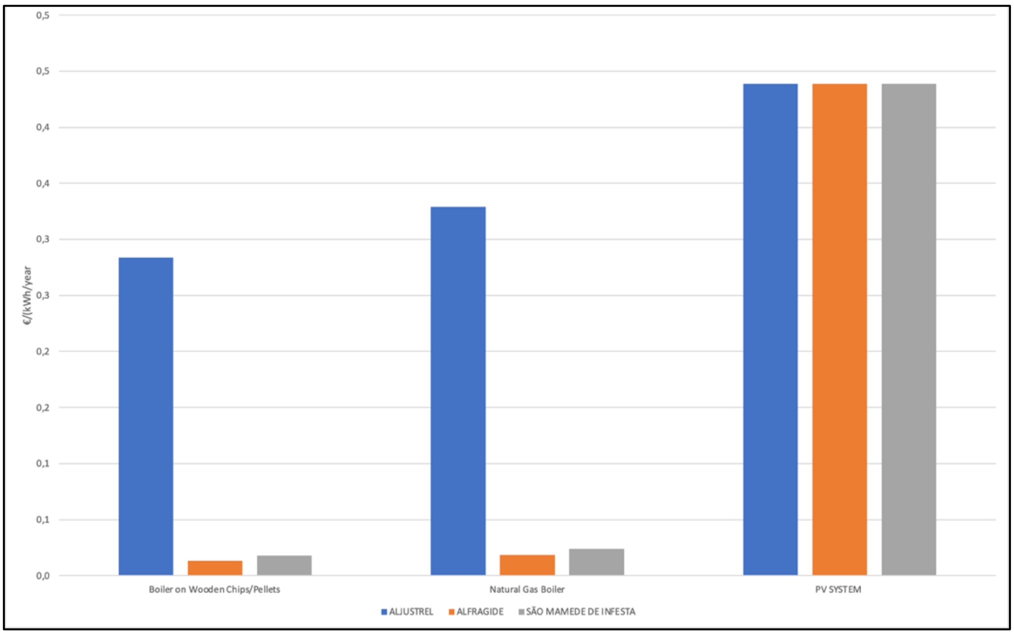


Figure 4.7 - Cost-Effectiveness of the implementation of 1 renovation level parameter.

4.2. Municipality of Arruda dos Vinhos

All 7 buildings assessed that belong to the Arruda dos Vinhos cluster are as seen from different typologies. Within this group of public buildings, we have that 1 building belongs to the Sports Facilities group (Municipal Football Field), 1 building belongs to the Cultural Buildings group (Municipal Library), 1 building belongs to the Educational Buildings group (S. Tiago dos Velhos School Center), and 4 buildings belong to the group of typologies associated with Social Centers (Citizen's Bureau, City Council, Study and Research Center, Youth Hostel).

First, as in the previous analysis, we will study the data that are extracted from the DSTool Benchmarking for the cluster of buildings in the municipality of Arruda dos Vinhos (detailed individual analysis is depicted in Annex III.

As above-mentioned, it should be noted that in Benchmarking, there is only 1 variable for each type of renovation. In the first Table 4.4, it is possible to find the current reference scenario of each building belonging to the Arruda dos Vinhos municipality. In the second Table 4.5 the renovation scenario after the energy efficiency measures are applied is presented.

Table 4.4 - Reference Scenario for the Municipality of Arruda dos Vinhos buildings.

Reference Scenario			
Building Name	**Energy consumption [kWh/year]**	**Primary energy consumption [kWh/year]**	**CO_2 emissions [t/year]**
Youth Hostel	46159	256438	24
Municipal Library	22667	83342	8
Municipal Football Field	14290	35724	3
Study and Research Center	3903	15522	1
City Council	15156	37890	4
S. Tiago dos Velhos School Center	7146	44699	4
Citizen's Bureau	40331	111872	11
TOTAL	149652	585487	56

Table 4.5 - Renovation Scenario for the Municipality of Arruda dos Vinhos buildings.

Renovation Scenario			
Building Name	**Energy consumption [kWh/year]**	**Primary energy consumption [kWh/year]**	**CO_2 emissions [t/year]**
Youth Hostel	44881	323760	31
Municipal Library	20417	91055	9
Municipal Football Field	36399	90997	9
Study and Research Center	12857	26695	3
City Council	39378	98444	9
S. Tiago dos Velhos School Center	9502	64007	6
Citizen's Bureau	30227	92133	9
TOTAL	193660	787091	75

The cumulative data is presented in Table 4.6, together with identifying the number of buildings and corresponding typologies, in this case, there are 4 different types for the Arruda dos Vinhos studied buildings.

Table 4.6 - Overview table of the buildings studied for Arruda dos Vinhos Municipality.

	Arruda dos Vinhos
Number of buildings	7
Number of typologies	4
Primary Energy Savings (MWh/year)	415
Co_2 emission reduction (tCO_2e/year)	38

Financial Savings (€)	56.855

Once again, from the comparison between the scenario before the renovation and after it, we found that there is a great advantage in implementing the measures previously described.

However, and for the reasons that have already been described, the renovation measures will be analyzed separately again through the graphs prepared with the data extracted from the tool.

As this cluster is composed by 7 buildings, it is necessary to divide the buildings into two parts. The first part -Arruda dos Vinhos Part I- it's composed of the Youth Hostel, Municipal Library, and the Municipal Football field buildings. And the second part-Arruda dos Vinhos Part II- it's composed by the Study and Research Center building, City Council, the S. Tiago dos Velhos School Center, and the Citizen's Bureau. Remembering that, once again, the first four graphs, Figure 4.8 to Figure 4.11 depict the years that it takes to have payback after implementing the measures shown there. As for the Figure 4.12 to Figure 4.15 these represent the related financial savings.

Figure 4.8 - Payback period of the implementation of 3 renovation levels parameters for Arruda dos Vinhos Buildings [part 1].

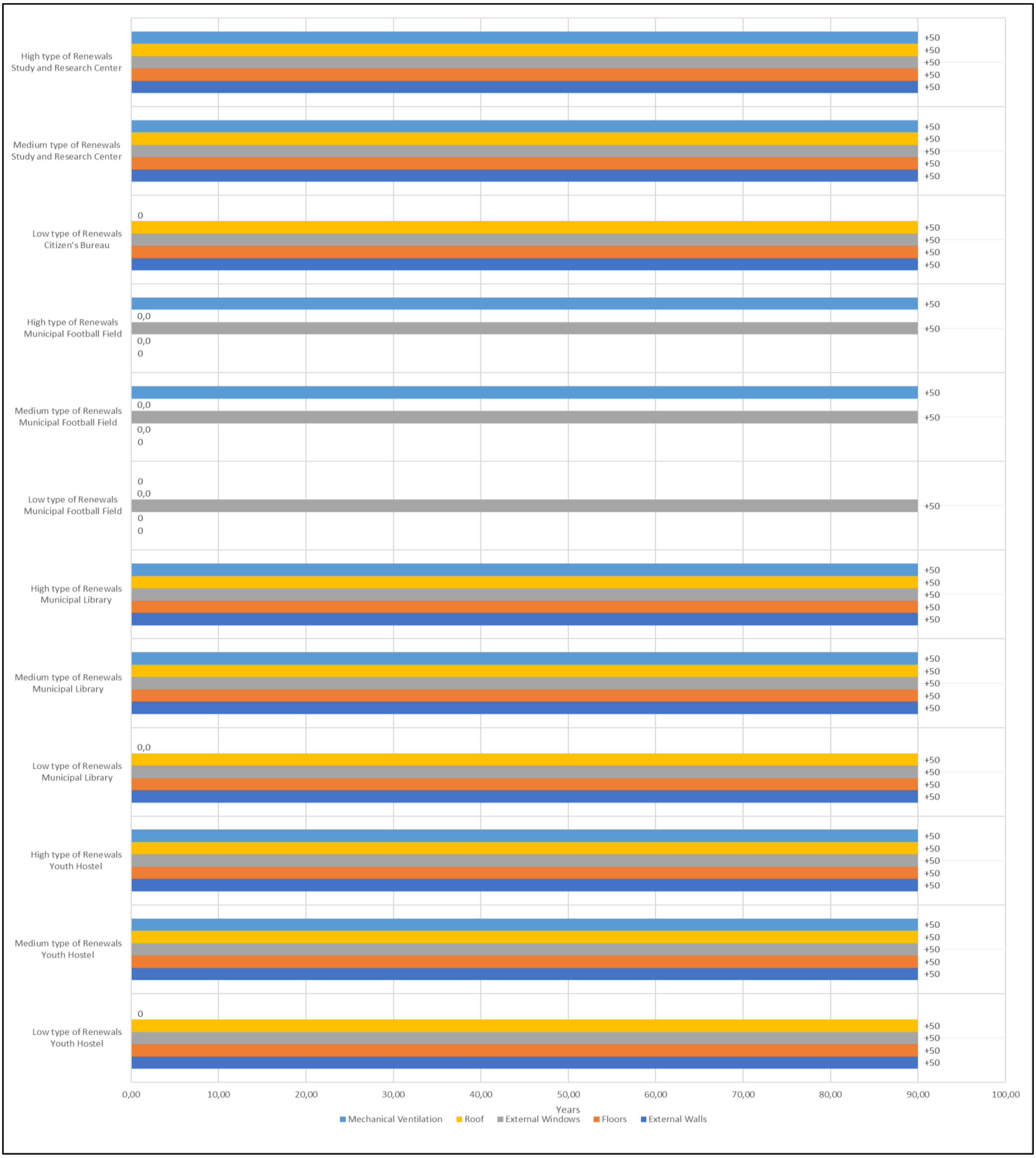


Figure 4.9 - Payback period of the implementation of 3 renovation levels parameters for Arruda dos Vinhos buildings [part 2].

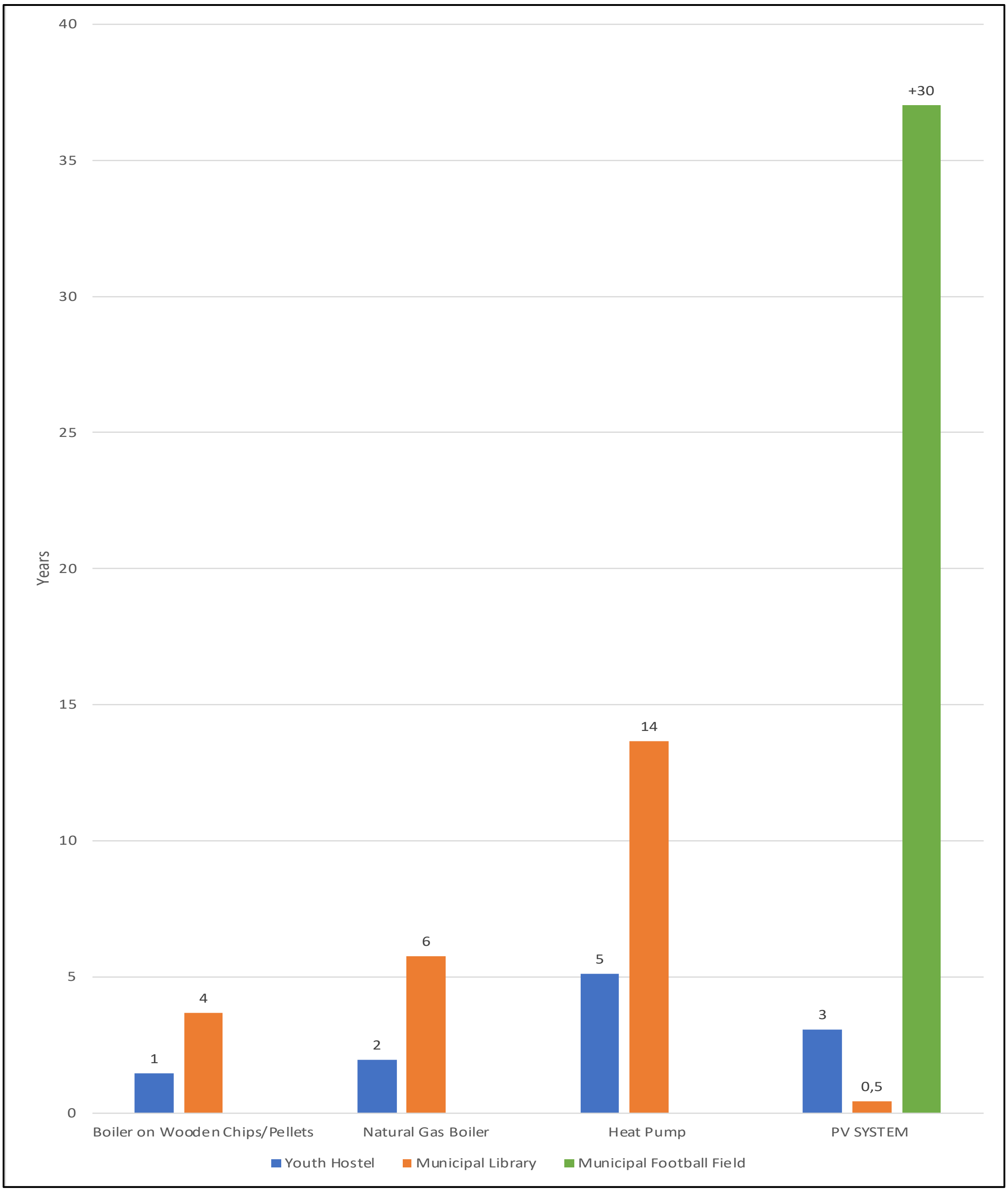


Figure 4.10 - Payback period of the implementation of 1 renovation parameters for Arruda dos Vinhos buildings [part 1].

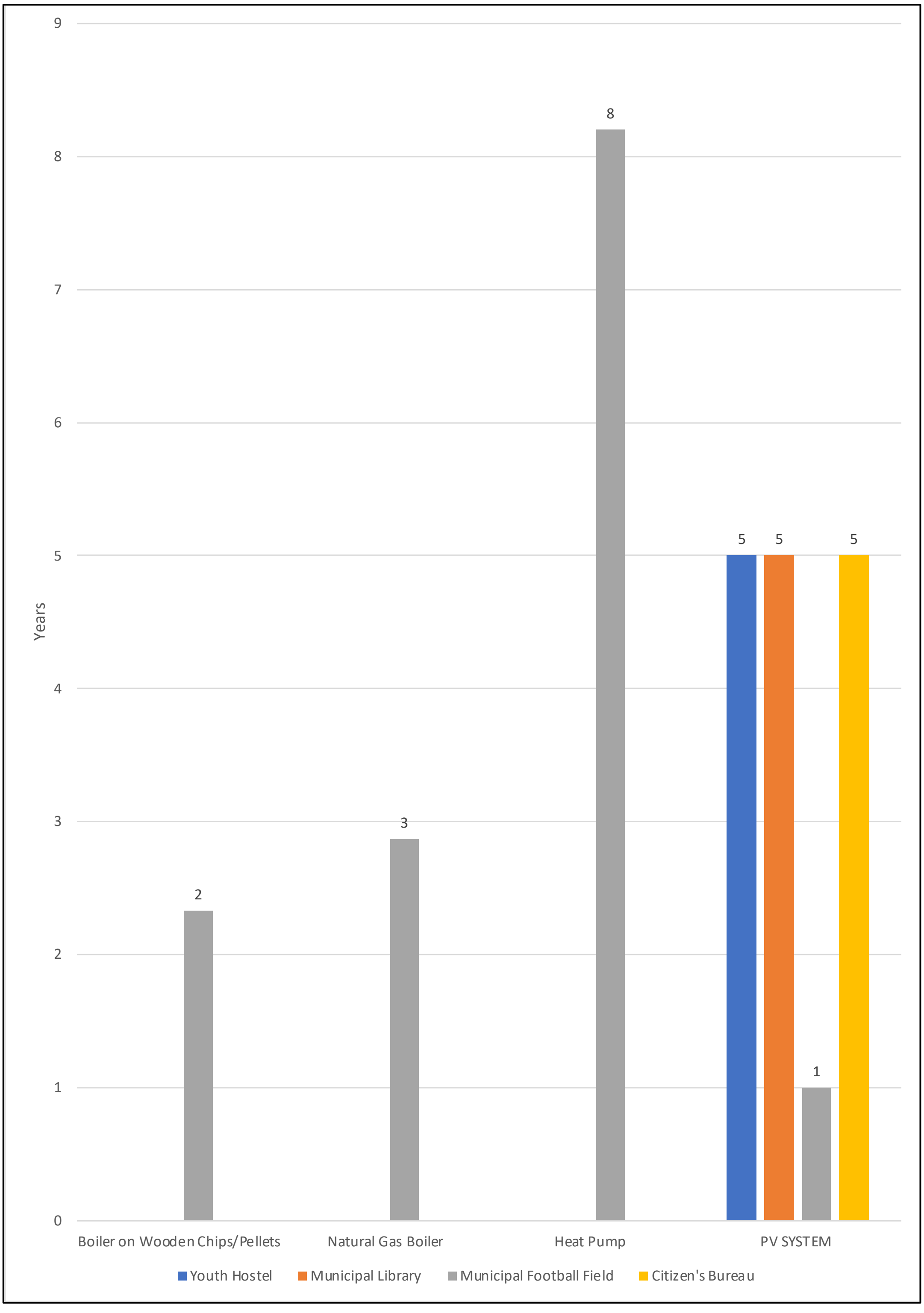


Figure 4.11 - Payback period of the implementation of 1 renovation parameter for Arruda dos Vinhos buildings [part 2].

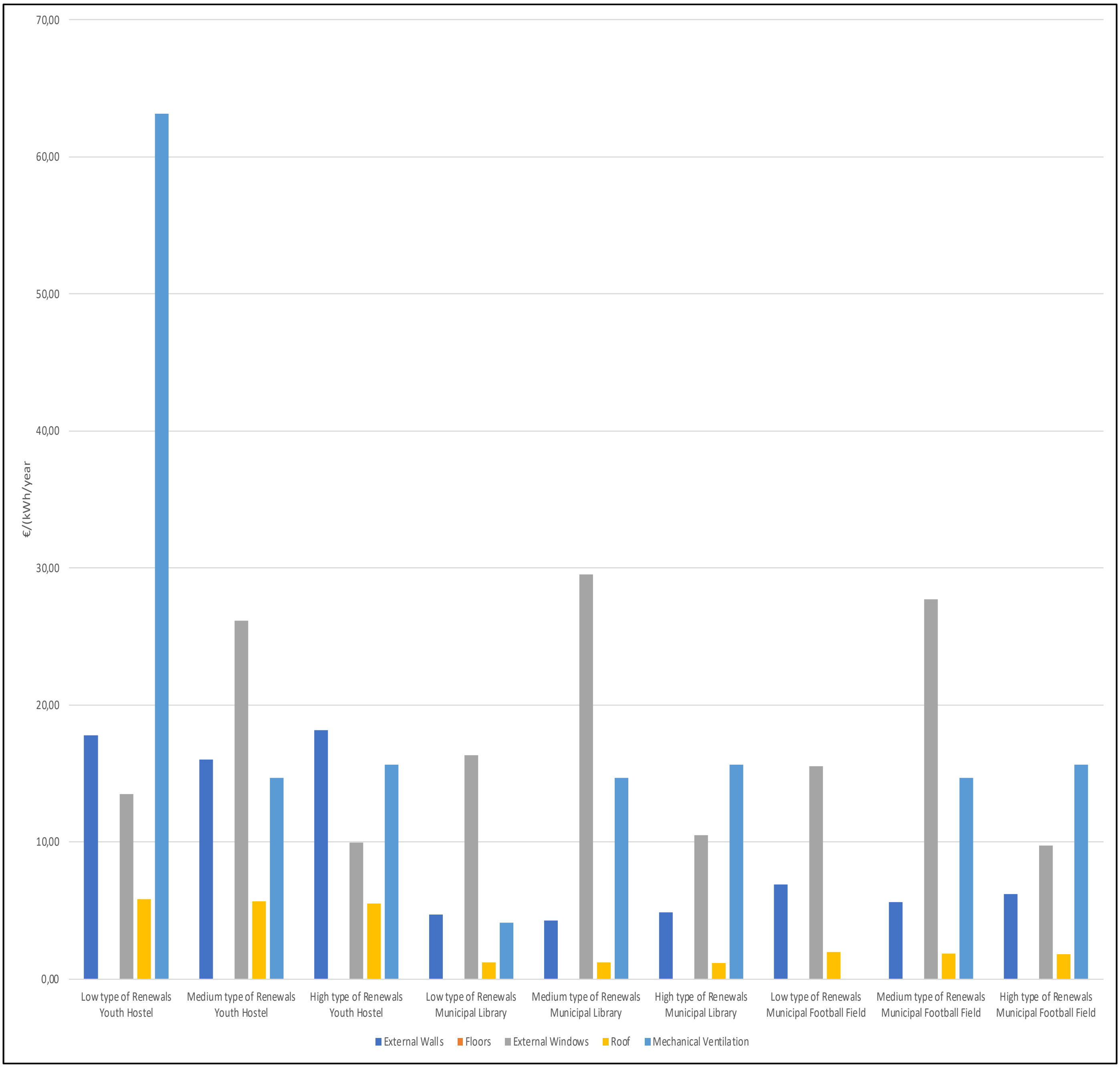


Figure 4.12 - Cost-Effectiveness of the implementation of 3 renovation levels parameters for Arruda dos Vinhos Buildings [part 1].

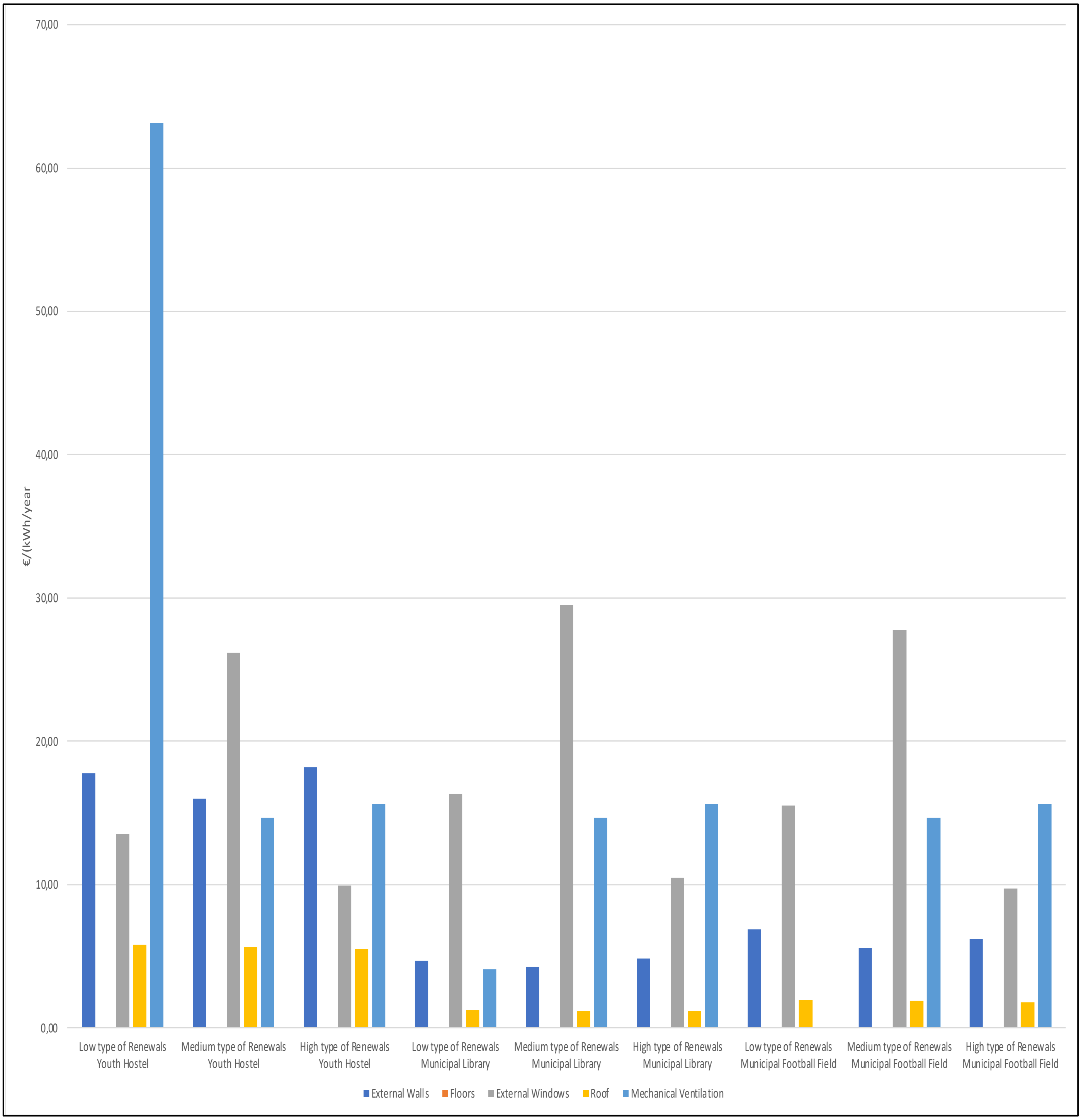


Figure 4.13 - Cost-Effectiveness of the implementation of 3 renovation levels parameters for Arruda dos Vinhos Buildings [part 2].

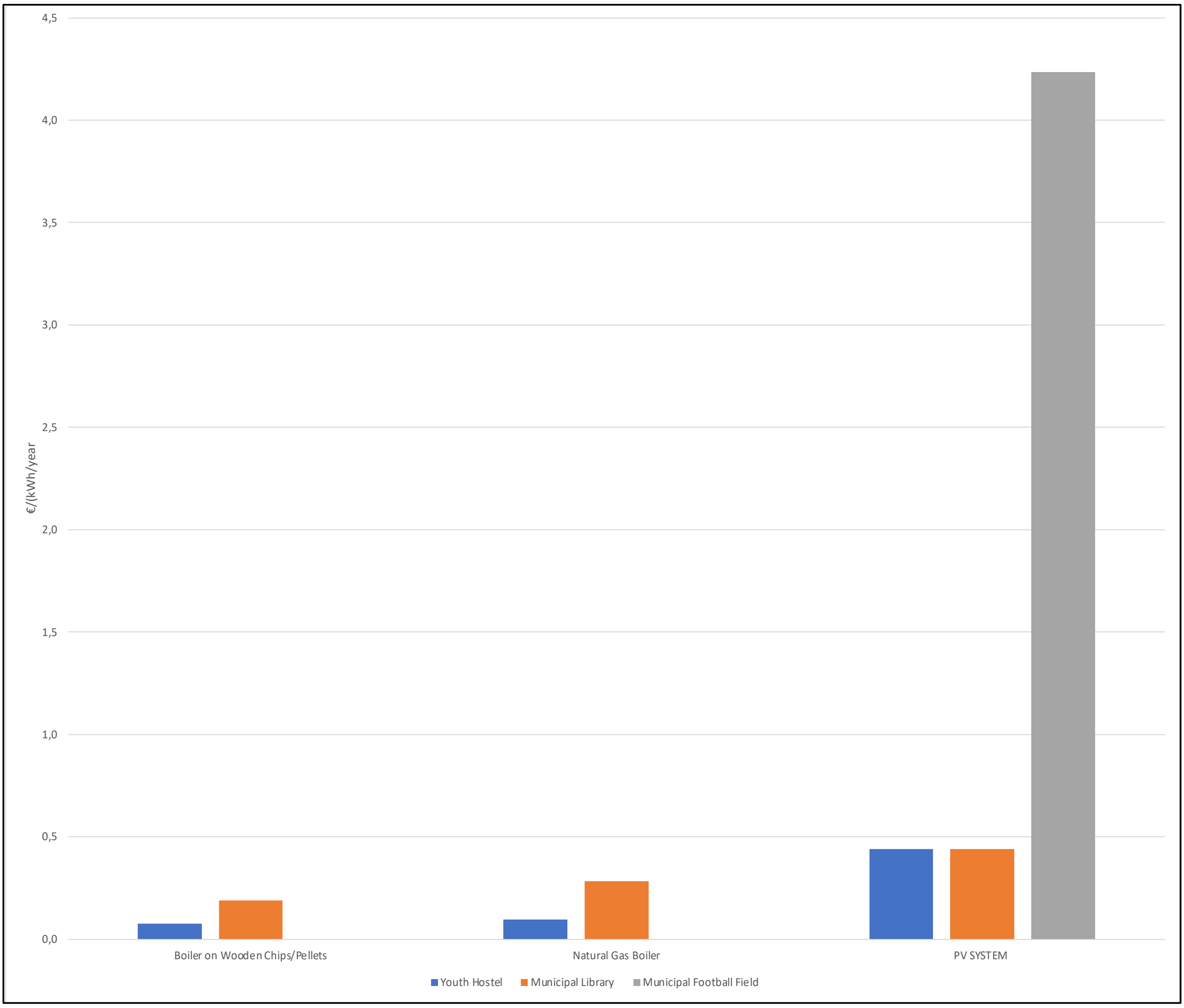


Figure 4.14 - Cost-Effectiveness of the implementation of 1 renovation level parameter for Arruda dos Vinhos Buildings [part 1].

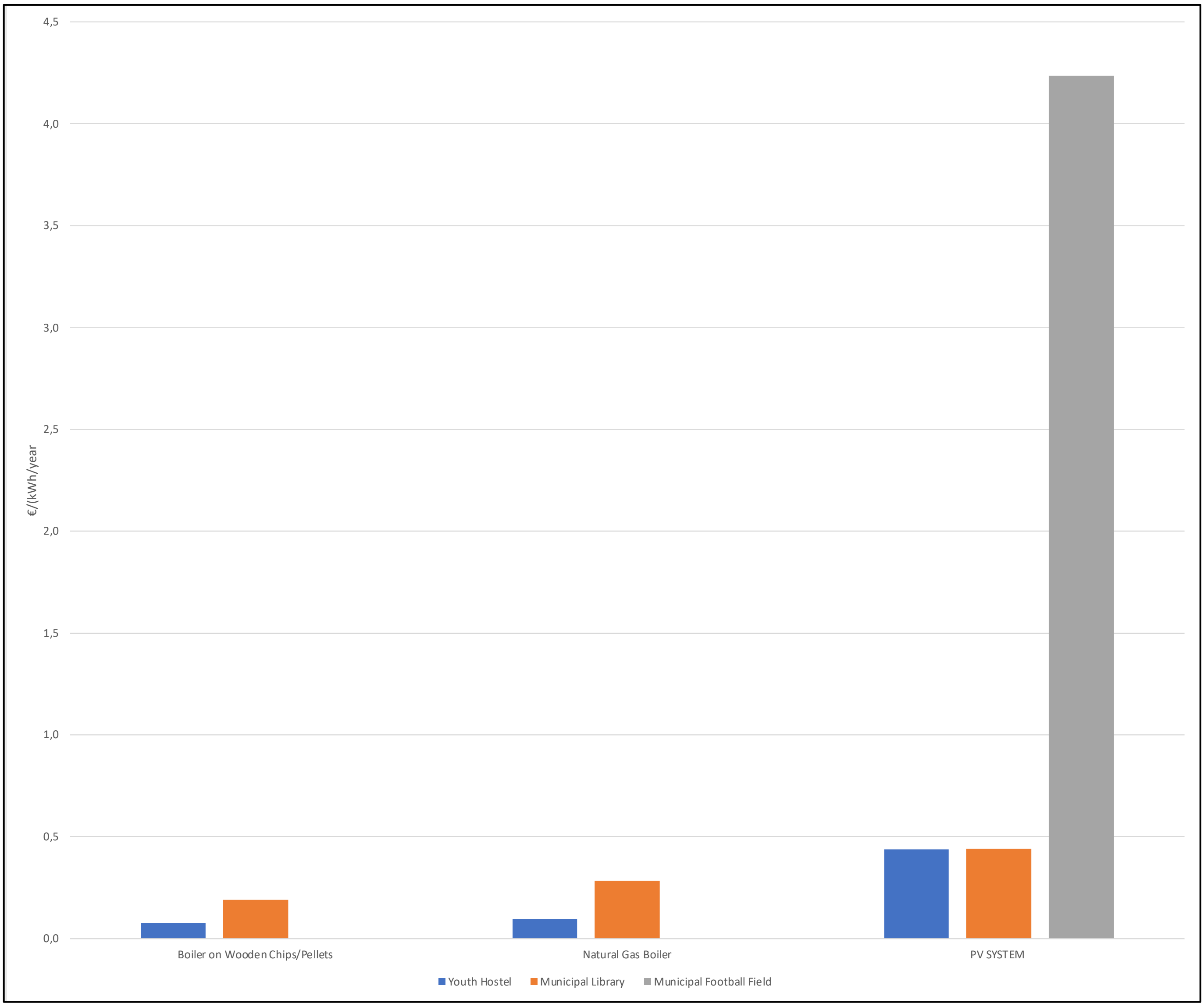


Figure 4.15 - Cost Effectiveness the implementation of 1 renovation level parameter for Arruda dos Vinhos Buildings [part 2].

4.3. AREANATejo - Regional Agency for Energy and Environment of North Alentejo and Tagus

AREANA Tejo is the last cluster to be analysed (detailed individual analysis is depicted in Annex IV. There are several municipalities belonging to AREANA Tejo however, only the municipalities of Arronches, Sousel, and Ponte de Sor are represented in this study. This group is composed of 12 buildings. This cluster has four different types of typologies, the typology of Sports Facilities (Arronches Municipal Stadium, Arronches Municipal Swimming Pool, Sousel Sports Complex, Ponte de Sor Municipal Stadium, and Ponte de Sor Municipal Swimming Pool), the typology of Offices (Arronches City Council, Sousel City Council, Ponte de Sor Aeronautic Campus, and Ponte de Sor Hangar 6), the typology of Cultural Buildings (Arronches Cultural Center, and Sousel Municipal Library), and the typology of Education Facilities (Sousel White House Kindergarten).

As mentioned above, first, the data extracted from the DSTool Benchmarking for the cluster of buildings in the municipality of AREANATejo will be studied, providing an overview of the current situation (Table 4.7) and the renovation (Table 4.8).

Table 4.7 - Reference Scenario for the AREANATejo Buildings.

Reference Scenario			
Building Name	**Energy consumption [kWh/year]**	**Primary energy consumption [kWh/year]**	**CO_2 emissions [t/year]**
Arronches Municipal Stadium	4513	14802	1
Arronches City Council	4	17	0
Arronches Municipal Swimming Pool	112047	106837	31
Arronches Cultural Center	20365	102717	10
Sousel Municipal Library	56625	332845	32
Sousel Municipal Sports Complex	285362	709268	113
Kindergarten Sousel White House	7033	13613	2
Sousel City Council	11438	77384	7

Ponte de Sor Campus Aeronautico	419989	3005994	286
Ponte de Sor Munici-pal Stadium	39182	213356	20
Ponte de Sor Munici-pal Swimming Pool	3004670	11731507	1313
Hangar 6	22652	56631	5
TOTAL	3983880	16364971	1821

Table 4.8 - Renovation Scenario for the AREANATejo buildings.

Renovation Scenario			
Building Name	**Energy consumption [kWh/year]**	**Primary energy consumption [kWh/year]**	**CO_2 emissions [t/year]**
Arronches Municipal Stadium	31032	81100	8
Arronches City Coun-cil	2	14	0
Arronches Municipal Swimming Pool	42925	181706	19
Arronches Cultural Center	82984	285167	27
Sousel Municipal Li-brary	91500	443942	42
Sousel Municipal Sports Complex	227781	1560525	150
Kindergarten Sousel White House	8909	27234	3
Sousel City Council	22115	128472	12
Ponte de Sor Campus Aeronautico	194714	3420817	326
Ponte de Sor Munici-pal Stadium	83415	381638	36

Ponte de Sor Municipal Swimming Pool	378397	13419377	1292
Hangar 6	28694	71735	7
TOTAL	1192469	20001728	1923

Aggregated results data are presented in Table 4.9, together with identifying the number of buildings and corresponding typologies; in this case just, there are four different types, for the AREANATejo scenario.

Table 4.9 - Overview table of the buildings studied for AREANATejo.

	AREANA Tejo
Number of buildings	12
Number of typologies	4
Primary Energy Savings (MWh/year)	2302
Co_2 emission reduction (tCO_2e/year)	309
Financial Savings (€)	658.624

As this cluster is composed of 12 buildings, here will only be presented the graphs that represent the three scenarios that contain the building that showed to have the best energy performance after the renovation measures, which is for the Ponte de Sor building: Hangar 6 of Ponte de Sor Municipal Aerodrome. For visualization purposes, we also included the swimming pool and municipal stadium of Ponte de Sor (Figure 4.16-Figure 4.19).

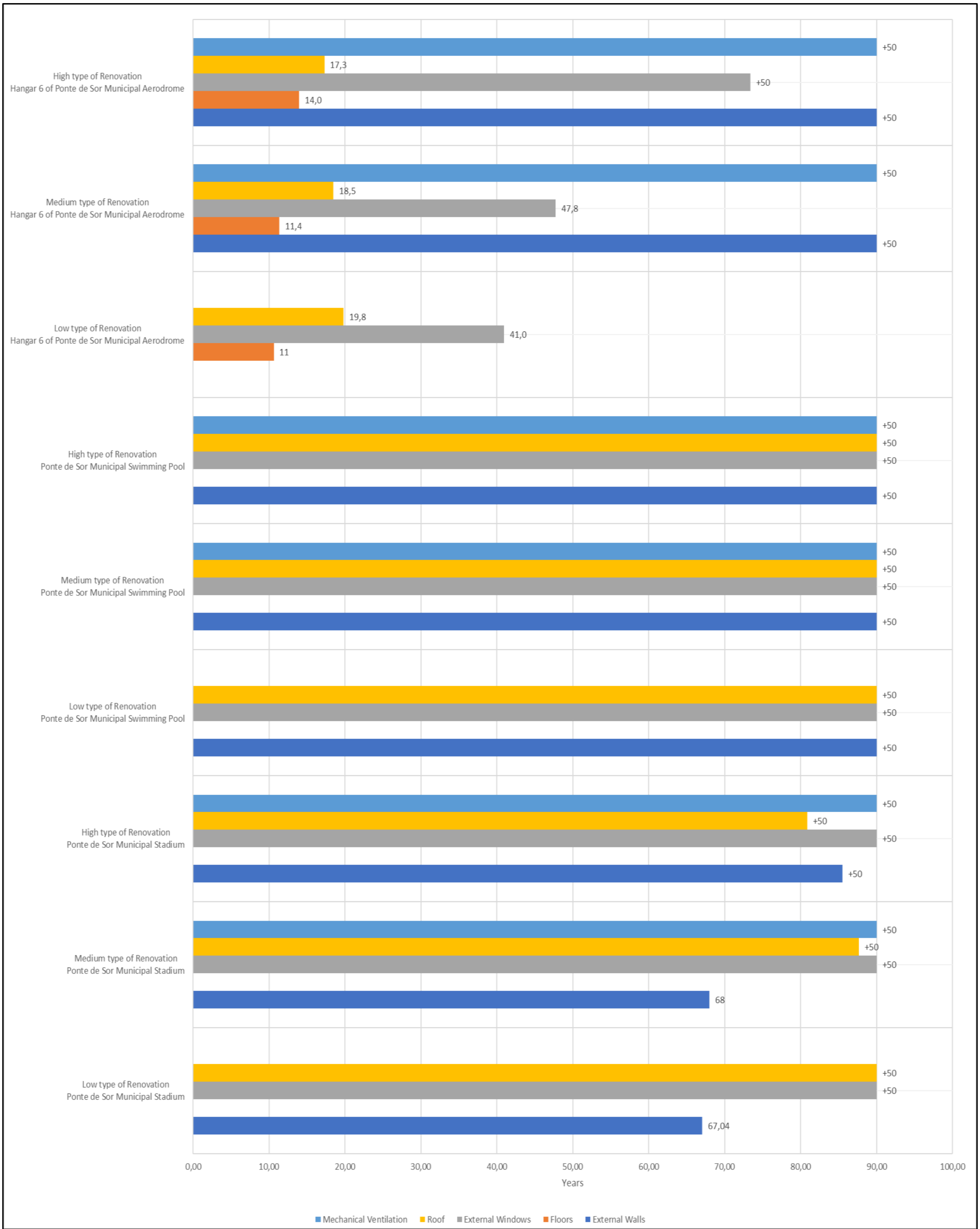


Figure 4.16 - Payback period of the implementation of 3 renovation parameters.

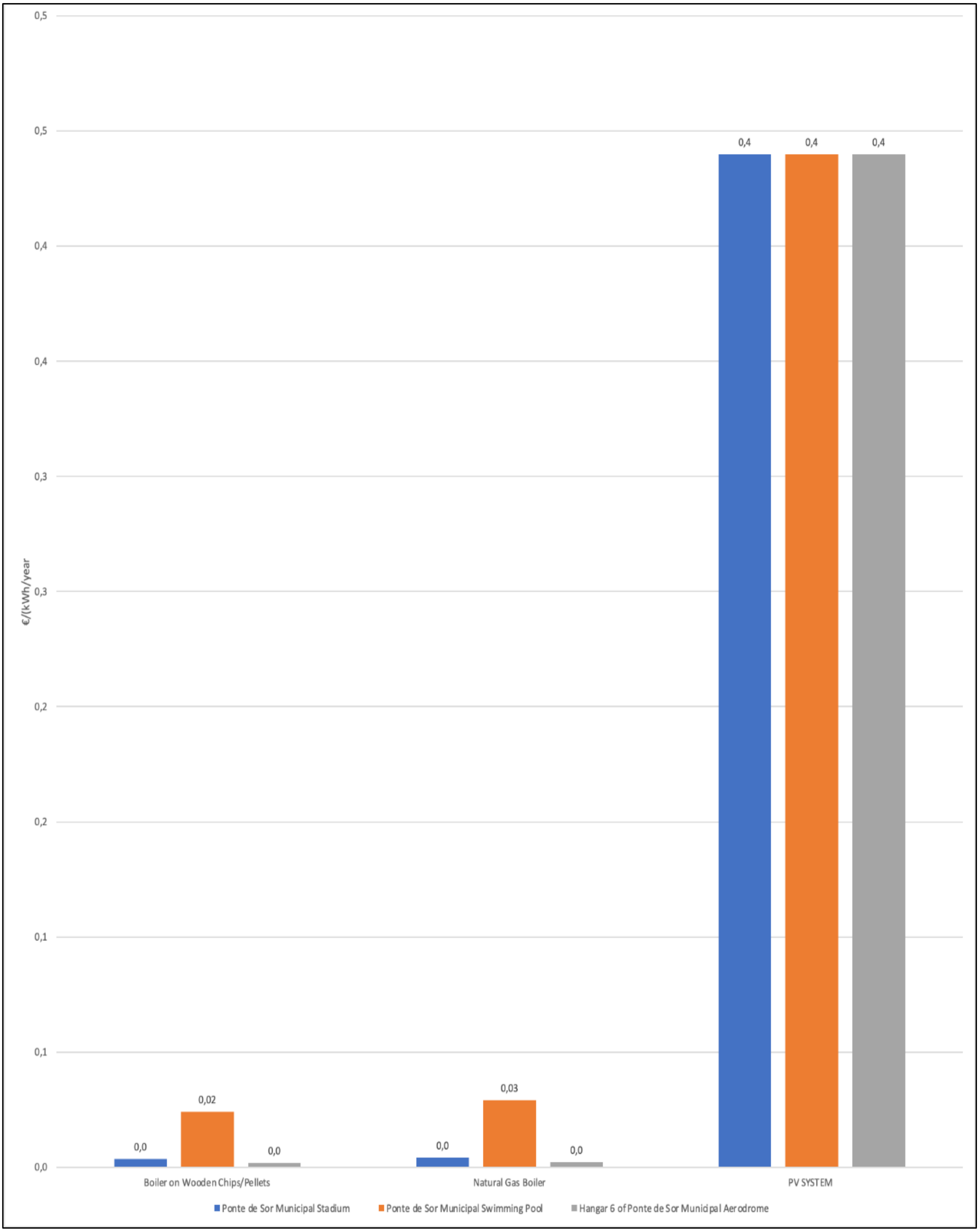


Figure 4.17 - Payback period of the implementation of 1 renovation parameter.

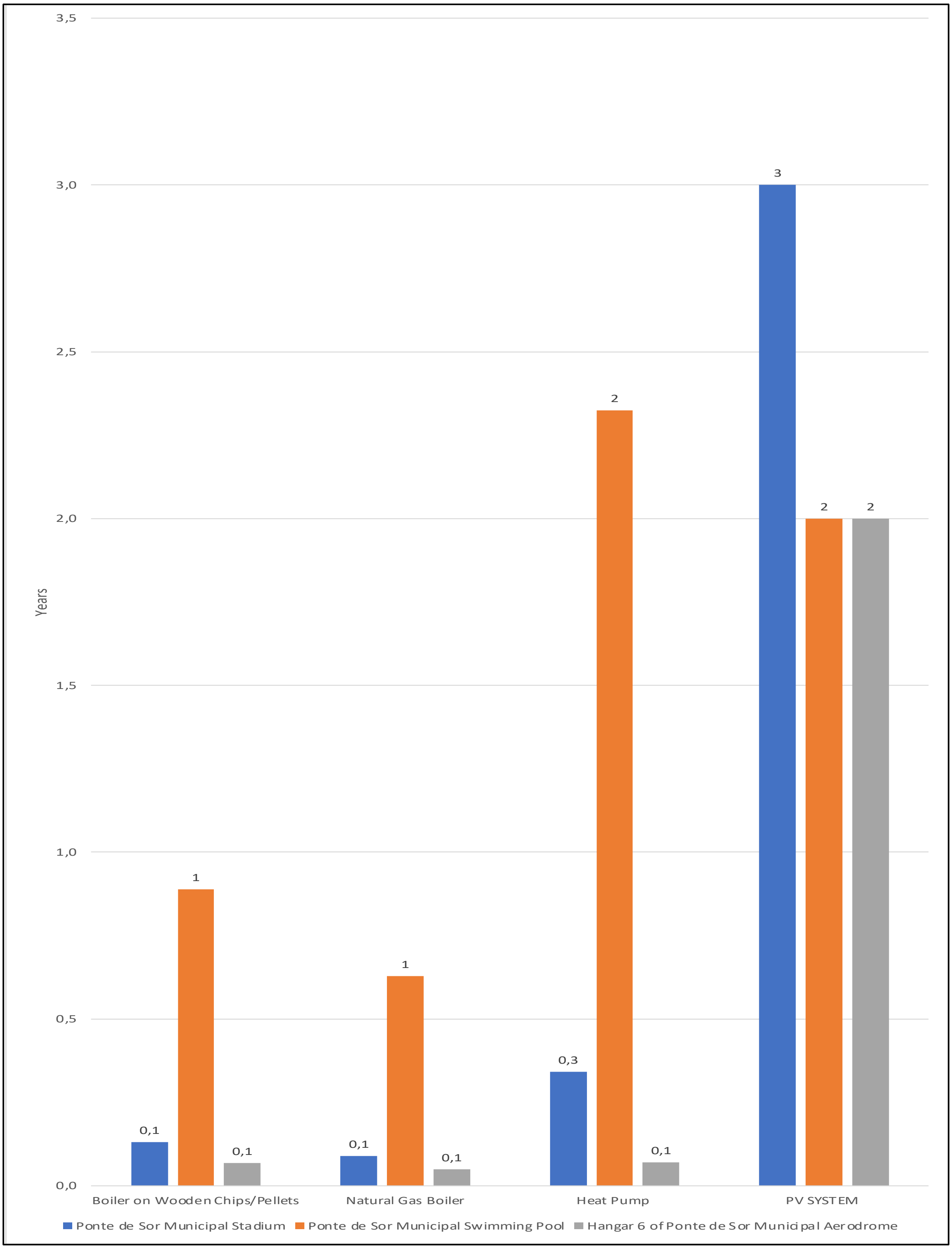


Figure 4.18 - Cost-Efficiency of the implementation of 3 renovation levels parameters.

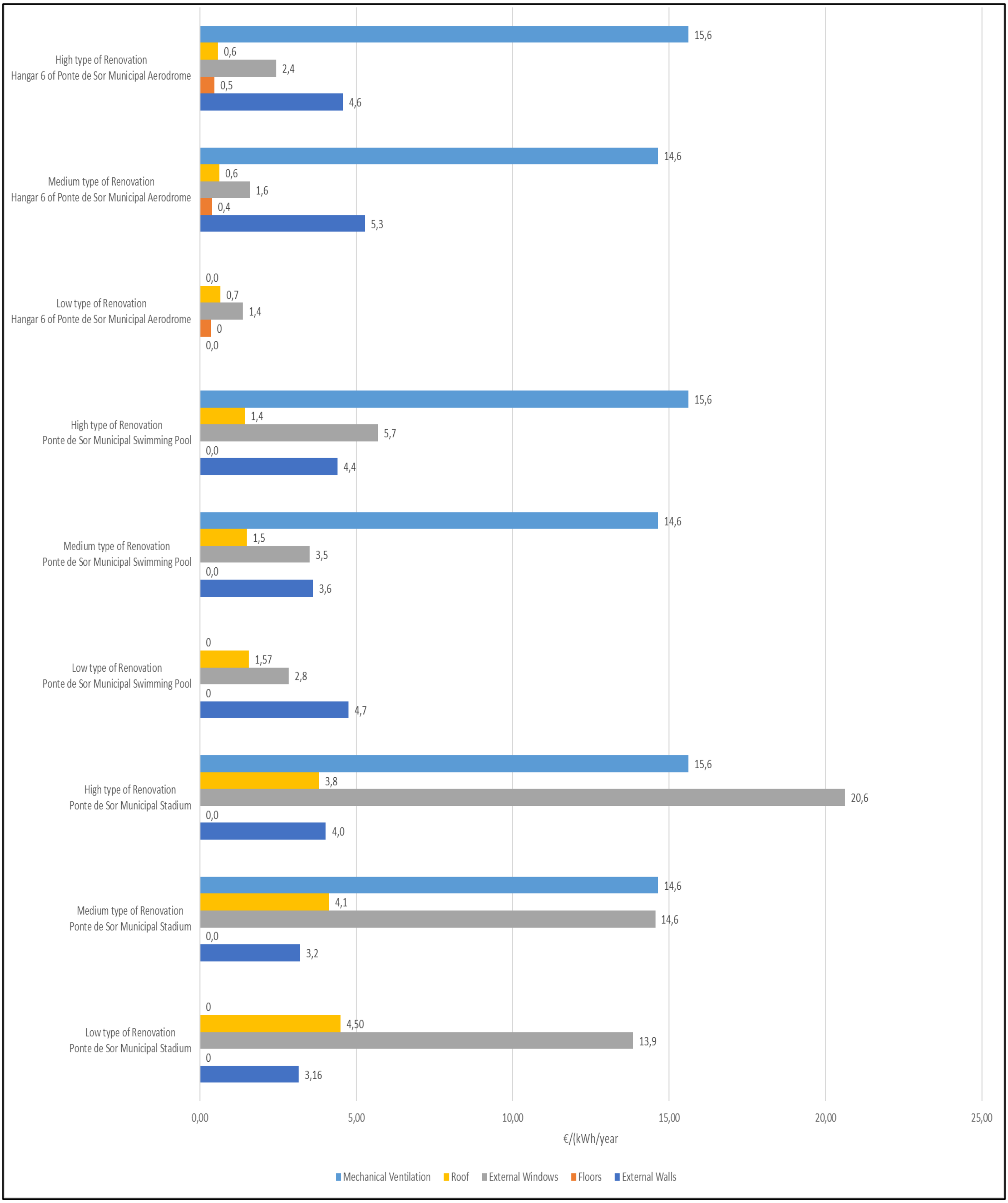


Figure 4.19 - Cost-Efficiency the implementation of 1 renovation level parameter.

5. MEASURES PRIORITIZATION

In this chapter, an overview summary of the DST results for the three buildings' clusters and regions will be given to help in the decision-making process in prioritizing renovation measures and increasing the energy performance of the public buildings. Once again, these measures will be prioritized by buildings, region, and typology.

5.1. LNEG - National Laboratory for Energy and Geology

For the buildings from LNEG, the Aljustrel campus, it can be verified that in terms of passive renovation measures, none presents a return over 50 years. This does not make the measures unfeasible, since they bring improvements in the energy performance of buildings; however, if the financial return is the most important factor for most decision-makers, then we are facing difficult measures to implement. Regarding the Alfragide campus, the measure that presents a lower financial return for any level of renovation is the floor's renovation. Among the renovation levels, we would have to give priority to Low since it is the one that, in the shortest time, presents the highest financial return. In the case of the São Mamede de Infesta campus, the renovation of the floor is again highlighted at all levels of renovation. We can also highlight the positive impact of the roof renovation for the Medium and High levels of renovation. However, of all these suggestions, the most viable one is the renovation of the floor under the Low investment level scenario.

Regarding the financial return of the Active measures for the Aljustrel Campus, it can be concluded that the implementation of a photovoltaic system, is the measure that brings a greater financial return, followed by the replacement of the climatization systems by Natural Gas Boiler Systems. Regarding the Alfragide campus, we have a payback in just five months with the replacement of the current climatization system with a Natural Gas Boiler system. On the São Mamede de Infesta campus, the current climatization system must be replaced by the Boiler on Wooden system, which represents the measure with a shorter payback period.

Looking now at the graphs above presented that represent the monetary savings given by energy saved per year in kWh/year we can again analyze by building. Regarding Passive renovation measures, we have that for the Aljustrel campus, the best solution to implement is the renovation of the roof under the Low-level scenario. It should be noted that this is one of the three buildings which has the highest savings after implementing the renovation measures. As for the Alfragide campus, the renovation measure that is the most favorable to apply is the renovation of External walls. As for the São Mamede de Infesta campus, regardless of the level of renovation, the most viable measure is the improvement of Mechanical Ventilation.

Considering the results depicted in the figures above for energy saved per year in kWh/year, It is easy to understand that the Aljustrel campus has the highest savings after implementing the measures. In this sense, for the Aljustrel campus the most favorable action is the implementation of photovoltaic systems. For the Alfragide and São Mamede de Infesta campuses, the most viable renovation, as it presents higher values, is once again the implementation of a photovoltaic system.

In this way, we can conclude that for the LNEG buildings cluster, it is suggested that stakeholders give priority to the renovation of the Aljustrel Campus as it is the one that will bring more significant savings, although with a more extended financial return. Among the measures that can be implemented, according to the data taken from DSTool, it is more feasible to implement passive measures, such as the renovation of the floor, and at the level of active measures, the integration of solar photovoltaic systems.

5.2. Municipality of Arruda dos Vinhos

As mentioned, Arruda dos Vinhos is the building cluster that presents the most recent buildings; therefore, the renovation measures will have less impact in this situation. However, this impact can still be sufficiently significant.

For all the buildings cases herein analyzed, it is essential to point out that the active renovation measures are those that play a more significant role, both in terms of energy savings and in terms payback.

We can point out that the building with the best savings rates is the Municipal Library of Arruda dos Vinhos. Here, the renovation measures are based on replacing the roof and implementing new climatization systems.

5.3. AREANATejo - Regional Agency for Energy and Environment of North Alentejo and Tagus

For this AREANA Tejo cluster, 16 graphs were developed that illustrate the situation of the buildings under analysis. Of all these graphs, in chapter 4.3. AREANATejo - Regional Agency for Energy and Environment of North Alentejo and Tagus, only selected buildings were targeted, based on the best performance of renovation measures.

Hangar 6 of Ponte de Sor, Municipal Aerodrome building, represents the building with the best values, followed by the Arronches Municipal Swimming Pool building, which is not depicted in the figures.

The active measures are those that play a prominent role in terms of increasing energy performance, with very low payback values.

5.4. Overall Comparative Analysis

Figure 4.15 depicts the energy savings and CO_2 emission reduction in each building after applying the renovation solutions. In this manner, deciding which building needs more intervention is easier. As expected, the line of CO_2 emission reduction follows the same trend as the energy savings; the larger the indicator of energy savings, the more significant the reduction of CO_2 emission indicators.

In the case of the LNEG cluster, it can be verified a large quantity of energy-saving with over 1400MWh per year for LEG1 as it is an old building with very poor energy and thermal performance compared with LEG2, a recent office building with high energy performance. In the case of the AREANA Tejo building cluster, AR11 and AR6 represent sports facilities and present the highest energy-saving potential together with the AR9. As a comparison by entities, LNEG buildings offer the highest potential in energy saving (Table 5.1), close to the total value representing energy saving of the buildings of AREANA Tejo, and the structures Arruda dos Vinhos present the lowest, as the buildings are more recent.

Table 5.1 - Summary of indicators per pilot regions.

	LNEG	AREANA Tejo	Arruda dos Vinhos
Number of buildings	3	12	7
Number of typologies	1	4	5
Primary Energy Savings (MWh/year)	3252	2302	415
CO_2 emission reduction (tCO_2e/year)	310	309	38

Financial Savings (€)	217.523	658.624	56.855

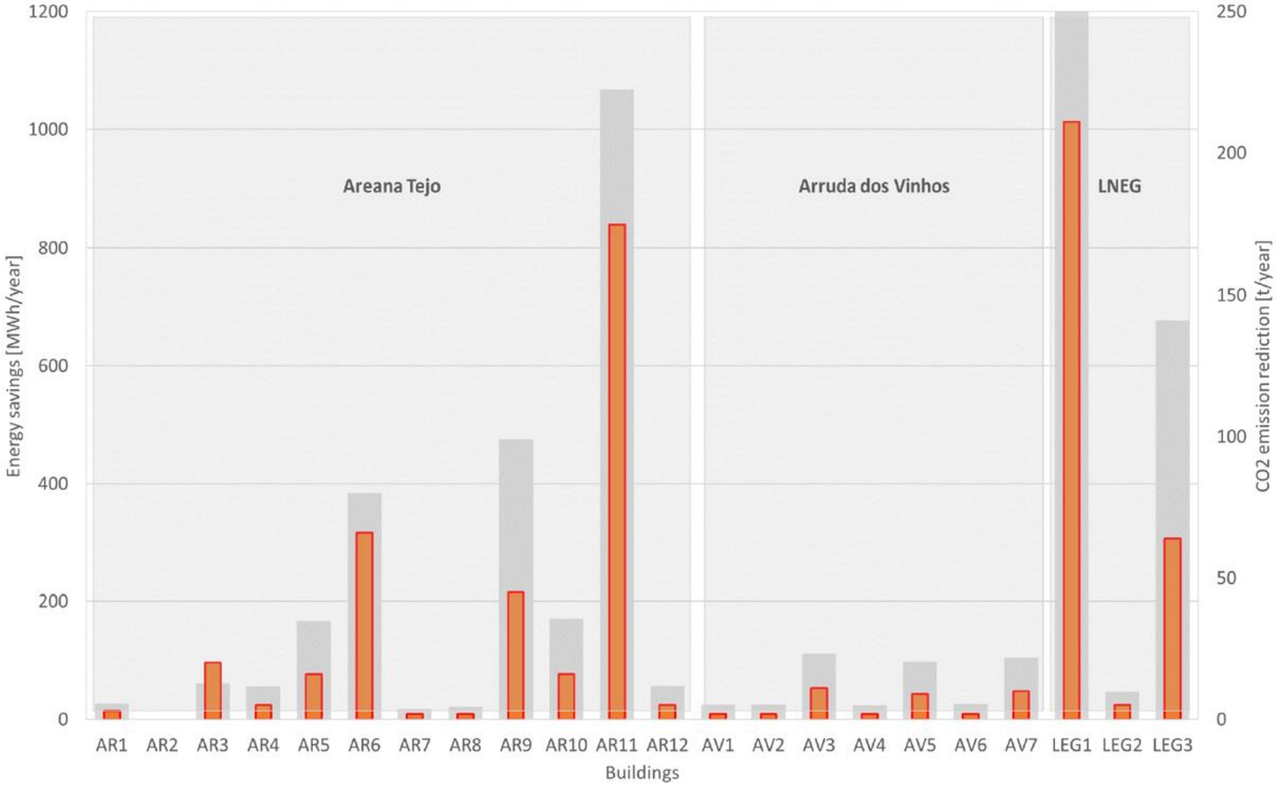


Figure 5.1 - Energy savings (MWh/year) and CO_2 emission reduction (t/year).

Regarding the corresponding financial savings resulting from adopting energy-efficient measures, in Figure 5.1 are plotted the results for the 3 clusters of buildings. Again, for the case where were verified highest energy savings, these correspond also with the highest financial saving for all three clusters.

For the AREANATejo building cluster, it can notice the highest financial savings for building AR11 corresponding to the municipal pool of Ponte Sor of about 501k€ per year, followed by an office building AR9 with about 120k€ per year, a value close to the office building of LNEG (LEG1) with financial savings about 135k€ per year. For the Arruda dos Vinhos building cluster, the financial savings vary between 2,5k€ per year in the Social center building (AV4) and the office building AV7, corresponding to 15k€ per year.

6. CONCLUSION

This chapter summarizes the main conclusions of the present dissertation, namely the research carried out for its development, the results obtained, the identified limitations to the study, and the recommendations for future studies that should be developed, to accompany the use of *PrioritEE* DStool by public authorities. The present study was developed based on the Portuguese public buildings that participated in the *PrioritEE Plus* project, which are energy certified under the most recent SCE (SCE, 2013).

The context and interest of the present study relates to the need, on the part of public entities, to improve the knowledge of their buildings, raise awareness regarding energy efficiency, as well as to understand which and how improving energy efficiency measures and renewable energy integration would be feasible. Thus, the main objective of the dissertation consisted of exploring the DSTool, carrying out a survey of various information taken from energy certificates, and obtaining other information necessary to characterize the different clusters of buildings: LNEG, Arruda dos Vinhos, and AREANATejo.

The sample of data collected on the 22 certificates obtained is restricted and potentially insignificant in terms of results for a national panorama. These certificates are not only few but are mostly assigned to buildings located in the south of Portugal. With regard to typologies, this sample mostly features service-type buildings, and their energy classification is generally a C (54% of the sample). As such, it is not feasible to extrapolate a common result that serves as a basis for the overall building stock.

With the use of the tool, it is possible to extract the best solutions for energy efficiency measures to be implemented in the different buildings of the cluster under analysis, as well as which solutions are commonly adapted to the different buildings of the cluster. The energy efficiency measures presented by the tool are divided among nine focus areas to find the most cost-effective measure (or set of measures), which will be prioritized by the DSTool and recommended to the decision-makers. The extracted results rank measures by savings, investment costs, and return on investment, either per each building or per group of selected buildings, such as building typology, net heated area, primary source of energy, etc. Thus, given the results of the present study, most of these buildings have significant improvement potential and need to be renovated to fulfill the goals and targets established at the national and international levels.

The National Laboratory of Energy and Geology (LNEG) is the group of buildings that have three fractions with the same typology - Offices - but with the most extensive geographical distribution, since the facilities are located in different areas of Portugal, from north to south of the country. It is the building on the Aljustrel Campus that represents the greatest need in terms of rehabilitation, given that it is the one with the highest energy consumption values. The renovation measure that presents the greatest viability is the renovation of the floor within the passive measures.

Arruda dos Vinhos is the region building cluster that presents the most recent buildings; therefore, the renovation measures bring less impact. However, this impact can still be sufficient significant. For all the buildings cases herein analyzed, it is essential to point out that the active renovation measures are those that play a more significant role, both in terms of energy savings, as in terms of payback. The buildings with the best saving rates is the Municipal Library, and the renovation measures to be implemented are the replacement of the roof and the replacement of new climatization systems.

The AREANATejo cluster represents the group of buildings that are geographically closest to each other. The Aerodrome - Hangar 6 of Ponte de Sor is the building that represents the best values in terms of energy performance after the implementation of the renovation measures.

An overall comparative analysis was made for all the buildings under study, and in the case of LNEG cluster it can be verified a large quantity of energy-saving with over 1400MWh per year for the Alfragide Campus as it is an old building with very poor energy and thermal performance compared with the Aljustrel Campus a recent office building with high energy performance. In the case of the AREANATejo building cluster, the Municipal Swimming pool of Ponte de Sor and the Municipal Sports complex of Sousel, represent sports facilities and present the highest energy-saving potential together with the Sousel city Council. As a comparison by entities, LNEG buildings offer the highest potential in energy saving, close to the total value representing energy saving of the buildings of AREANATejo, and the structures Arruda dos Vinhos present the lowest, as the buildings are more recent.

This type of analysis is important to inform the energy and resource managers of the respective building (or group of buildings) so that they are aware if, according to the current scenario, their buildings are fit and have the necessary conditions to resort to funds and/or financing that promote efficiency, whether in terms of energy or the use of resources in general, prioritizing renewable energies and self-consumption, so as to reduce primary energy consumption by at least 30%.

Only in this way will the goals and milestones for a path towards economic recovery and climate transition be possible, and tools such as DSTool are an asset to facilitate this process.

6.1 Study Limitations

In developing this dissertation, several limitations were identified, however, the one that was most evident was the difficulty in obtaining the necessary data to fill in the necessary inputs for the tool, since these data often do not exist or are not included in the buildings energy performance certificates, which made it necessary to contact the energy managers of buildings with a lack of information.

Another limitation of the present study is related to the difficulty of understanding potential errors associated with the data provided by the certifying entity, regarding the energy certification of commercial buildings and local administration services. In the processing of these data, some inaccuracies were detected, namely inconsistencies between the values of global energy consumption and the different types of consumption, among other inaccuracies that were detected and resolved whenever possible during the processing of data. Information lapses are equally frequent, detecting the lack of information several times, namely in the Lighting part. In this sense, additional effort was necessary to try to correct the gaps found. As such, data analysis and processing was not fully achieved, with some information that was not possible to insert in DSTool and be considered for the study. Thus, it is extremely important that in the future, there is greater accuracy in the survey and input of the resulting data within the scope of energy certification so that this information can be worked on and result in the dissemination of important and necessary data to evaluate and assist in compliance with the various national and international commitments.

6.2 Future Developments

In the past years and with the publication of the Green Deal, energy renovation has become a key mission toward energy savings and decarbonization of the building stock. Special attention is still paid to the public buildings dealing with challenges regarding nZEB's effective implementation and promotion of energy efficiency and renewable energy investments use in existing public buildings. Moreover, most public authorities need to enhance their institutional and technical capacity in the field of Energy Efficiency (EE) and use of Renewable Energy Sources (RES) to contribute to the Energy Performance of Buildings and the Energy Efficiency Directives, promoting renovation solutions and packages of measures adapted to various regional contexts.

In Portugal, the European legislation and plans contextualize and support the implementation of energy efficiency measures and nZEB performance.

In Portugal, European and national targets are currently in place to achieve carbon neutrality and promote energy efficiency in existing buildings, a path to converting them into nZEB buildings requirements. Running the national program of Building Energy Certification System (SCE) gives an important database of energy assessment details for the energy exploitation conditions of buildings. Another priority program was set by the Long-Term Strategy for the Renovation of Buildings (ELPRE), in line with the European EPBD and Green Deal commitment, following demanding energy efficiency criteria or support for the construction of new buildings with a primary energy demand towards NZEB requirement. A contribution from the Recovery and Resilience Plan (PRR) program appends an exceptional implementation period lasting until 2026 for investments foreseen in the field of health, housing, social responses, and qualifications and skills, through which support is provided for the renovation of buildings and infrastructures.

The National Carbon Roadmap (RNBC), published in 2012, and the Roadmap for Carbon Neutrality 2050 (RNC2050), published in 2019, are the key plans pushing the country's overall decarbonization agenda. In 2019, the Government also presented the National Integrated Energy and Climate Plan (PNEC2030) with the primary objective of achieving carbon neutrality in 2050 through the decarbonization of the economy and the energy transition in 2021-2030 horizon. PNEC 2030 aims explicitly to urban renovation, promoting energy efficiency, and integrating renewable energies in buildings as a strategy to reduce dependence on fossil fuels alignment of the national economy with a trajectory of carbon neutrality. A strategy of European policies for urban renovation was set to promote energy performance and renovation goals in buildings implemented by the European Directive Energy.

The present study intends to encourage the analysis and obtain information and data on commercial and service buildings since these are important vectors for implementing measures that promote energy efficiency. Thus, through this dissertation, such information is collected regarding this type of buildings. However, the present study covers a tiny fraction of buildings and should be extended to include more buildings in the tool.

Concerning the prioritization analysis of measures provided by DSTool, it is suggested that in the future, this type of analysis be carried out with raw data, that is, without these being grouped by type of measure, as the results only reflect which are the priority measures for action and which typologies they belong to. Thus, through this analysis of the raw data, not only will the priority measures to be implemented be identified, such as the typology and the buildings or fractions where these should be implemented in a more judicious way. After presenting decision-makers with the improvement measures that should ideally be implemented, it is important to understand, in future work, whether the measures were implemented and, if so, whether they correspond to expectations in terms of energy and finances. It is also important to carry out questionnaires to those responsible or representatives of the buildings to understand the measures that were not implemented, to understand the reason why actions that are easy and quick to implement are not implemented, with the aim of understanding what fails in the implementation of these measures that promote the energy performance of buildings.

In summary, the main suggested measures for the development of future work are centered on the following:

- Promoting analysis and obtaining information on commercial and service buildings.

- Extend and develop the tool's scope of application, so that it can also include residential buildings, for example, Social Housing, which in many cases are also managed by local public authorities)

- Adapt the tool to the data provided in energy performance certificates.

- Standardization of data collected by decision-makers, so that they fill in the gaps in energy certificates.

- Consider other methods/tools of analyzing the data and disseminating the results obtained.

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A.

Annex I - Energy consumption and energy dependency figures

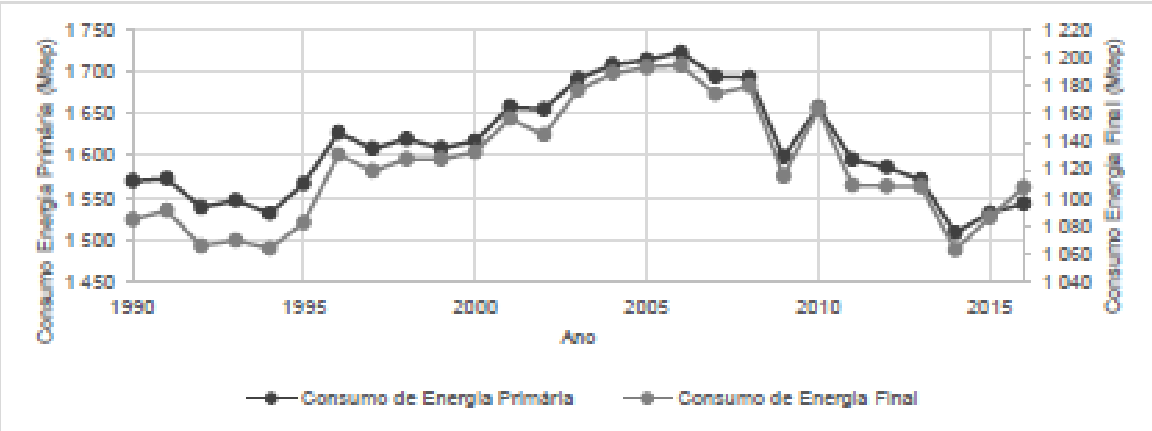

Figure I. 1 - Primary and final energy consumption recorded in the European Union, for the period between 1990 and 2016. Source: adapted from Eurostat (2018a; 2018c).

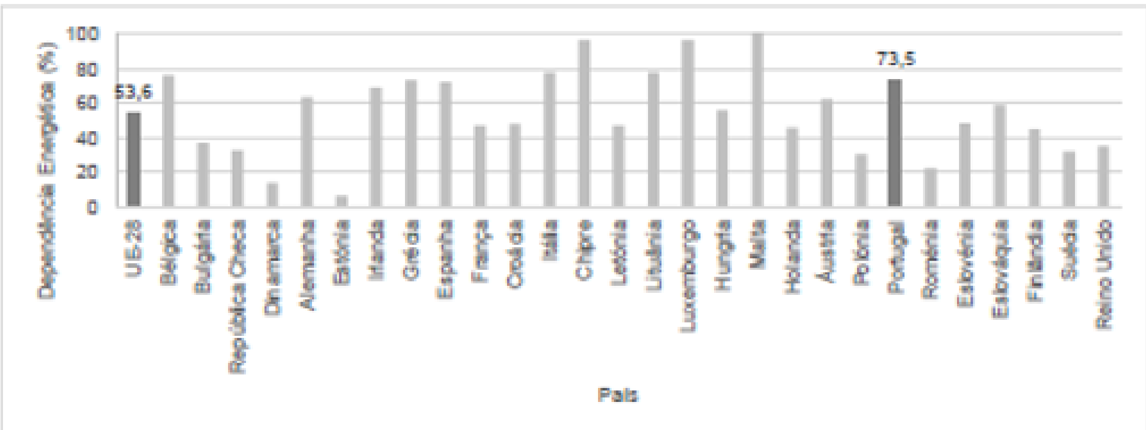

Figure I. 2- Energy dependence of the European Union, in 2016. Source: adapted from Eurostat (2018b).

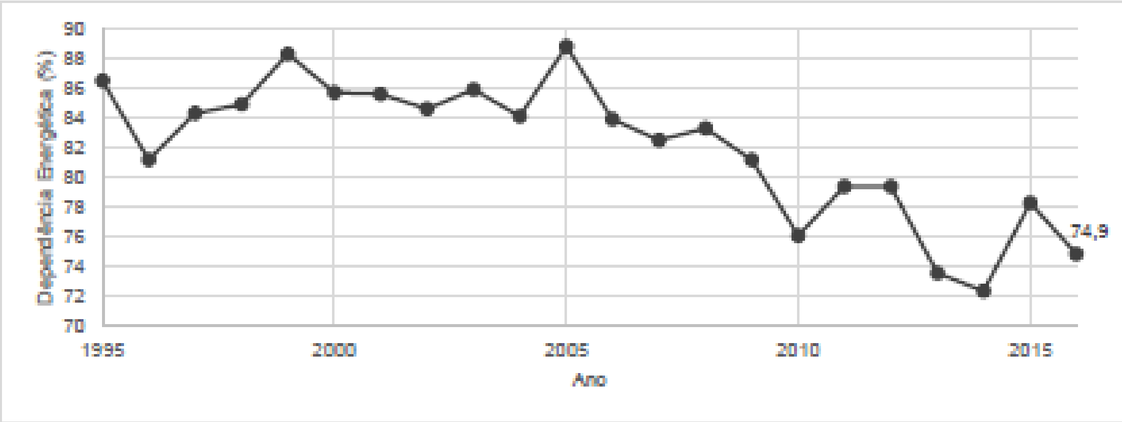

Figure I. 3 - Portugal's energy dependence, for the period between 1995 and 2016. Source: adapted from DGEG (2018c).

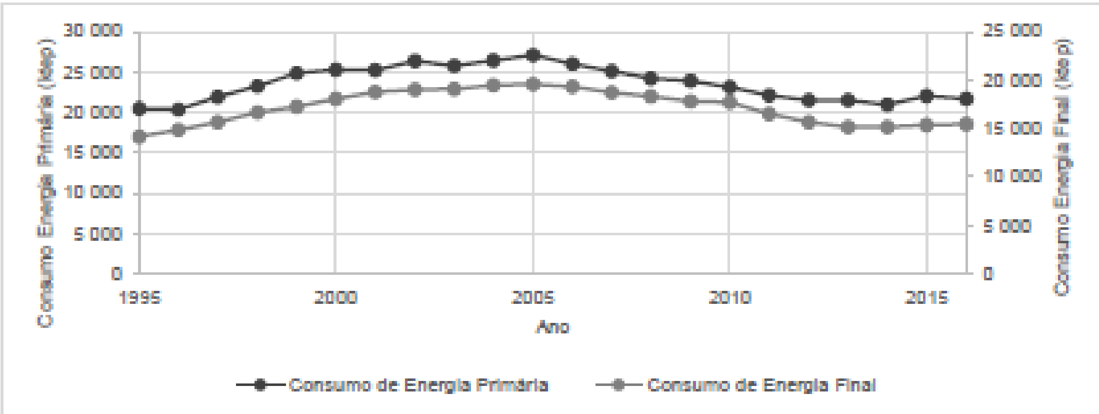

Figure I. 4 - Primary and final energy consumption recorded in Portugal, for the period between 1995 and 2016. Source: adapted from DGEG (2018b; 2018c).

B.

Annex II - LNEG

Table II. 1- LNEG tags for each building

Selected buildings	
Building name	**Tag**
LNEG - Campus Alfragide	Building #1
LNEG - Campus São Mamede de Infesta	Building #2
LNEG - Campus Aljustrel	Building #3

Table II. 2 - Reference Scenario of LNEG buildings

Selected buildings - reference scenario			
Building tag	**Energy consumption [kWh/year]**	**Primary energy consumption [kWh/year]**	**CO_2 emissions [t/year]**
Building #1	3548834	10080274	968
Building #2	191807	726529	69
Building #3	7414	49759	5
Total	**3748055**	**10856561**	**1042**

Table II. 3 - Renovation Scenario of LNEG buildings

Selected buildings - renovation scenario			
Building tag	**Energy consumption [kWh/year]**	**Primary energy consumption [kWh/year]**	**CO_2 emissions [t/year]**
Building #1	2607970	8721485	830
Building #2	289004	1093027	104
Building #3	26423	97282	9
Total	**2923398**	**9911794**	**994**

Table II. 4 - KPI's of LNEG buildings

Key Performance Indicators						
Building tag	**Thermal energy consumption [kWh/m²]**		**Electric energy consumption [kWh/m²]**		**Renewable energy percentage [%]**	
	Reference	**Renovation**	**Reference**	**Renovation**	**Reference**	**Renovation**
Building #1	19	0	26	0	0	0
Building #2	49	11	70	0	0	100
Building #3	22	20	61	0	0	100

Total for Selected Buildings

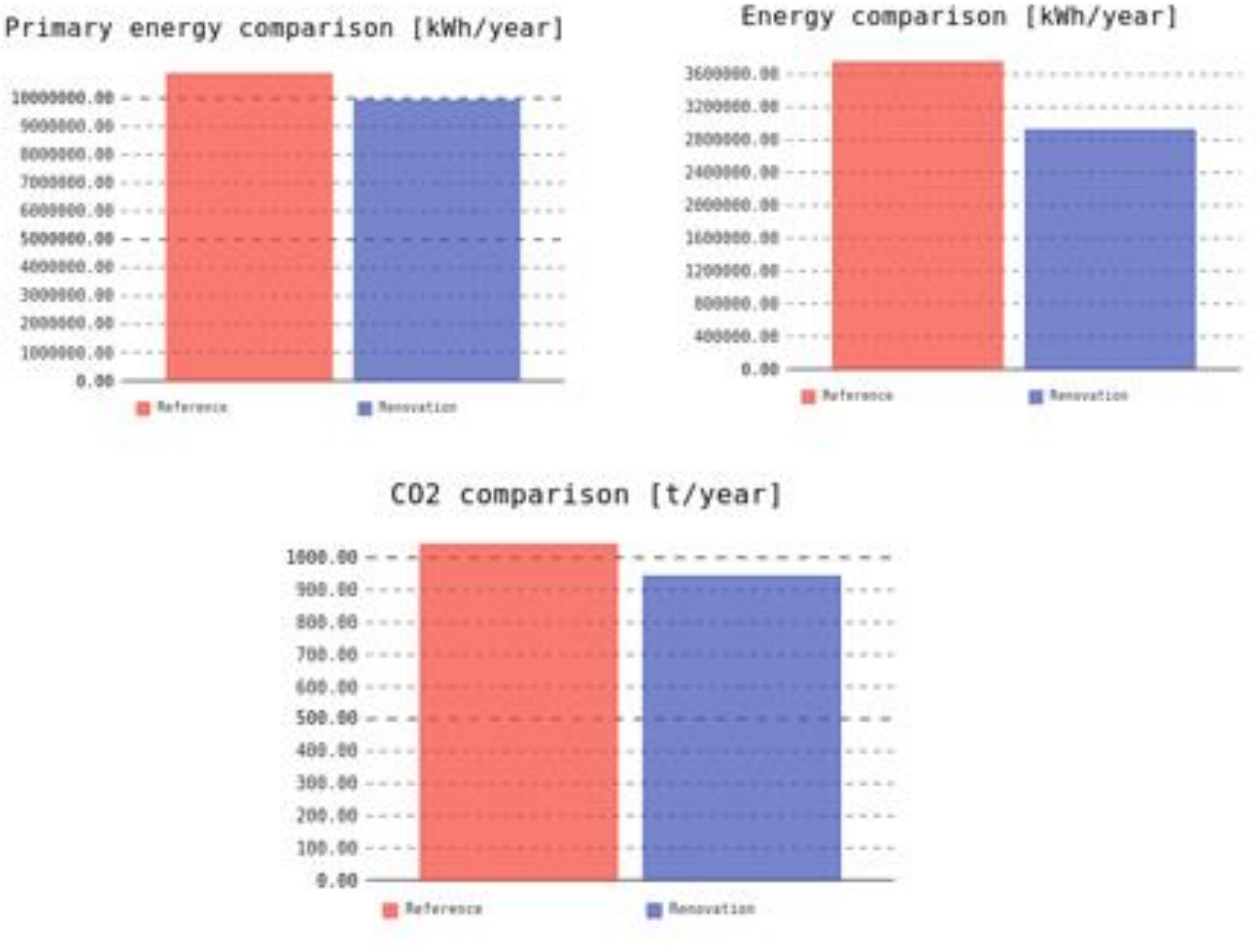

Figure II. 1 - Total comparison of the summation of energy, primary energy and CO_2, of the LNEG Buildings before and after the renovation.

Comparison of Buildings

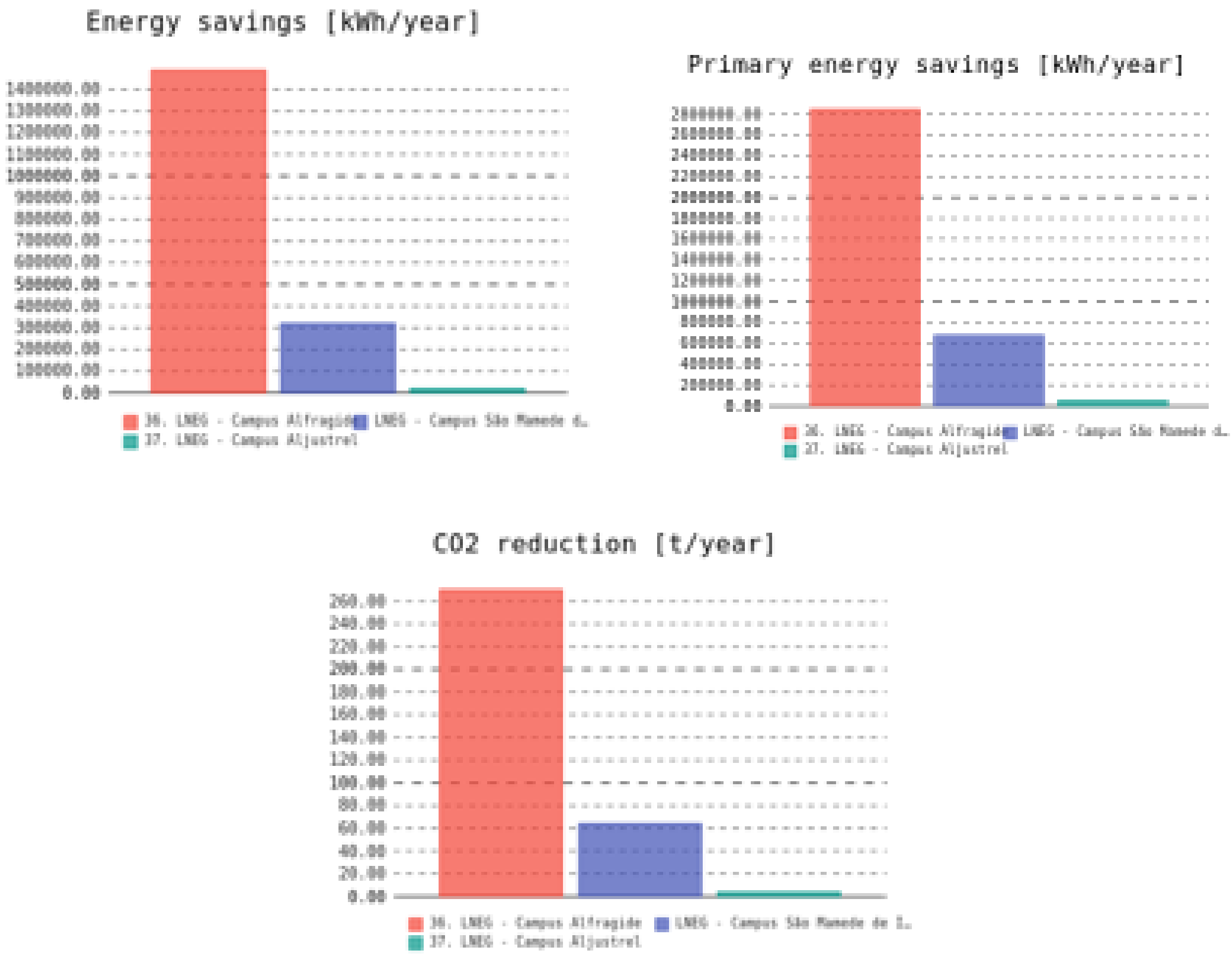

Figure II. 2 - Comparison of energy, primary energy and CO_2, of the LNEG Buildings.

C.

Annex III - Municipality of Arruda dos Vinhos

Table III. 1 - Arruda dos Vinhos tags for each building

Selected buildings	
Building name	**Tag**
Pousada da Juventude	Building #1
Biblioteca Municipal Arruda dos Vinhos	Building #2
Campo de Futebol Arruda dos Vinhos	Building #3
Centro de Investigação	Building #4
Câmara Municipal Arruda dos Vinhos	Building #5
Centro Escolar S. Tiago dos Velhos	Building #6
Loja do Cidadão - Arruda dos Vinhos	Building #7

Table III. 2 - Reference Scenario of Arruda dos Vinhos buildings

Selected buildings - reference scenario			
Building tag	**Energy consumption [kWh/year]**	**Primary energy consumption [kWh/year]**	**CO_2 emissions [t/year]**
Building #1	46159	256438	24
Building #2	22667	83342	8
Building #3	14290	35724	3
Building #4	3903	15522	1
Building #5	15156	37890	4

Building #6	7146	44699	4
Building #7	40331	111872	11
Total	**149652**	**585487**	**56**

Table III. 3 - Renovation Scenario of Arruda dos Vinhos buildings

Selected buildings - renovation scenario			
Building tag	**Energy consumption [kWh/year]**	**Primary energy consumption [kWh/year]**	**CO_2 emissions [t/year]**
Building #1	44881	323760	31
Building #2	20417	91055	9
Building #3	36399	90997	9
Building #4	12857	26695	3
Building #5	39378	98444	9
Building #6	9502	64007	6
Building #7	30227	92133	9
Total	**193660**	**787091**	**75**

Table III. 4 - KPI's of the Arruda dos Vinhos buildings

Key Performance Indicators						
Building tag	**Thermal energy consumption [kWh/m²]**		**Electric energy consumption [kWh/m²]**		**Renewable energy percentage [%]**	
	Reference	**Renovation**	**Reference**	**Renovation**	**Reference**	**Renovation**
Building #1	36	0	117	44	0	71
Building #2	22	3	78	57	0	5
Building #3	42	14	120	16	0	100
Building #4	30	19	63	6	0	100
Building #5	22	8	47	0	0	100
Building #6	10	3	60	42	7	22
Building #7	19	9	57	22	0	11

Total for selected Buildings

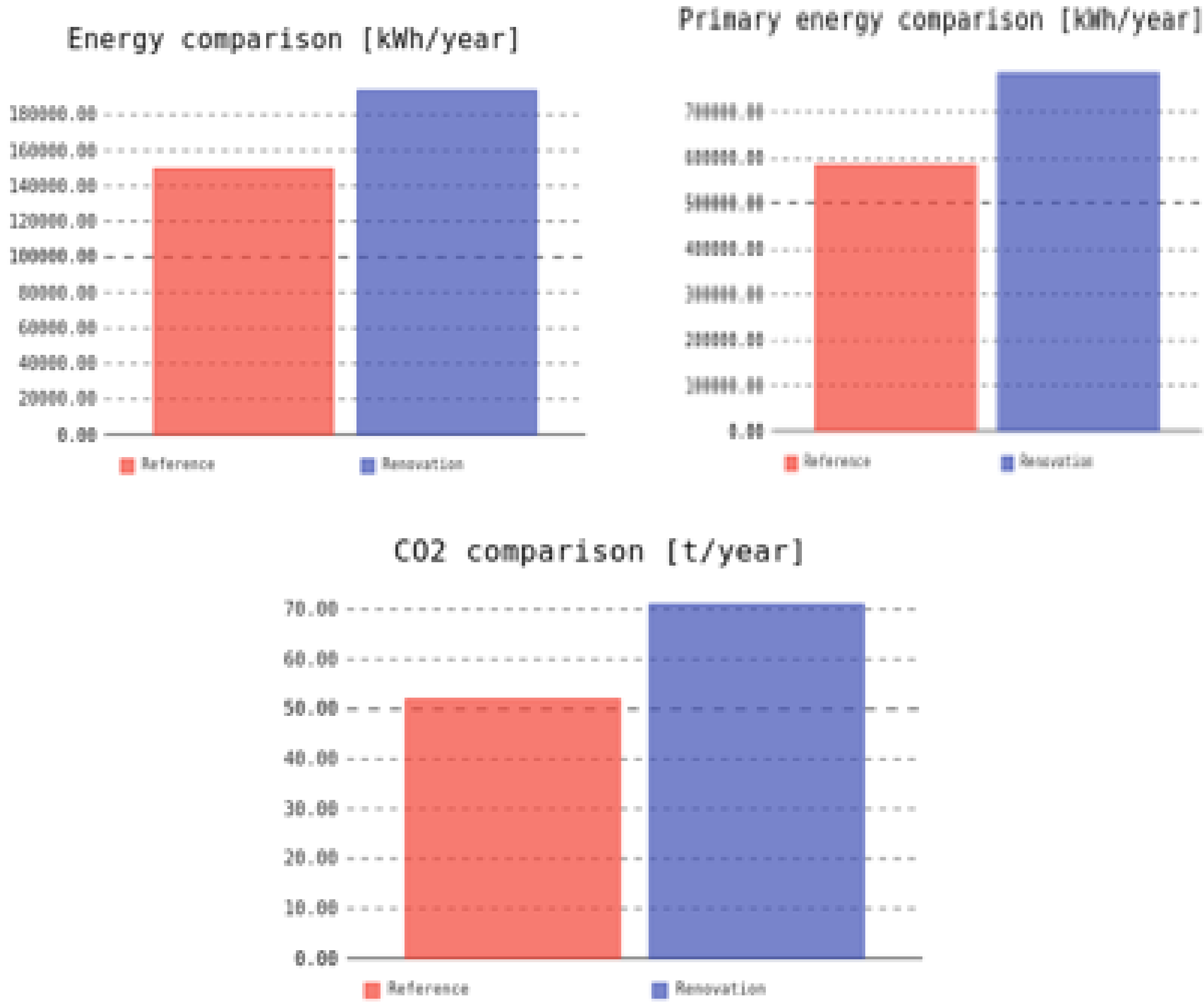

Figure III. 1 - Total comparison of the summation of energy, primary energy and CO2, of the Arruda dos Vinhos Buildings before and after the renovation.

Comparison of Buildings

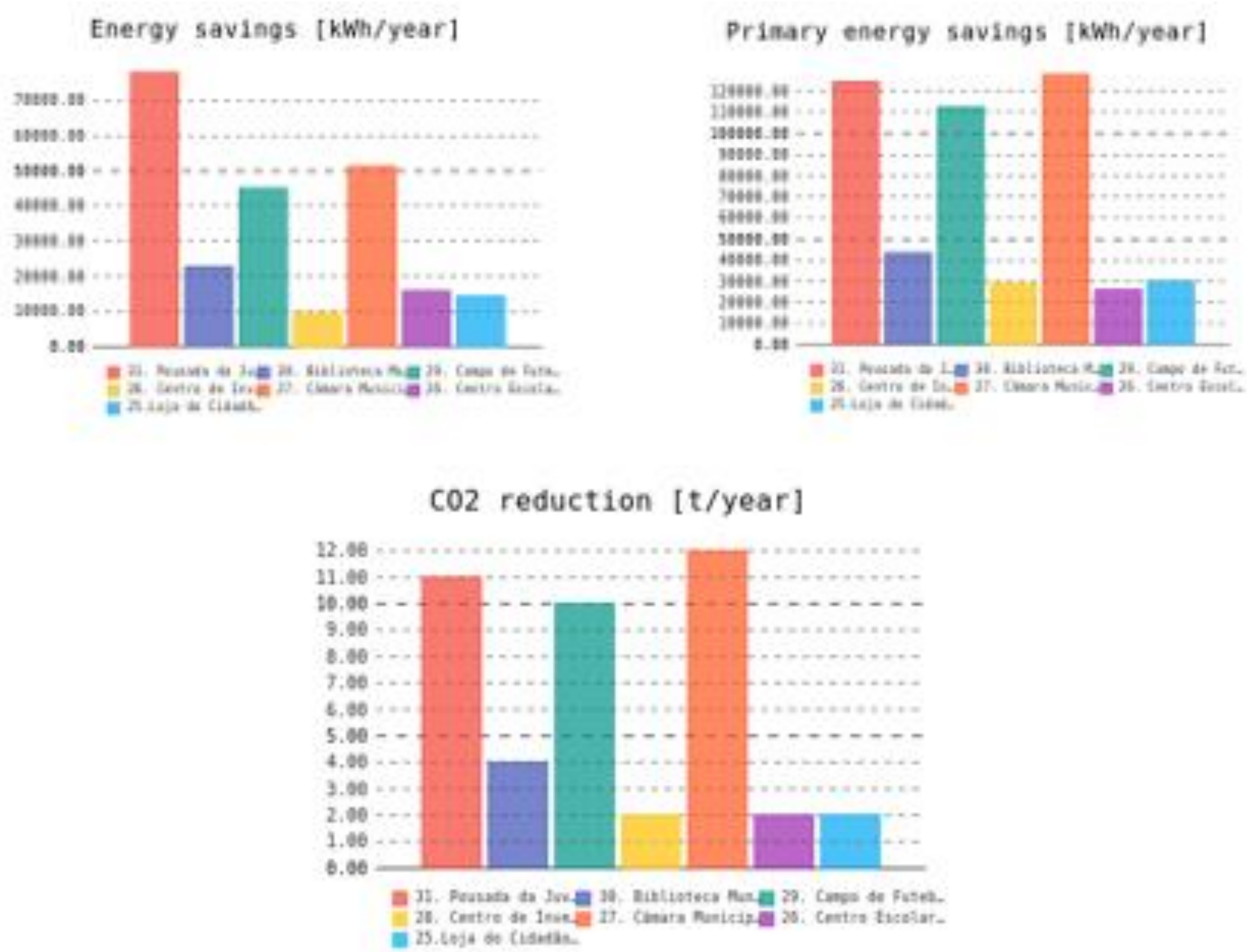

Figure III. 2 - Comparison of energy, primary energy and CO_2, of the Arruda dos Vinhos Buildings.

D.

Annex IV - AREANATejo - Regional Agency for Energy and Environment of North Alentejo and Tagus

Table IV. 1 - AREANATejo tags for each building

Selected buildings	
Building name	**Tag**
Hangar 6. Aerodromo	Building #1
Piscina Municipal de Ponte de Sor	Building #2
Estádio Municipal Ponte de Sor	Building #3
Campus Aeronáutico Ponte de Sor	Building #4
Paços do Concelho de Sousel	Building #5
Jardim Casa Branca	Building #6
Complexo Desportivo Sousel	Building #7
Biblioteca de Sousel	Building #8
Centro Cultural de Arronches	Building #9
Piscinas Municipais Arronches	Building #10
Câmara Municipal Arronches	Building #11
Estádio Municipal de Arronches	Building #12

Table IV. 2 - Reference Scenario of AREANATejo buildings

Selected buildings - reference scenario			
Building tag	**Energy consumption [kWh/year]**	**Primary energy consumption [kWh/year]**	**CO_2 emissions [t/year]**
Building #1	22652	56631	5
Building #2	3004670	11731507	1313
Building #3	39182	213356	20
Building #4	419989	3005994	286
Building #5	11438	77384	7
Building #6	7033	13613	2
Building #7	285362	709268	113
Building #8	56625	332845	32
Building #9	20365	102717	10
Building #10	112047	106837	31
Building #11	4	17	0
Building #12	4513	14802	1
Total	**3983880**	**16364971**	**1821**

Table IV. 3 - Renovation Scenario of AREANATejo buildings

Selected buildings - renovation scenario			
Building tag	**Energy consumption [kWh/year]**	**Primary energy consumption [kWh/year]**	**CO_2 emissions [t/year]**
Building #1	28694	71735	7
Building #2	378397	13419377	1292
Building #3	83415	381638	36
Building #4	194714	3420817	326
Building #5	22115	128472	12
Building #6	8909	27234	3
Building #7	227781	1560525	150

Building #8	91500	443942	42
Building #9	82984	285167	27
Building #10	42925	181706	19
Building #11	2	14	0
Building #12	31032	81100	8
Total	**1192469**	**20001728**	**1923**

Table IV. 4 - KPI's of the AREANATejo buildings

Key Performance Indicators						
Building tag	**Thermal energy consumption [kWh/m²]**		**Electric energy consumption [kWh/m²]**		**Renewable energy percentage [%]**	
	Reference	**Renovation**	**Reference**	**Renovation**	**Reference**	**Renovation**
Building #1	25	16	481	469	0	1
Building #2	468	0	409	332	0	23
Building #3	57	20	163	61	0	81
Building #4	50	0	68	0	23	0
Building #5	13	0	85	60	0	17
Building #6	24	0	43	3	0	100
Building #7	61	0	39	0	100	0
Building #8	54	10	98	0	0	0
Building #9	6	26	26	17	0	31
Building #10	86	1	1	0	100	0
Building #11	0	0	0	0	0	0
Building #12	3	1	10	0	0	0

Total for selected Buildings

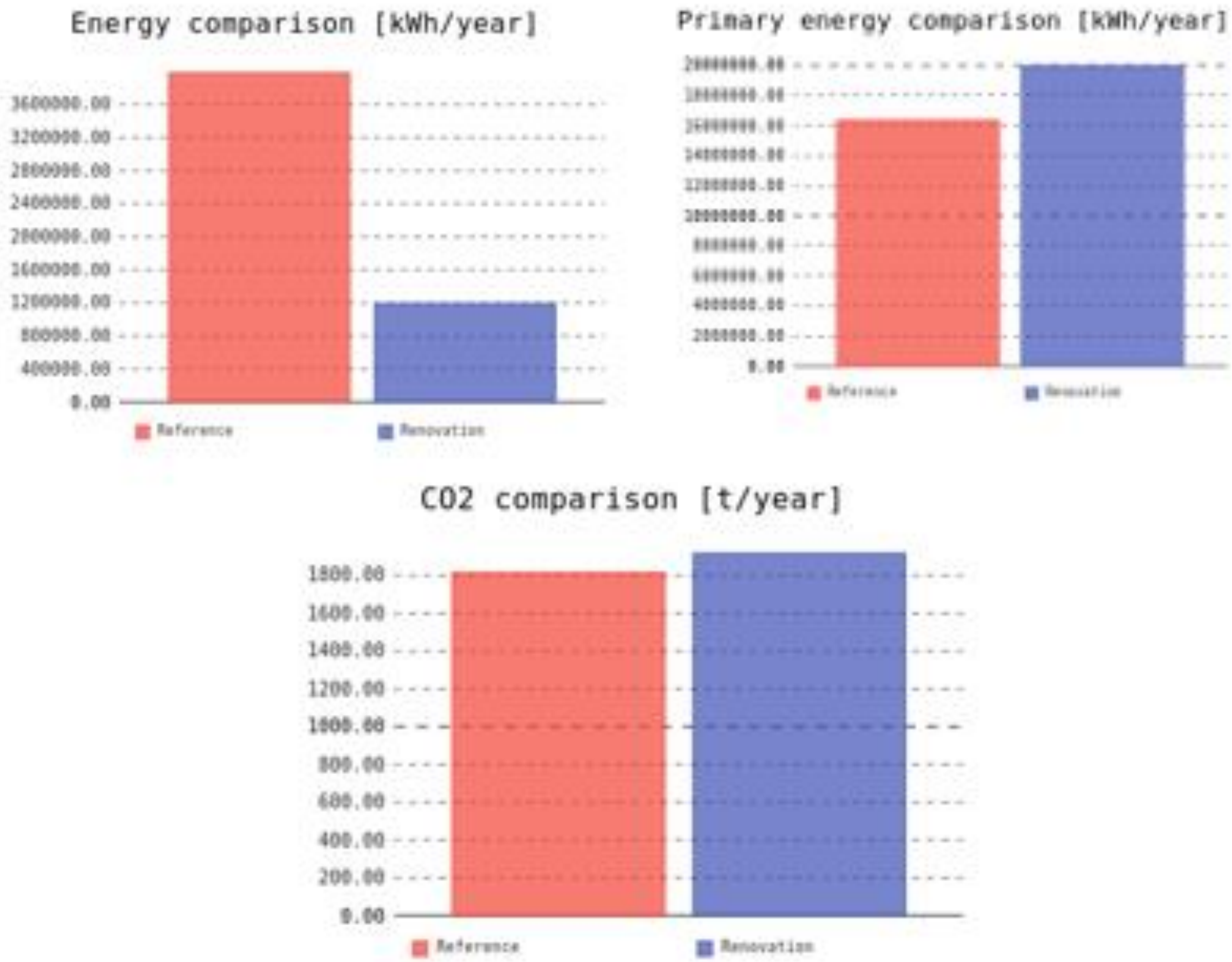

Figure IV. 1 - Total comparison of the summation of energy, primary energy and CO_2, of the AREANATejo Buildings before and after the renovation.

Comparison of Buildings

Figure IV. 2 - Comparison of energy, primary energy and CO_2, of the AREANATejo Buildings

E.

Annex V - EC Data Input

In the first stage, when the user selects the option to create a new building it is requested to choose the region where the building is located (Figure V.1). Since we are placing the data referring to the Citizen's Shop of Arruda dos Vinhos, we selected “Arruda dos Vinhos”.

Considering that a Portuguese building is being studied, the respective example of an Energy Certificate shown here is in Portuguese.

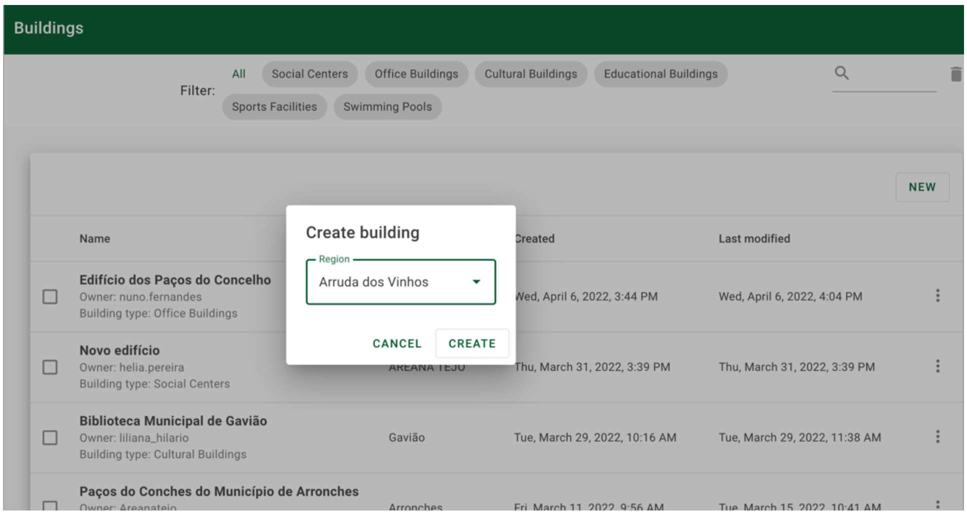

Figure V.1 - Selection of the region where the building is located. Source: DST Data Tool.

After this, the user is redirected to the page “BASIC INPUT”. Here, the user is asked for basic data regarding location, building typology, and energy data, among others. It is on the first page of the certificate that we can find the data relating to its location. The figures below – Figure V.2 and Figure V.3 - represent, respectively, the data that are requested in the tool as well as an excerpt from the first page of the certificate where we can find this information.

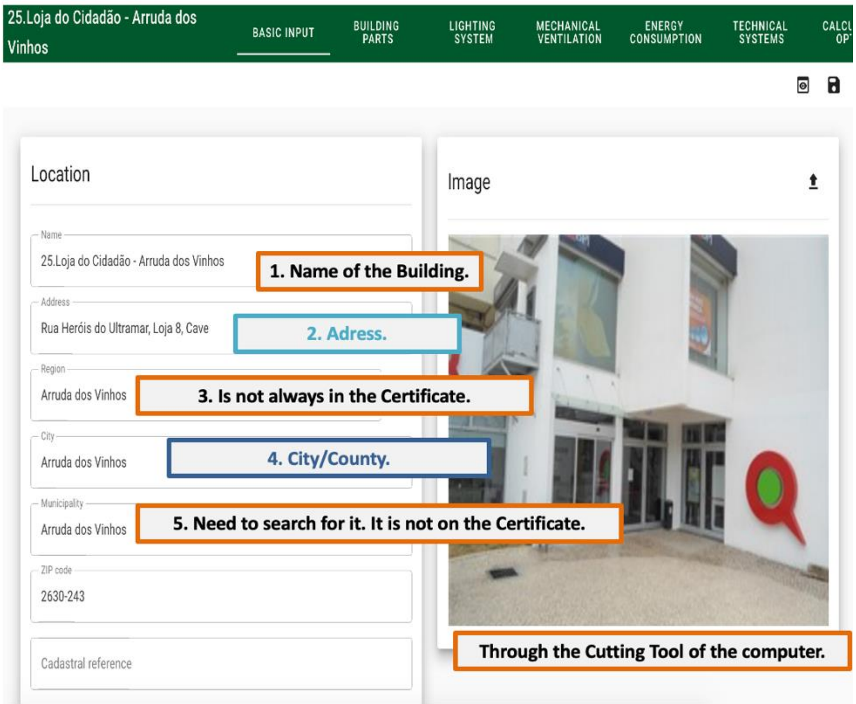

Figure V. 2 - Data related to building location. Source: DST Data Tool.

Figure V.3 - First page of certificate. Source: DST Data Tool.

Then, the user is presented with a world map, to locate where the building is located. This function is not automatically found, so the user must place the cursor over the appropriate place, as shown in Figure V.4.

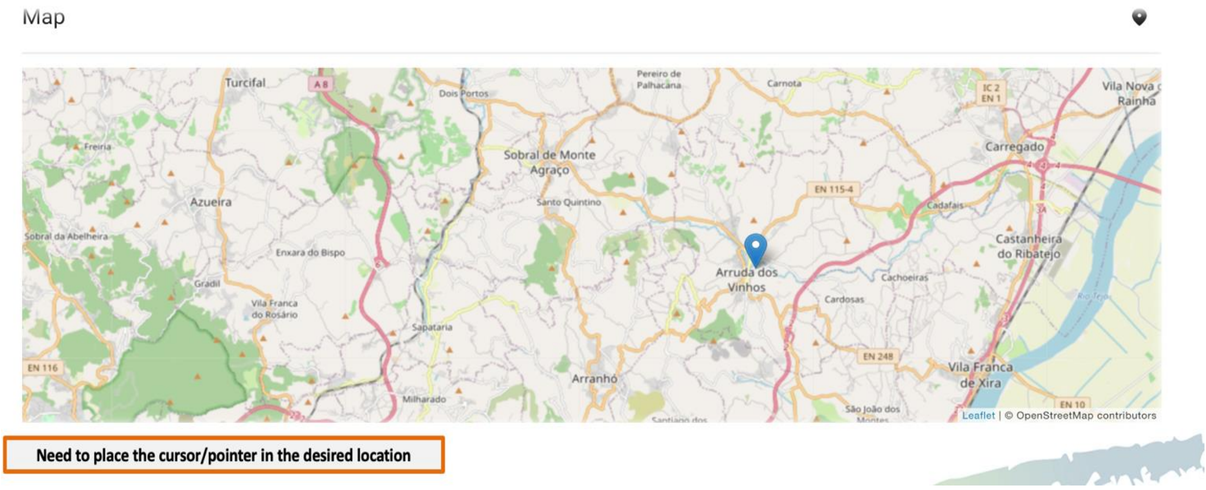

Figure V. 4 - World map to locate de building. Source: DST Data Tool.

Still within the Basic Input, as shown in Figure V.6. We are asked for some technical information about the building. This information is found on pages 1 and 2 in the attached EC in the Annex VI.

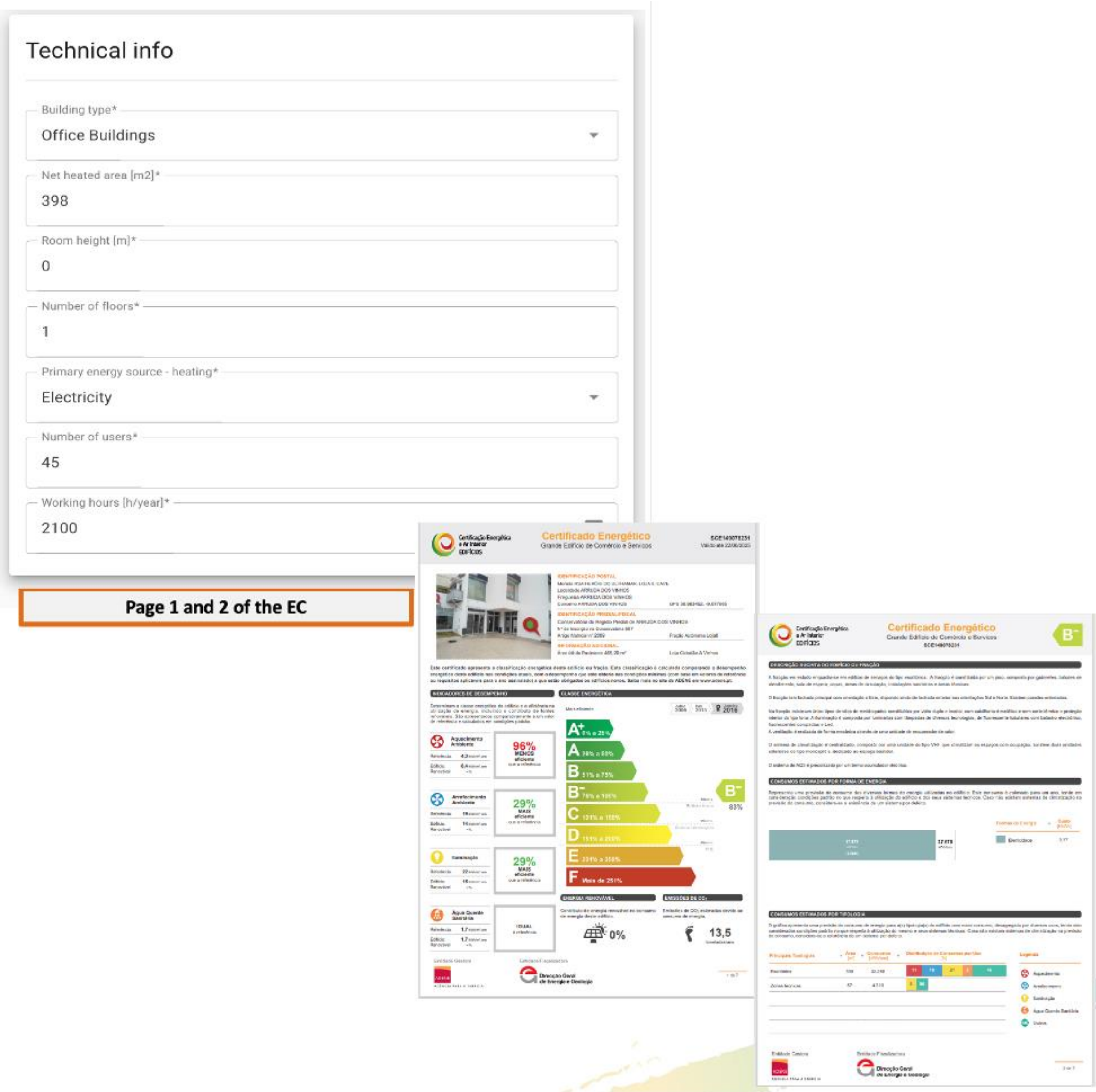

Figure V. 5 - Technical information about the building. Source: DST Data Tool.

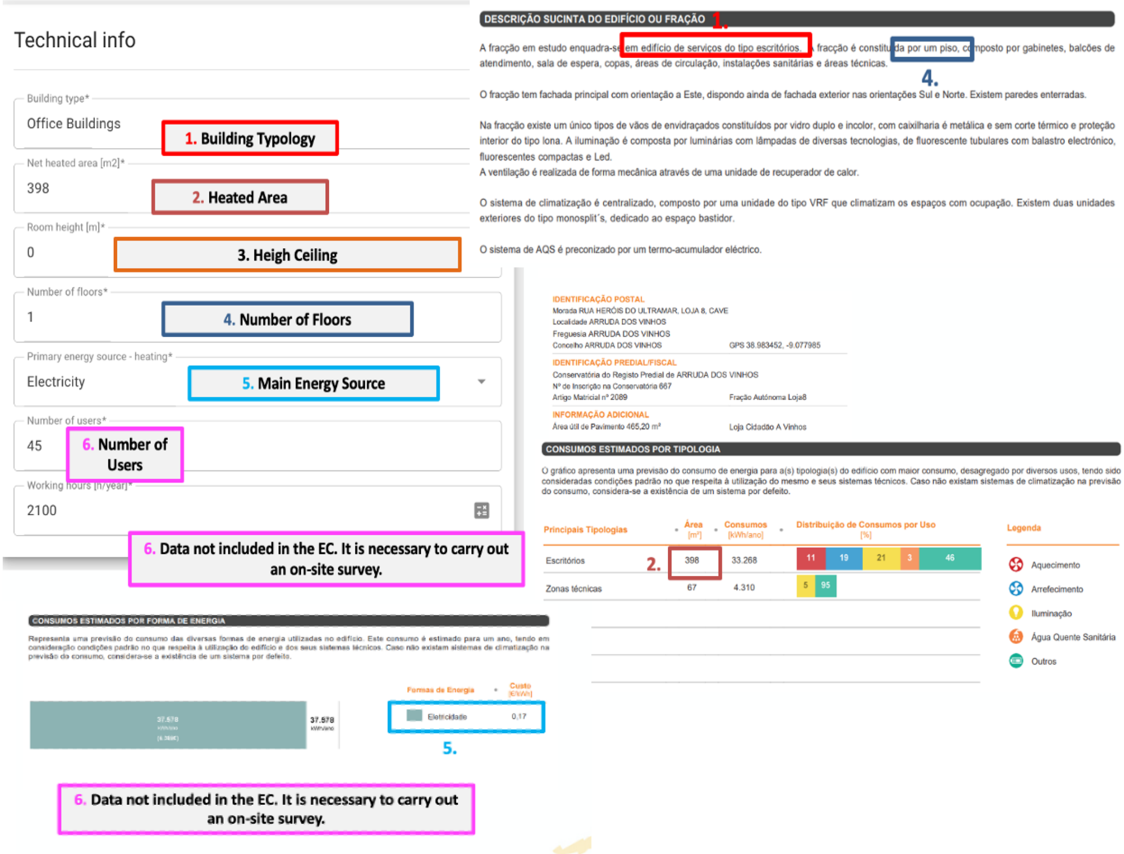

Figure V. 6 - Information extraction diagram. Source: DST Data Tool.

In the next box, the user must fill in the fields relating to the date of the energy certificate (which day it was issued), the energy class of the building, and the CO_2 emissions caused by the building. These data can be found on pages 1 and 2 of the Energy Certificate, as shown in Figure V.7.

Figure V.8 represents the scheme from which the important data for filling in these fields are taken.

It is important to note a detail when the user is filling in the field of the date of issue of the Energy certificate. Energy certificates only show the expiry date of the same, so we do not have information regarding the date of issue. However, we know that the validity period, according to the Energy Certification System (SCE), is 10 years for Small Commercial and Service Buildings. As such, from the certificate's expiration date, we need to subtract 10 years to fill in this field.

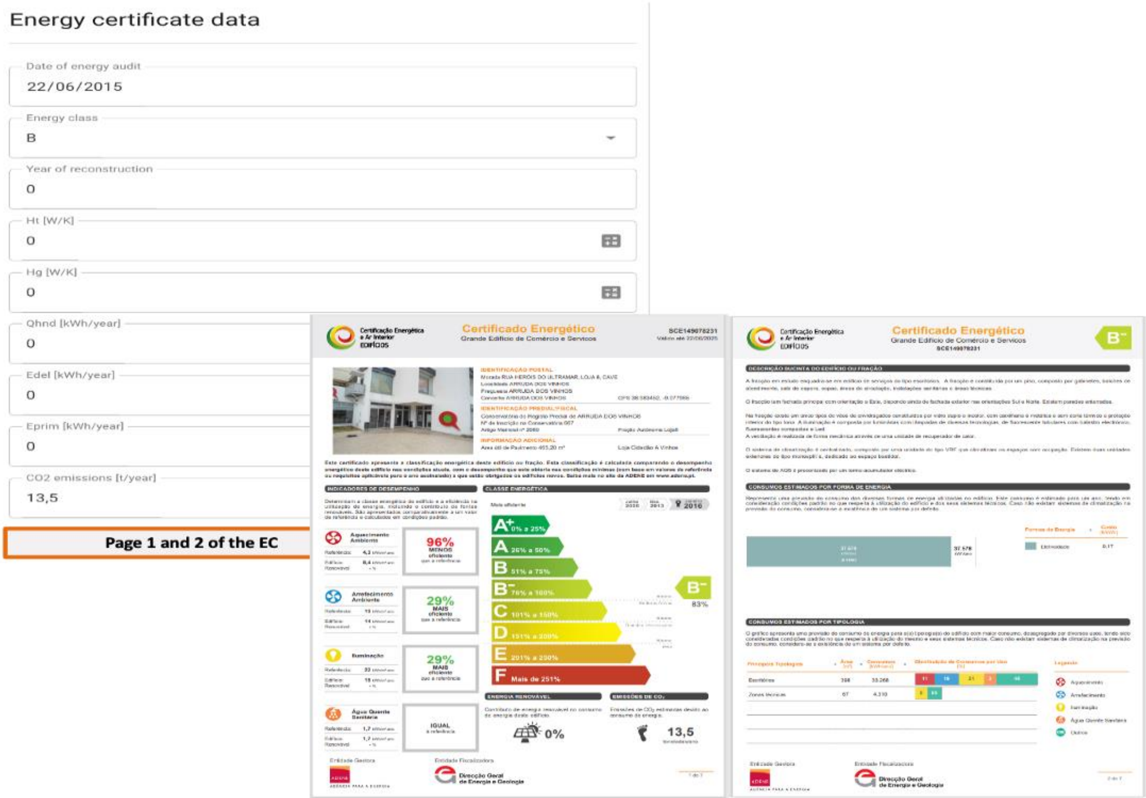

Figure V. 7 - Pages 1 and 2 of the Energy Certificate. Source: DST Data Tool.

In the section on “Other Data”, it is requested a brief description of the building; a brief summary of which equipment and air conditioning systems exists in the building; whether it is a heritage building or not; and the name of the building owner.

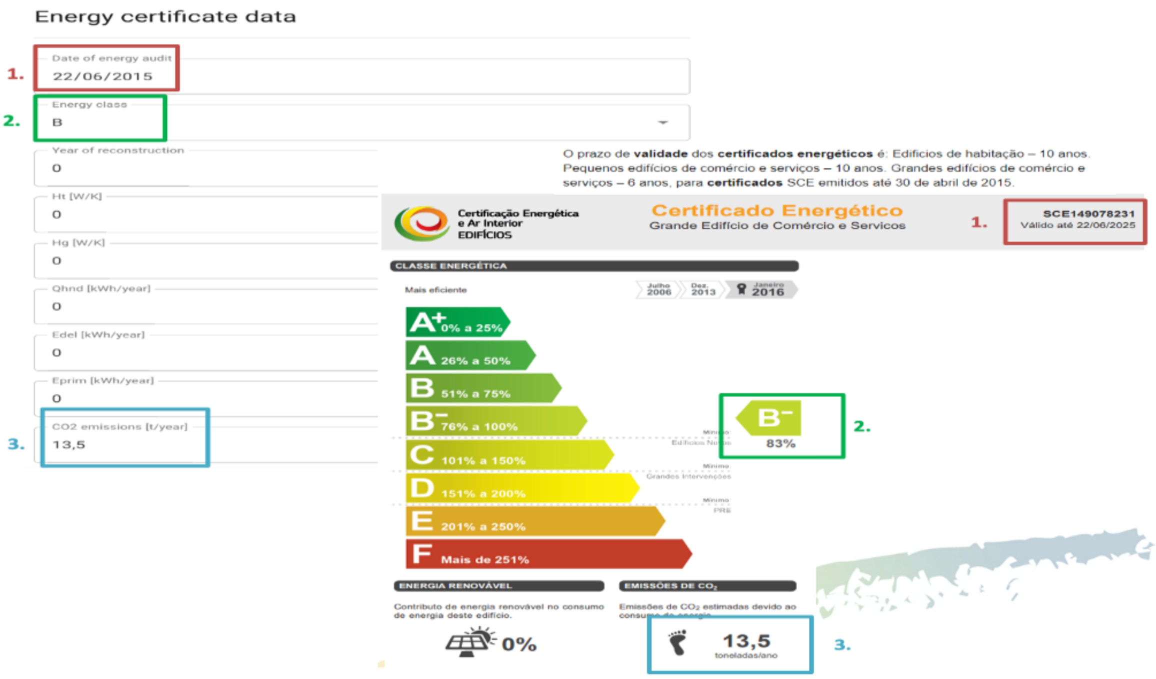

Figure V. 8 - Important data extraction scheme. Source: DST Data Tool.

And the year of construction (Figure V.9). All this information, except for the year of construction of the building, can be found on the second page of the EC.

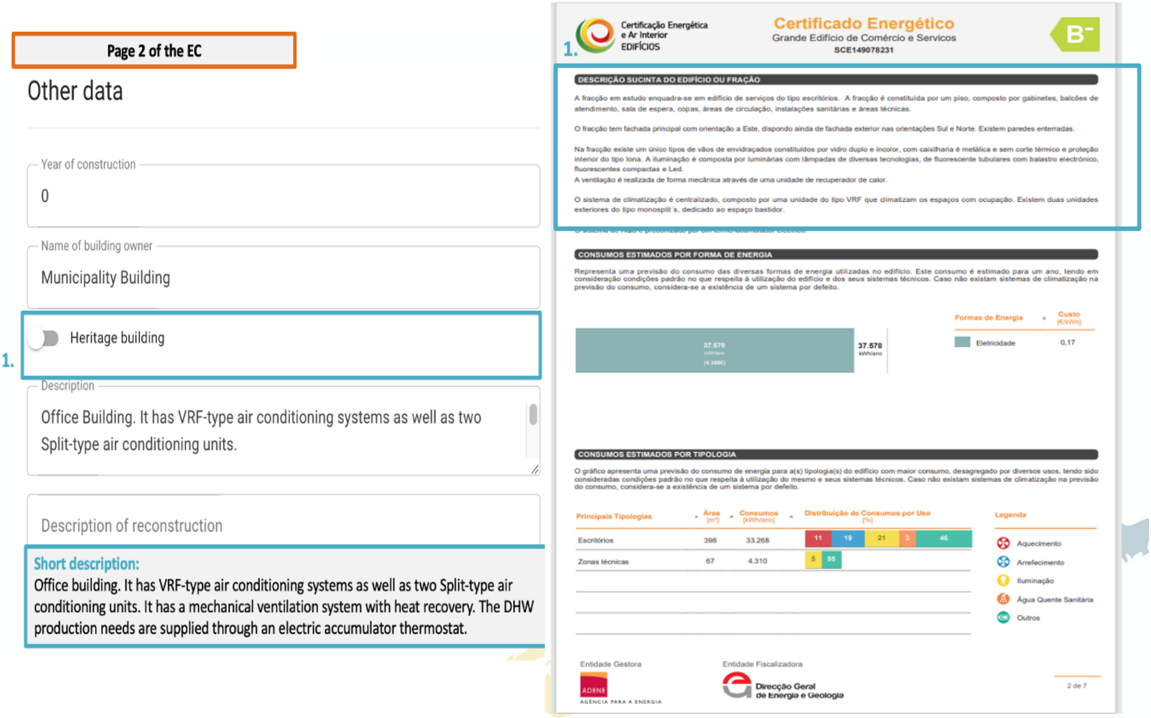

Figure V. 9 - Introduction of other relevant data. Source: DST Data Tool.

After filling in the section of “Basic Input”, the tool will request the user to start to fulfill the characteristics of the “Building Parts”. This section is divided into four groups: the characteristics of the “External Walls”, of the “Windows”, of the “Roof” and of the “Floors”. We begin by presenting the procedures for the wall data (Figure V.10).

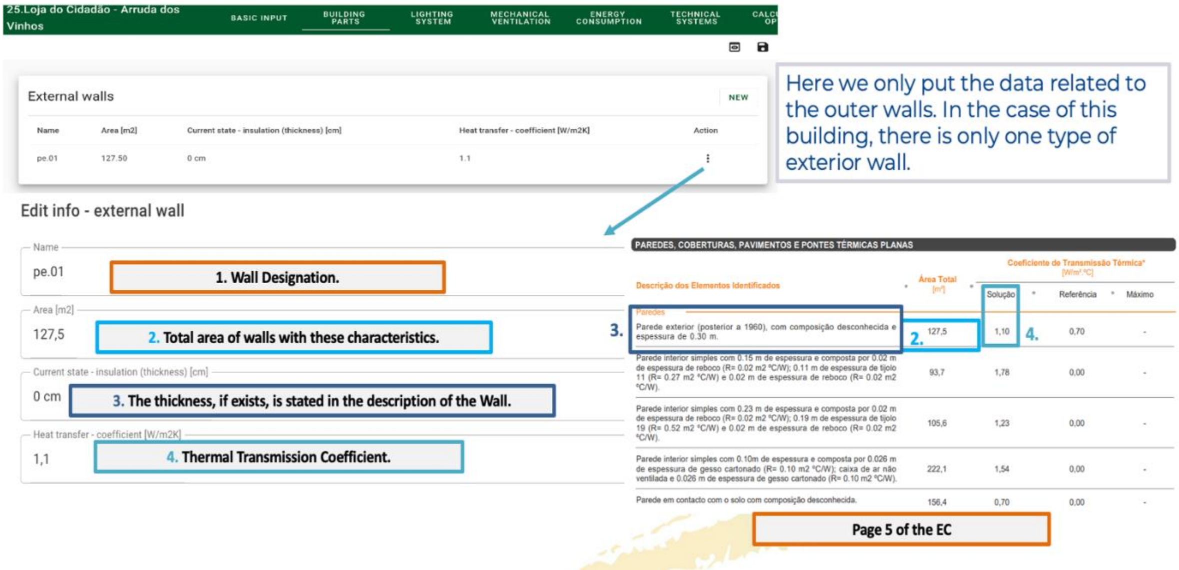

Figure V. 10 - Procedures for wall data. Source: DST Tool Data.

In the “External Walls” part, the user must add all the different types of exterior walls that the building includes, and each type of wall varies depending on its thickness and materials. For each external wall, the wall designation is requested, the value of the area that satisfies all the walls of that type, as well as the value of the insulation thickness of the walls. The information about the external walls can be found on the fifth page of the EC.

The following procedures are for the windows data input (Figure V.11).

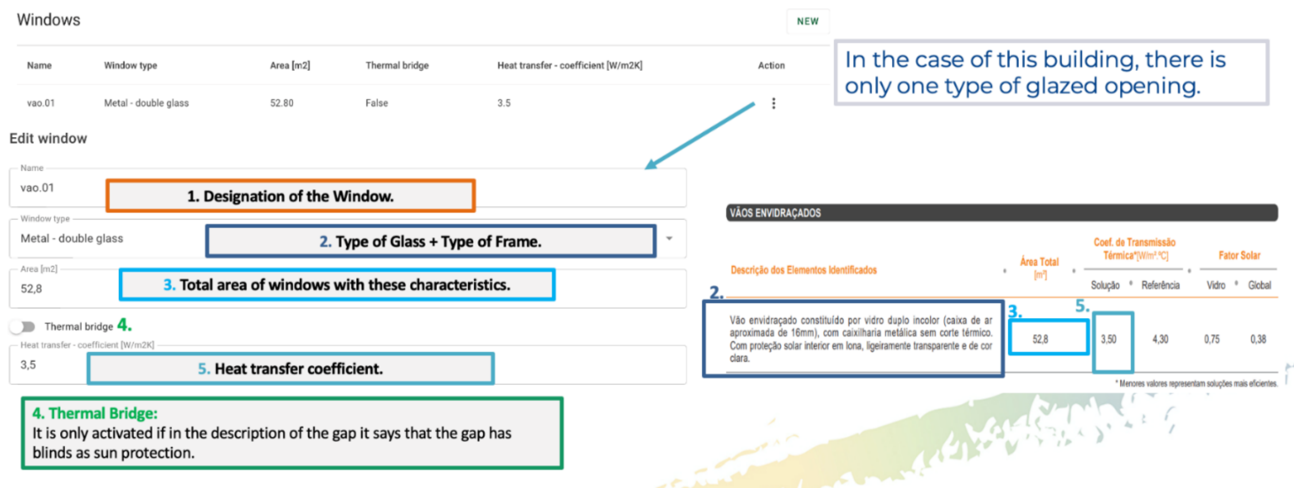

Figure V. 11- Procedures for windows data. Source: DST Tool Data.

As for Exterior Windows field, once again it will be asked for the name to be given to the type of windows. The user is also asked to choose from a list, that already exists by default, the constitution of this type of windows and to identify which is the heat transfer coefficient. This information, for this case study, can be found on page 6 of the EC. Note that the Thermal Bridge is only activated when in the text of the window description it is mentioned that it has sun protection, as is the case of blinds.

The next part is dedicated to the roofs of the building (Figure V.12). After the user fulfil the name of the type of roof, once more it will be requested to choose the roof type, by a list that already exists by default. Also, the total area of the roof is requested, as the thickness of the insulation and the heat transfer coefficient. For this case, the information can be found on the page 5 of the EC.

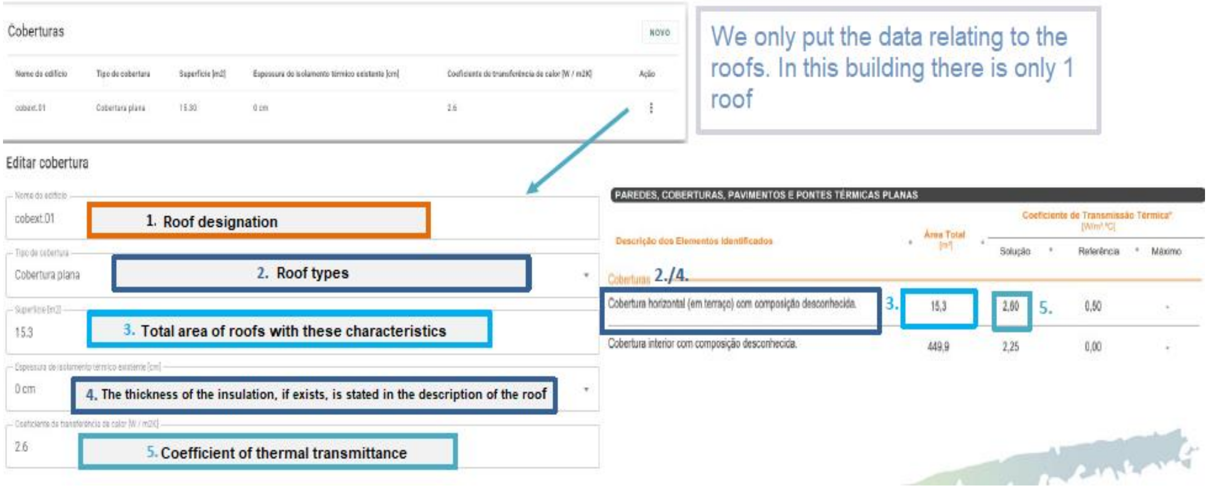

Figure V. 12 - Procedures for roof data. Source: DST Tool Data.

The last requirement to be filled in Building Parts is the information about the different floor types (Figure V.13). In this part the data concerning the interior floors that correspond to floors are placed. The surface area, the thickness of the existing thermal insulation and the heat transfer coefficient are identified.

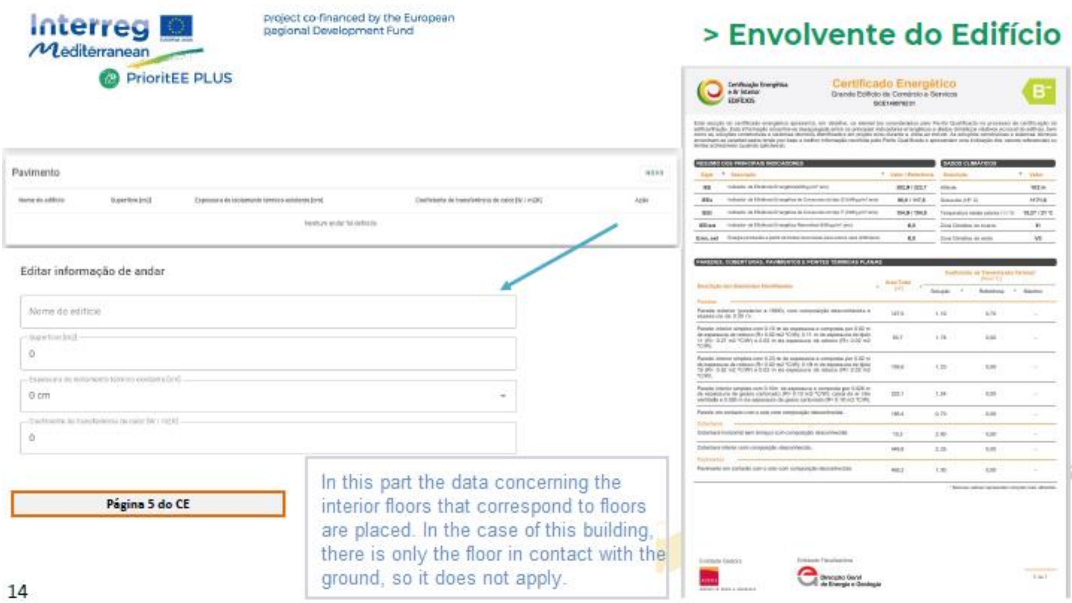

Figure V. 13 - Procedures for floors data. Source: DST Tool Data.

Page 6 of the EC contains the data relative to the lighting systems, where a detailed description of the existing lighting systems in the building in question is made through the input of its main characteristics such as the type of lamp, power, and number of lamps of the same type (Figure V.14).

Figure V. 14 - Procedures for lighting systems data. Source: DST Tool Data.

The page for inserting data regarding the ventilation of the buildings is on page 7 of the EC. This page refers to the existence, or not, of a ventilation system with heat recovery, as well as the description of the identified elements. The Figure V.15 shows the layout of page 7 of the EC.

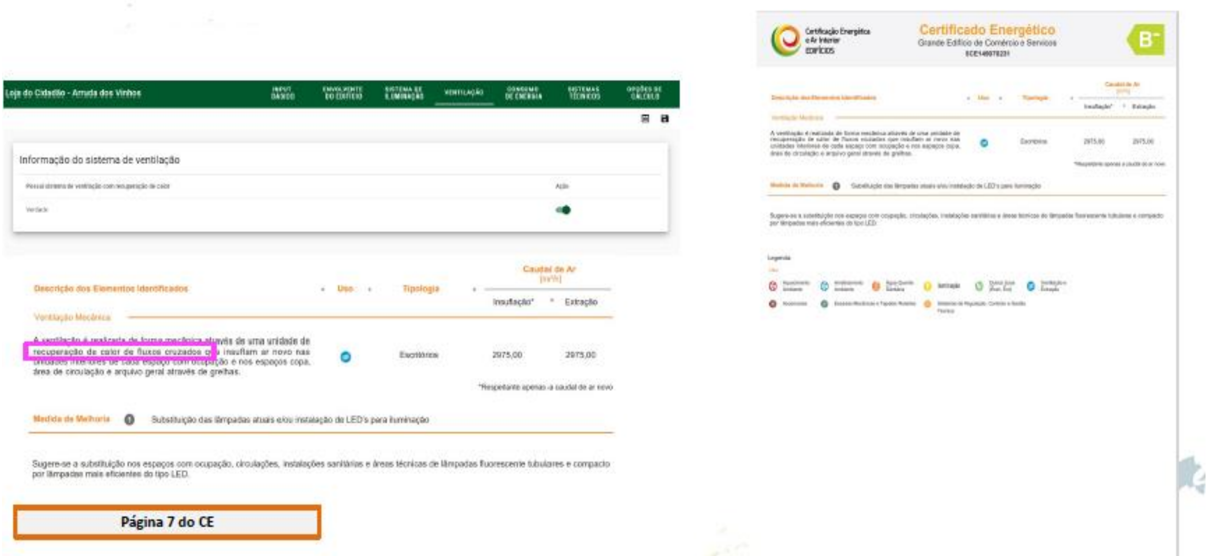

Figure V. 15 - Procedures for ventilation systems data. Source: DST Tool Data.

After entering all the data concerning the characteristics of the building, from its floors, walls, roofs, lighting and ventilation systems, the energy consumption is calculated. The Figure V.16 shows the main layout of the energy consumption calculation section. In the Figure V.17, we can see in detail the energy consumption calculation referring to the space heating system.

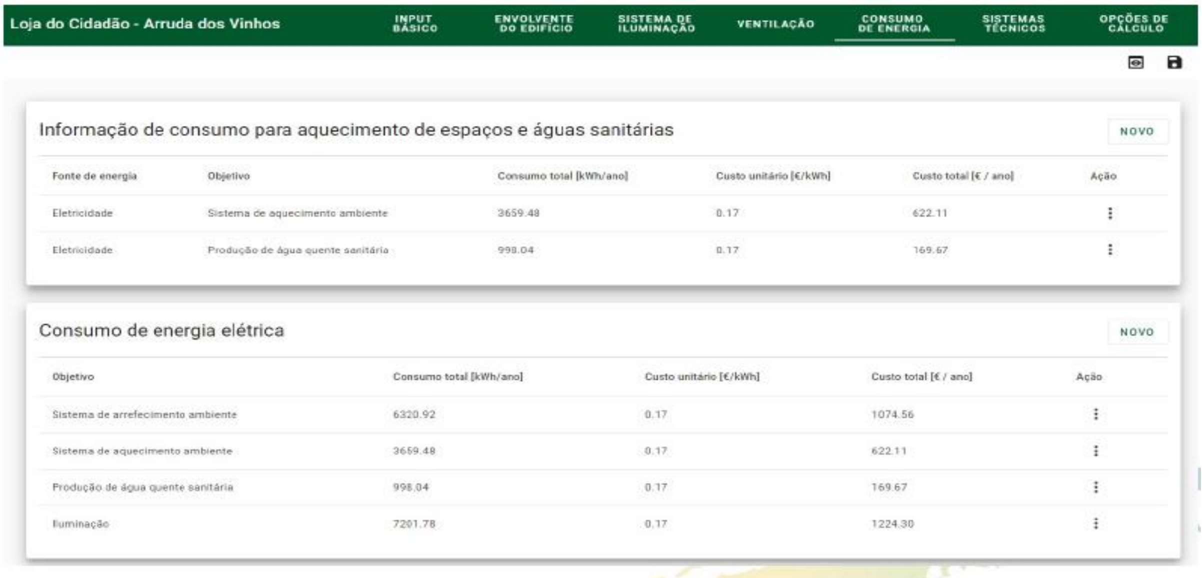

Figure V. 17 - Energy consumption calculation section. Source: DST Tool Data.

Figure V. 16 - Energy consumption calculation referring to the space heating system Source: DST Tool Data.

This process will be repeated for the electricity consumption corresponding to a space cooling system, domestic hot water production and lighting. Finally, it is also possible to describe the technical systems responsible for the heating and cooling systems, where a detailed description of all the identified elements is made (Figure V.18 and Figure V.19).

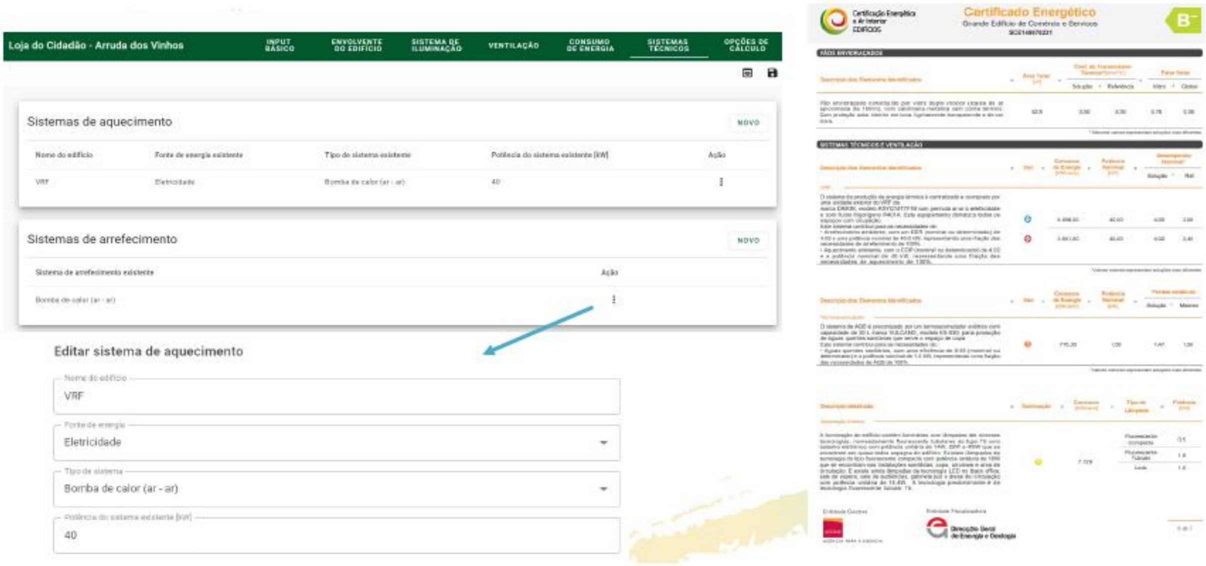

Figure V. 19 - Technical systems description. Source: DST Tool Data.

Figure V. 18 - Technical systems description - Heating system. Source: DST Tool Data.

2023

RAQUEL OURIVES DA SILVA

TESTING THE USE OF THE PRIORITEE DECISION SUP-PORT TOOL IN PORTUGAL TOWARDS DESCARBONISED PUBLIC BUILDINGS

NOVA SCHOOL OF SCIENCE & TECHNOLOGY