Universidade do Minho
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Bruna Oliveira Onety

Cost-effectiveness and resilience of energy renovation interventions with the nZEB objective in a social housing neighbourhood in Braga, Portugal

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Master's Dissertation
Master in Sustainable Construction and Rehabilitation

Work developed under the supervision of
Professor Doctor Manuela Almeida

February 2022

Direitos de Autor e Condições de Utilização do Trabalho por Terceiros

ACKNOWLEDGMENTS

A professora Manuela Almeida, pela orientação, e ao Ricardo Barbosa que me auxiliou durante parte da realização dessa dissertação.

A minha família pelo apoio incondicional de sempre, mesmo de longe.

Aos meus amigos, por estarem sempre presentes, fisicamente ou não.

A Joel Vaz, pelo suporte, principalmente na reta final dessa jornada.

STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.

I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

Resumo

Os edifícios com necessidades quase nulas de energia (nZEBs) surgem como uma das medidas apontadas pela EU para redução do consumo energético e das emissões dos gases de efeito estufa nos edifícios. Tendo em vista que grande parte do edificado português não cumpre as atuais exigências da regulamentação térmica e é normalmente caracterizada por elevadas necessidades energéticas, surge a necessidade de renová-lo para níveis de desempenho energético superiores, de modo que consumam menos energia e ao mesmo tempo garantam as condições mínimas de conforto aos utentes. Considerando os pilares da sustentabilidade, faz-se necessário incluir nessa análise para alem dos âmbitos social e ambiental, o aspeto económico, sendo esse um ponto ainda mais delicado para populações mais carentes. Para isso, esse estudo utilizou a metodologia de custo-ótimo para análise da rentabilidade das propostas de reabilitação energética para um bairro social em Braga, norte de Portugal. Foram estudadas soluções típicas utilizadas no país, englobando medidas passivas, sistemas técnicos e a utilização de energias renováveis, sendo esse último essencial para obtenção dos níveis nZEB, para alem do custo-ótimo objetivado. A combinação entre as medidas de reabilitação foi capaz de atingir redução de até 95 % em termos de energia primária, comparado ao cenário de referência.

A simulação dinâmica foi o método de quantificação energética utilizada para o estudo, e foi feita utilizando o EnergyPlus através da interface gráfica do DesignBuilder. Esse método utiliza ficheiros climáticos que são normalmente gerados com base nos dados obtidos das estacões meteorológicas de cada região. Porém, considerando as projeções de alterações climáticas e o aumento da temperatura global previsto, surge a expectativa de que o comportamento térmico dos edifícios sofra alterações, alertando para a necessidade de análise da resiliência das soluções de renovação energética propostas. A fim de ponderar essas alterações, o estudo recorreu a ficheiros climáticos futuros para 2020 e 2050, convertidos através da ferramenta CCWorldWeatherGen que considera o cenário A2 de emissões. Após adaptação da metodologia convencional, os resultados apresentaram novo gráfico de custo-ótimo com comportamento similar ao primeiro, com redução de até 94% em termos de energia primária para as propostas de reabilitação testadas, em relação ao cenário de referência, apresentando, porém, maiores custos globais proporcionais em relação ao mesmo.

Palavras-Chave

Alterações climáticas, custo-ótimo, nZEB, reabilitação energética, simulação energética

ABSTRACT

Nearly zero-energy buildings (nZEBs) appear as one of the measures identified by the European Union to reduce energy consumption in buildings and emissions of greenhouse gases. Considering that a large part of the Portuguese building stock was built decades ago, and the current thermal regulation is not met, these buildings are usually characterized by poor thermal performance and high energy consumption needs. Thus, there is a need to replace renovate them to present a better thermal performance, by consuming less energy and at the same time guaranteeing the minimum comfort conditions for users, in a sustainable way. Considering the pillars of sustainability, it is necessary to include in this analysis, in addition to the social and environmental spheres, the economic aspect, which is an even more delicate point in the case of populations with less financial conditions. For that, this study will use the cost-optimal methodology to define the best proposal for energy renovation for a social neighbourhood located in Braga, northern Portugal. Typical solutions used in the country will be studied, encompassing not only passive measures but also technical systems and the use of renewable energies, the latter being essential for obtaining nZEB levels, in addition to the objective optimal cost. The combination of rehabilitation measures was able to achieve a reduction of up to 95% in terms of primary energy, compared to the reference scenario.

A dynamic energy simulation will be the method of energy quantification used for the study and will be done using EnergyPlus through DesignBuilder's graphical interface. This method uses weather files that are normally generated based on data obtained from meteorological stations in each region. However, considering the projections of climate change and the predicted increase in global temperature, there is an expectation that the thermal behavior of buildings will change, warning about the need to analyse the robustness and resilience of the proposed energy renovation solutions. To consider these changes, the study will use future climate files for 2020 and 2050, converted through the CCWorldWeatherGen tool that considers the A2 emissions scenario. After adapting the conventional methodology, the results showed a new cost-optimal graph with similar behavior to the first one, with a reduction of up to 94% in terms of primary energy for the tested renovation proposals, concerning the reference scenario, presenting, however, higher proportional global costs.

KEYWORDS

Climate change, cost-optimal, energy renovation, energy simulation, nZEB.

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List of Abbreviation

AC Alternate Current

ACH Air Changes per Hour

ASHRAE The American Society of Heating, Refrigerating, and Air-Conditioning Engineers

BES Building Energy SimulationCDD Cooling Degree Days

CDF Cumulative Distribution Functions

CO^2e Carbon dioxide equivalent

COP Coefficient of Performance

DB Design Builder

DC Direct Current

DHW Domestic Hot Water

ECM Energy Conservation Measures

EER Energy Efficiency Ratio

EPBD Energy Performance of Buildings Directive

EPS Expanded Polystyrene

EU European Union

FS Finkelstein-Schafer

GCM General Circulation Models

GDP Gross Domestic ProductGHG Greenhouse Gasses

GUI Graphical User Interface

HDD Heating Degree Days

HVAC Heating, Ventilation, and Air ConditioningIEA International Energy Agency

IPCC Intergovernmental Panel on Climate Change

kWh Kilowatt per hour

MIT Massachusetts Institute of Technology

Mton Million tons

MW Mineral wool

MWh Megawatt hour

nZEB Nearly Zero-Energy Buildings

PV Solar Photovoltaic Systems

RCCTE Regulation on Thermal Behaviour Characteristics of Buildings

REH Regulation on the Energy Performance of Residential Buildings

RI Reference intervention

RQSECE Regulation on the Quality of Energy Systems for Air Conditioning in Buildings

RSECE Regulation of Energy Systems for Air conditioning in Buildings

SHGC Solar Heat Gain Coefficient

SRES Special Report on Emission ScenariosST Solar Thermal

sq square

TMY Typical Meteorological Yeartoe Ton of oil equivalent

VT Visible Transmittance

Chapter 1: Introduction

This section presents the framework of the topics covered in this study and identifies the corresponding motivation for carrying out the research. In addition, it defines the main goals established and briefly identifies the structure of the dissertation.

1.1 Framework

The idea that growth could be constrained by resources and environmental limitations was not a major concern for most of the world's population until the 1970s. A series of scientific reports such as "Limits to Growth" and "The Population Bomb" by Paul Ehrlich surfaced in this period, warning about the fact that the world population was becoming very large in comparison to the resources needed to sustain it, especially considering the increasingly wealthy lifestyle of the population, stimulated in large part by the capitalist system. Also, in the same period, several reports were released in the scientific community demonstrating the environmental problems linked to this type of growth, such as global warming, acid rain, and the depletion of the ozone layer [1].

In this context, the concept of sustainability arises with increasing strength, defending the premise that the needs of the present society must be met without compromising the needs of future generations, so that global economic development is pursued without causing irreparable damage to ecology and environment, nor socioeconomic, security and cultural disruptions [2], [3].

Among the existing economic activities, the civil construction sector is one of the biggest contributors to the use of resources and the generation of environmental impacts, being one of the main consumers of energy globally, and responsible for the production of ⅓ of greenhouse gas emissions in the world. Also, by allowing the use of relatively easy and economically viable measures to have significant savings potential (around 22% in 2010), it is one of the sectors that is gaining increasing attention in this context [4], [5].

So, to mitigate these impacts, some strategies have been investigated and developed in recent decades. It was noticed that in terms of energy, sustainability can be guided mainly by the principles related to the expansion of the use of alternative sources, combined with conservation and a surge of energy efficiency. In the European Union (EU) scenario, one of the priorities concerns this last principle. In addition to protecting the environment (energy production and use account for 94% of CO^2 emissions), the EU is concerned with ensuring greater security in energy supply and reducing energy needs. After all, it was realized that if nothing changed, the EU's external dependence would reach around 70% in 2030, also alarming the political and economic interests of the community [4].

In this context, the "European directive on the energy performance of buildings" (EPBD) has been introducing progressively higher demands in terms of energy behaviour. In the EPBD recast from 2010, the concept of "nearly zero-energy buildings" (nZEB) was introduced, based on the principles of high energy efficiency and use of renewable energy sources to ensure that the energy needs of the building are met, even partially. Initially, the concept was aimed at new buildings built from 2020, but later it was also extended to existing buildings, after all, the slow pace of replacement would reduce the effectiveness of the proposal in the coming decades [6], [7].

Portugal is no exception in this scenario, and until 2004 it showed a progressive increase in energy consumption, in the order of 7% per year, compared to 1999 [4]. Among the total consumed by the country, the household sector represents a share of about 18% concerning other activities, lagging behind the industry and transport sector [8]. Besides, most of the existing building in the country is marked by an old regulation, not consistent with current concerns, presenting mostly poor thermal behaviour [9]. Thus, it is noted the importance of studying energy renovation in buildings for residential use in the country, to identify improvement solutions capable of mitigating environmental impacts, and also improving the thermal comfort of users.

However, it is important to mention that the concept of sustainable development is based not only on the pillars that refer to the environment and social impacts but also on the economic pillar. Therefore, the framework given by the directive requires that the energy performance of buildings is linked to levels of economic viability, which can be determined through the application of the cost-optimal methodology [10]. The definition of an optimal level of profitability includes "the energy performance in terms of primary energy that leads to the minimum cost during the life cycle of the building". This methodology becomes a useful tool in the decision-making process since it has not yet been possible to find a systematic and direct approach that allows for a large-scale general energy renovation, given the existing peculiarities concerning each project, region, climate, financial context, etc. [10].

Besides, due to the complexity involved in the renovation processes (need to reconcile the work of various specialties and the risk generated from the occurrence of failures and unplanned costs), and consequently the hesitation on the part of the various actors involved in the process, such as investors and owners, the cost-effectiveness analysis can contribute to the reduction of the project's risk and uncertainties, demonstrating in a way closer to reality the cost-benefit ratio of the proposed improvement packages, for example. Also, it demonstrates that when the total cost is calculated, which covers not only construction costs but also maintenance and use throughout the life cycle of the building, the deepest renovations can often bring results more significant in the long run, offsetting the initial investment cost, replacing conventional thinking of choosing systems with high operating costs at the expense of more effective solutions even if with higher construction costs involved.

It is worth mentioning that this pillar gains even more relevance when addressing the issue of the neediest communities, who have less power of choice and need solutions that suit their realities. Unfortunately, the logic found in the construction sector is often marked by-products that do not match the needs and the economic capacity of the end-users. According to data released by Eurostat still in 2020, Portugal has approximately 19% of the population in conditions of energy poverty, translated by the family's inability to heat or cool their home properly, which can lead to several problems, including in terms of health, being then one more justification that demonstrates the urgency to apply efforts to at least minimize this situation [11], [12].

Finally, it is of great importance to mention that the optimal cost levels aforementioned are calculated only with the existing climatic conditions, without considering possible changes amplified by the current climate changes and which can mean a significant variability in the energy needs of a building.

Recognizing the importance of existing buildings and the optimized energy use for achieving the goals defined for sustainable development, mainly the substantial reductions in CO^2 emissions, it is important to define strategies and renovation scenarios that guarantee the resilience of these solutions throughout the life cycle of the building. This should be done considering future climate scenarios in the cost-optimal analysis associated with obtaining the nZEB level in energy renovation interventions, also including increased risk and intensity of extreme events such as floods, strong winds, and heatwaves [13].

1.2 Goals

Determination and optimization of renovation packages, which include building envelope solutions, equipment, and renewable energy supply, at the neighbourhood level, using climate files, thus considering the current climate and future climate projections.

This study is expected to be able to investigate variations in the cost-effectiveness of energy renovation scenarios and the robustness of the results calculated with the current climate. It is also expected to adopt the cost-optimal analysis to incorporate the evolution of energy needs according to the expected change in the climate that the buildings are exposed to. It will also help to identify the most appropriate measures to ensure the resilience of the energy renovation proposed to be carried out in social housing neighbourhoods.

1.3 Dissertation structure

This dissertation is divided into six sections. Section 2 contains the literature review with the main content that serves as a basis for understanding the context in which the main themes addressed in this dissertation are involved. Section 3 provides in detail the methodology developed in this study to achieve the goals set out in section 1. The first section also contains the framework and the dissertation structure.

The case study for this dissertation is presented in section 4, which encompasses a social house neighbourhood in Braga, north of Portugal. After identifying and characterizing the building, an analysis of the building energy performance is performed, creating a solution that is taken as a reference in this study. The method of energy quantification used for the study was the dynamic simulation, and it was performed using the "EnergyPlus" with the support of a graphical user interface. For this study, the "DesignBuilder" tool was adopted.

Section 5 encompasses different typical renovation scenarios, proposed to achieve the nearly zero-energy buildings (nZEB) level. For the cost-effectiveness analysis, renovation packages were proposed for the building envelope, equipment, and renewable energy supply. Thus, to determine the optimal energy performance levels, the cost-optimal methodology was used, and it is also encompassed in this section. It is worth mentioning that the perspective considered in this study was the private one so the fees and subsidies were also applied to the investment. To obtain prices, the "Gerador de Preços" of CYPE was the main query tool, and financial calculations were done with the assistance of "Microsoft Excel".

To determine the thermal performance of the building, it is necessary to include climatic files in the simulation program, since they have a direct influence on the thermal behaviour of the case study. However, whereas buildings must be designed for a life cycle of 50 years in Portugal, or 30 years in case of a renovation, to analyse building resilience it is important to consider in the energy simulation the climate change data expected for the coming decades. Therefore, a resilience analysis also appears in Section 5, through an adaptation of the cost-optimal methodology, considering not only the current climatological but also the forecast for 2050 [10]. For this purpose, the "CCWorldWeatherGen" was used, which is a file generator for worldwide climate change weather data ready for use in building performance simulation programs. It is based on the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (AR3) model summary data of the HadCM3 A2 experiment [14].

Finally, the last section encompasses the conclusions of the study developed and the themes and questions that emerged with its development, opening up to possible future work.

Chapter 2: State of the art

The literature review presented in this section encompasses the problems faced by the world involving the limits to the development and the negative effects of the model that has been used by the world population. In addition, the main concepts concerning the expected sustainable development are referenced. Data placing Portugal and the European Union in the scenario of energy use are identified in this section, as well as the context of the building sector in this panorama. A summary of the energy policies established to meet the goals proposed by the EU is also provided, as well as the main concepts related to the nZEB. Finally, this section alerts to climate change and its possible effects on the energy behaviour of buildings and the thermal comfort of users, especially the risk that people most exposed to these changes can face, i.e. families in a situation of energy poverty.

2.1 Limits to growth

According to [1], several very surprising and, many would say, pessimistic scientific reports about the future emerged around 1970, including the “Club of Rome’s” Limits to Growth and The Population Bomb by Paul Ehrlich.

The Limits to Growth was the result of a computer model generated at the Massachusetts Institute of Technology (MIT) that encompassed a very basic projection of the human population, including birth rate and death rate, industrial production per capita, food production per capita, pollution, and non-renewable resources, which is modelled as an entity that runs out over time. This model evolves based on the socio-political decisions and environmental impact that the current regulations will have on the future [1].

In “The Population Bomb” study, Paul Ehrlich introduces the many problems that arise from the increased human population growth rate. Many of those problems are related to the finite number of resources that Earth has compared to the needs of an increased population. Paul Ehrlich was heavily criticized during the seventies for his pessimistic views on global population growth, although many of his predictions are currently being felt across the globe. The finite resources that Earth currently has are proving to be insufficient to cover the population growth needs, especially in terms of energy consumption. Although pessimistic and extremely alarmist “The Population Bomb” has been a reference in many social-economic studies across the globe [1].

M. King Hubberts, a Shell oil geologist, also raised concerns related to the limits of oil production and the possible impacts on the global population. Hubbert predicted that over time the non-renewable energy sources usage would follow a bell-shaped curve (Figure 1), where a rapid increase associated with the increased population growth would have a peak halfway through the natural limits of the resources and pollution levels. After that peak, the non-renewable resource usage would decrease, associated with an increase in research and change to renewable energy sources and social politics to protect the environment from pollution levels across the globe [1].

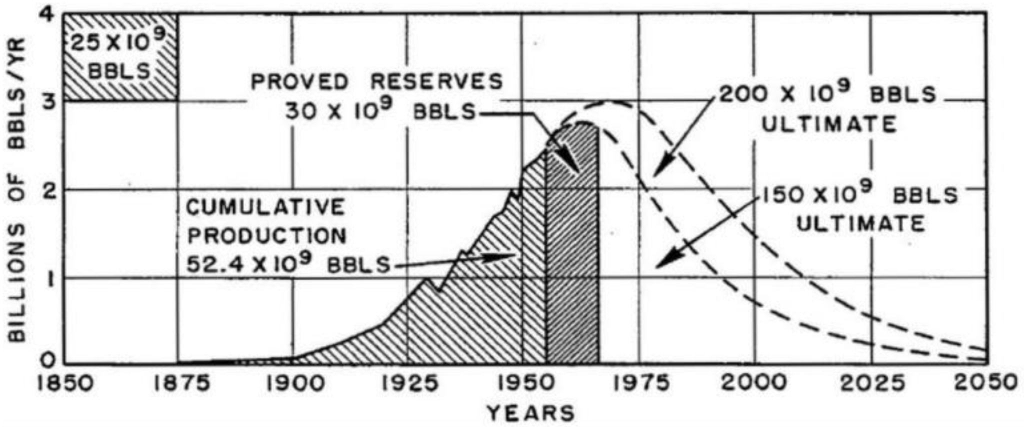


Figure 1: Bell-shaped curve associated with non-renewable energy consumption over time [15]

These reports implied in many ways that the human population appeared to be becoming too large relative to the resource base needed to sustain them – especially at a relatively high level of wealth – and that it appeared that some rather severe "falls" in populations and civilizations may be in store. Meanwhile, many new reports in scientific journals have been published on the many environmental problems such as acid rain, global warming, pollution of various kinds, loss of biodiversity, and the depletion of the Earth's protective ozone layer. The oil shortage, gasoline lines, and some electricity shortages in the 1970s and early 1980s seemed to lend credence to the view that our population and economy had in many ways exceeded the world's "carrying capacity" for that is, the ability of the world to support humans and their increasingly rich lifestyle [1].

2.2 Sustainable development

In the context of ensuring current humanity's development needs are met without compromising the future generation's needs [16], the term sustainable development emerged in the eighties in both the World Conservation Strategy and in the book entitled "Our Common Future", also known as the

Brundtland Report. The term was created for academic inquiry, to force political change and social action on the importance of the sustainable path. The concept of sustainable development is defined as the maintenance and sustainable utilization of the goods and services provided by our natural ecosystems and biosphere processes. The opposite side of sustainable development leads to our environmental functions being unfulfilled, leading to famished in less wealthy populations and destruction of our ecosystems [2].

Although the possibilities for sustainability are many and provide favourable outcomes, there are currently technological limits to achieving it. These limits are not absolute and are managed by our technological advancements and the organizational pressure on the research of new sustainable forms. Even though nature also plays a big part in this equation, there are physical limits to our biosphere to absorb the effects of human activity regardless of the sustainability path society follows [2].

Nowadays, technology is already able to push society onto a new era of economic growth while protecting our limited earthly resources and protecting the percentage of humanity with less economic resources, not least because the Commission considers that widespread poverty is no longer inevitable.

Sustainable development requires that everyone has their basic needs met and that everyone is allowed to fulfil their aspirations for a better life. A world where poverty is endemic will always be subject to ecological catastrophes and others. Therefore, organizations and governments should focus on every member of society independent of wealth or geographical location [2].

Equity distribution of resources should be mandatory for all nations regardless of political power or wealth. The most affluent countries and organizations should lead by example in this aspect to guarantee sustainable development across the globe. For example, in their energy usage and forms of energy acquisition, it is mandatory to reduce non-renewable energy sources and to guarantee that the population size and growth are under the productive potential of the respective ecosystem [17].

Having these points in view, it is possible to see that more than a restricted concept that refers only to the ecological scope, sustainability also encompasses other dimensions such as economic and social, through the recognition that these three pillars must be considered together for lasting prosperity in a balanced way, as represented by Figure 2 [18].

Ultimately, sustainable development is not a rigid state of harmony, but a process of change in which the direction of investments, the orientation of technological development, and institutional change are compatible not only with present needs but also with the future. The process is not expected to be easy or straightforward but painful choices must be made [2].

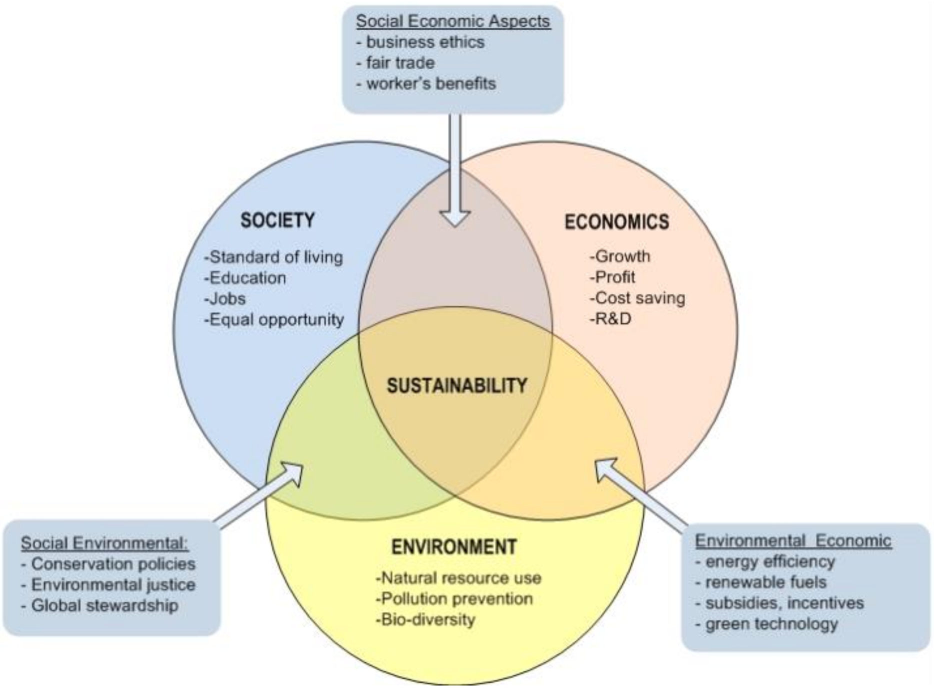


Figure 2: Interplay of the environmental, economic, and social aspects of sustainable development [19]

2.3 Energy efficiency

Until the industrial revolution, the planet was large and the resources were in abundance compared to the population needs. The world was divided into nations, well-defined sectors (such as the energy sector, agriculture, and trade), and broad areas of interest (the environment, economy, and social). With globalization, the borders and the sectors began to dissolve. This applies, especially in the last decade, to the various global 'crises' that have public attention: an environmental crisis, a development crisis, and an energy crisis. They are all one [2].

All forms of economic production and exchange involve the transformation of materials, which in turn requires energy. In 2004, the Green Paper entitled "Towards a European strategy for the security of energy supply" showed, however, that the European Union was extremely dependent on external energy supply, representing at that time 50% of the needs and estimating that this figure would increase to 70 % by 2030, if current trends persist, increasing the risk of interruption or difficulties in energy supply [5].

The Green Paper also alerted to the fact that the security of energy supply was essential for future sustainable development, being important not only to reduce dependence on imports but also to limit greenhouse gas emissions [20]. Portugal is no exception in this scenario.

2.3.1 Energy dependency

One of the main objectives of the national energy policy is to reduce external energy dependence. Over the last twenty years, Portugal has shown an energy dependency between 70% and 90% (Figure 3), a consequence of the lack of national production of fossil energy sources, such as oil or natural gas, which have a very significant weight in the total consumption of primary energy. However, the commitment to renewable energies and energy efficiency has allowed Portugal to reduce its energy dependence to levels below 80%. With the accounting of energy production from heat pumps as a renewable source from 2014, energy dependence decreased by about 2 p.p. The variability of the hydrological regime also has a great influence on the production of hydroelectricity and, consequently, on energy dependence. However, the National Energy and Climate Plan 2021-2030 (PNEC 2021) sets a target of 65% in 2030, so, there is still a way to go, and it is necessary to continue investing efforts so that the proposed objectives are achieved [21].

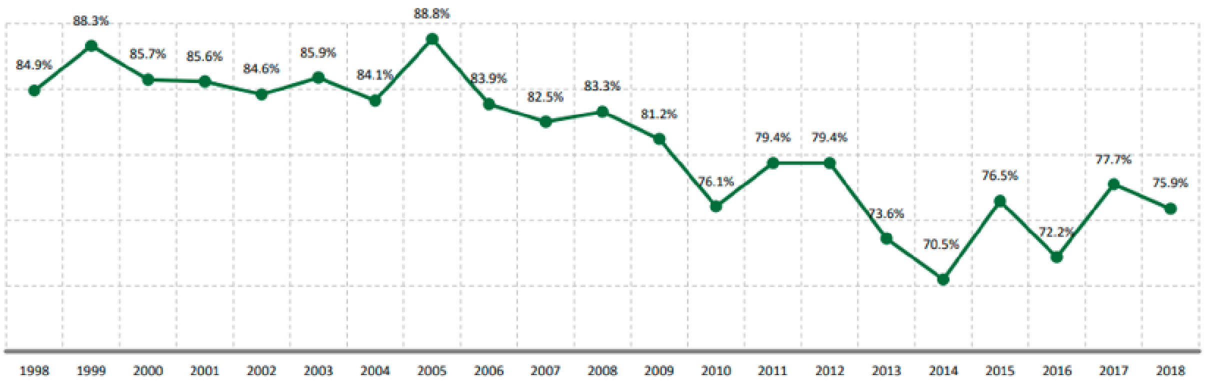


Figure 3: Evolution of energy dependence in Portugal

[21]

Comparing energy dependence among European Union countries (EU-28), it can be seen in Figure 4 that, even in 2018, Portugal ranked 7^{th} among countries with the highest energy dependence, around 20 p.p. above the EU average. 28 [21].

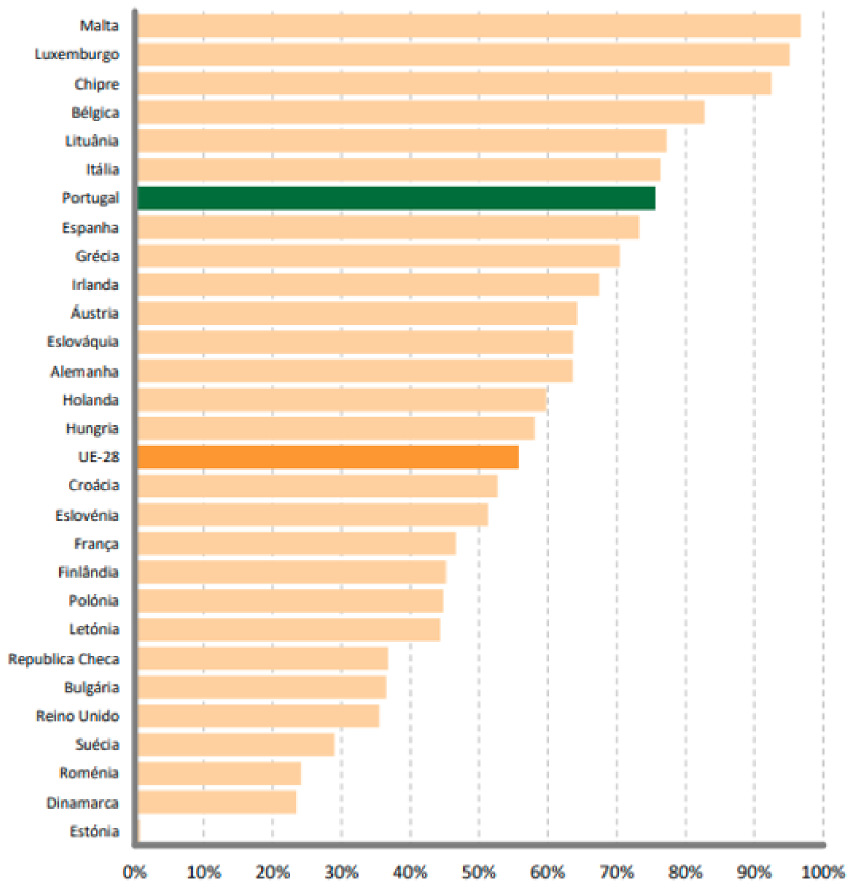


Figure 4: Energy dependency in the EU-28 in 2018

[21]

2.3.2 Energy Intensity

The energy intensity of the economy in terms of primary energy provides a measure of the energy efficiency of the economy, that is, the amount of energy needed to produce one unit of Gross Domestic Product (GDP). In 2018, regarding the energy intensity of the economy in terms of primary energy, it showed values at 122.3 tons of oil equivalent per million euros (toe/M€2011), which corresponds to -4.8% compared to 2017, as presented in Figure 5. The energy intensity of the economy in terms of final energy was 89.6 toe/ M€2011 representing -0.8% compared to 2017. Finally, regarding the energy intensity of the economy in terms of electricity, it stood at 266.1 MWh/M€2011, corresponding to +0.4% compared to 2017 [21].

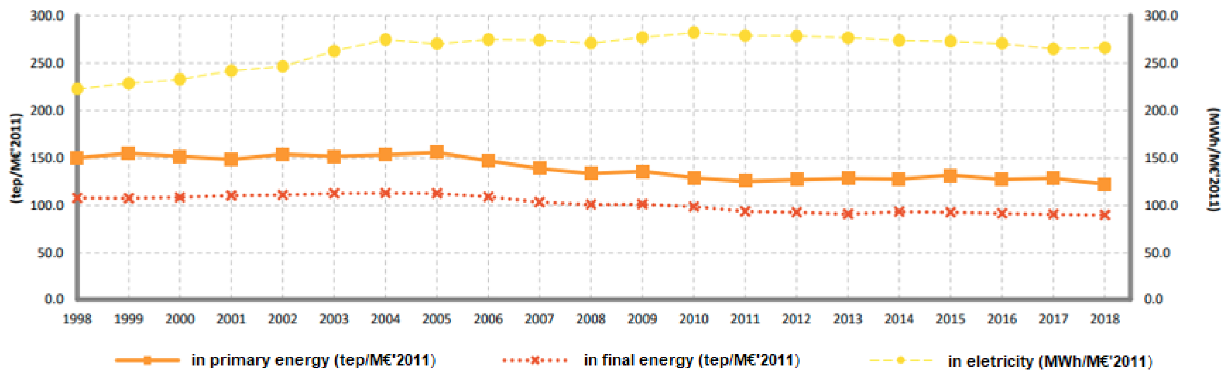


Figure 5: Evolution of energy independence in Portugal

[21]

Comparing energy intensity in terms of primary energy among European Union countries (EU-28), it can be seen in Figure 6 that, even in 2018, Portugal was the 15th country with the lowest energy intensity in the economy, around 10 p.p. above the EU-average. 28 [21].

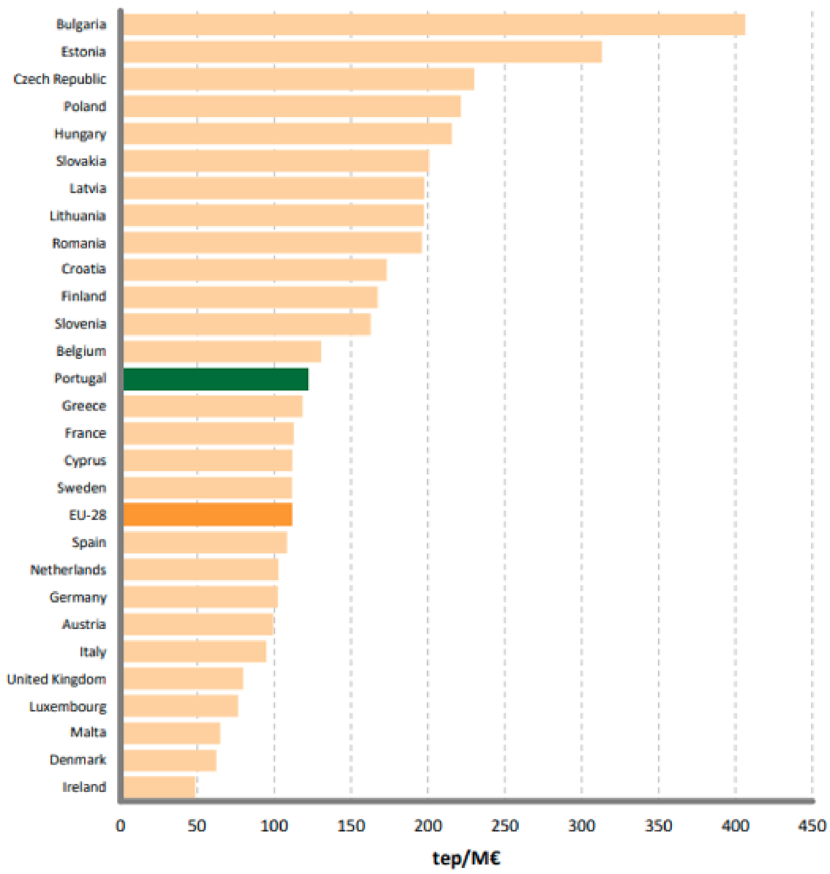


Figure 6: Energy intensity in terms of primary energy in the EU-28, in 2018

[21]

2.3.3 Greenhouse gas emissions

Emissions of greenhouse gases (GHG) in 2018 stood at 67.4 million tons of carbon dioxide equivalent (Mton CO^2e). Because the energy sector represents around 70% of total GHG emissions and considering that in 2018 hydro production increased by around 79% compared to 2017, emissions from the energy sector from 2017 to 2018 decreased by 5.5%. Analysing the period 2005 to 2018, it was found a decrease of 22% in total emissions and 24% in emissions from the energy sector, as presented in Figure 7 [21].

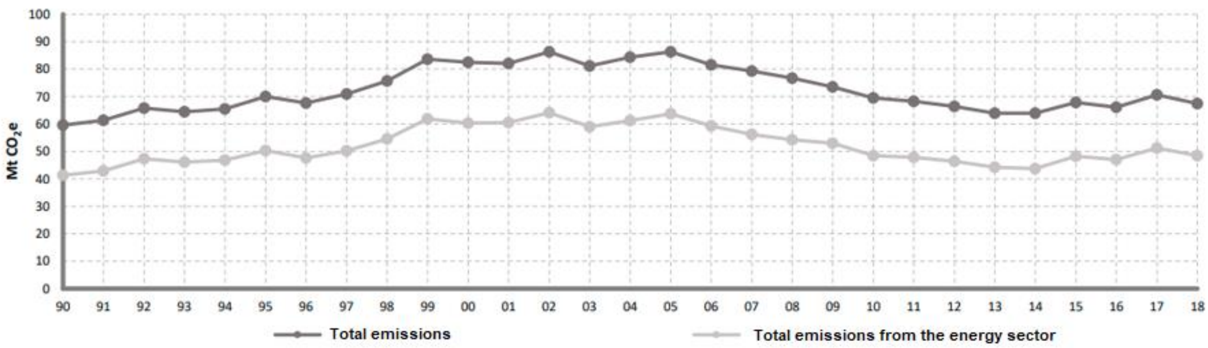


Figure 7: Evolution of GHG emissions in Portugal

[21]

The per capita GHG emissions indicator in the same year was 6.6 tons/inhabitant (Figure 8), corresponding to -4.4% compared to 2017.

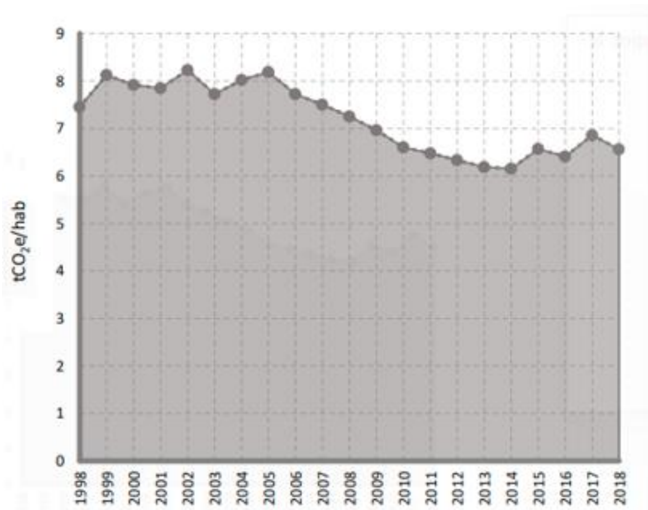


Figure 8: Evolution of the per capita GHG emissions in Portugal

[21]

Comparing total GHG emissions per inhabitant at the level of EU-28 countries, in 2018, it is noted that Portugal had one of the lowest values, approximately 24% below the average value registered in the EU-28, as presented in Figure 9 [21].

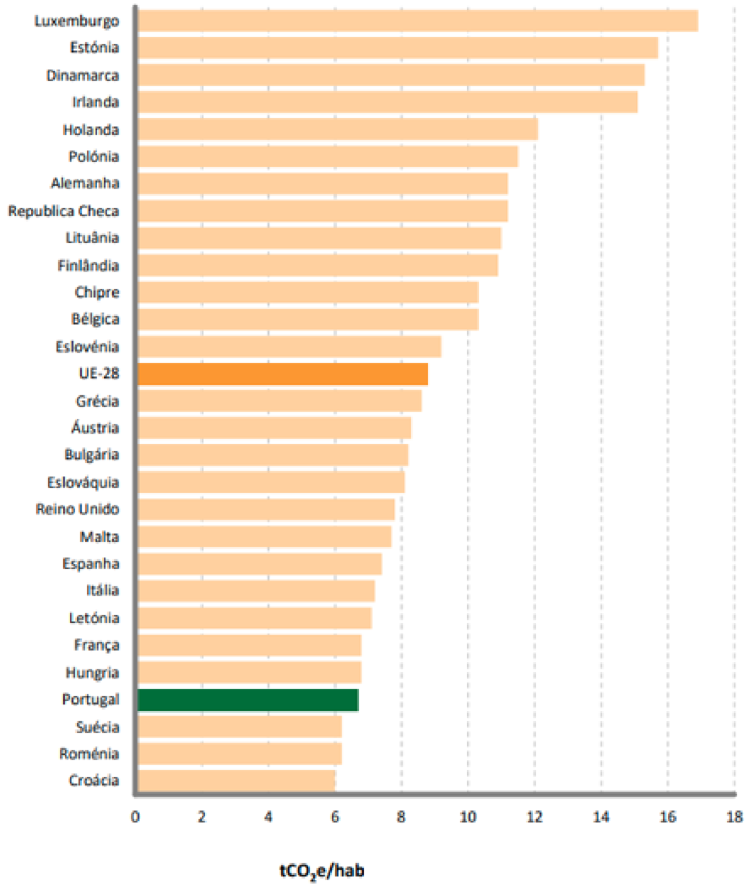


Figure 9: Per capita emissions in the EU-28 in 2018

[21]

2.3.4 The building sector

The urbanization rate has been growing all over the world and the option for life in urban centers already reaches more than 50% of the world population. The interaction between buildings, their surroundings, the metabolism of cities, and the way they evolve involve complex factors that impact sustainability and, therefore, must be fully understood [22].

Buildings are responsible for about 36% of total greenhouse gas emissions and 40% of energy consumption in the European Union, so they have an immense potential to contribute to combating climate change through, mainly, energy efficiency gains, to guarantee not only a reduction in consumption and emissions but also to increase the safety and comfort standards of users [23].

Although Portugal presents numbers below the European average, where among the sectors, the domestic one presents contributions in the range of 18% for energy consumption [8], [22], regarding data from 2019, it is still a significant value that deserves attention. It is also worth mentioning that the construction sector is one of the most relevant sectors in terms of wealth generation and occupation, also enabling a direct impact in this regard [24]. The contribution of the different sectors is presented in Figure 10.

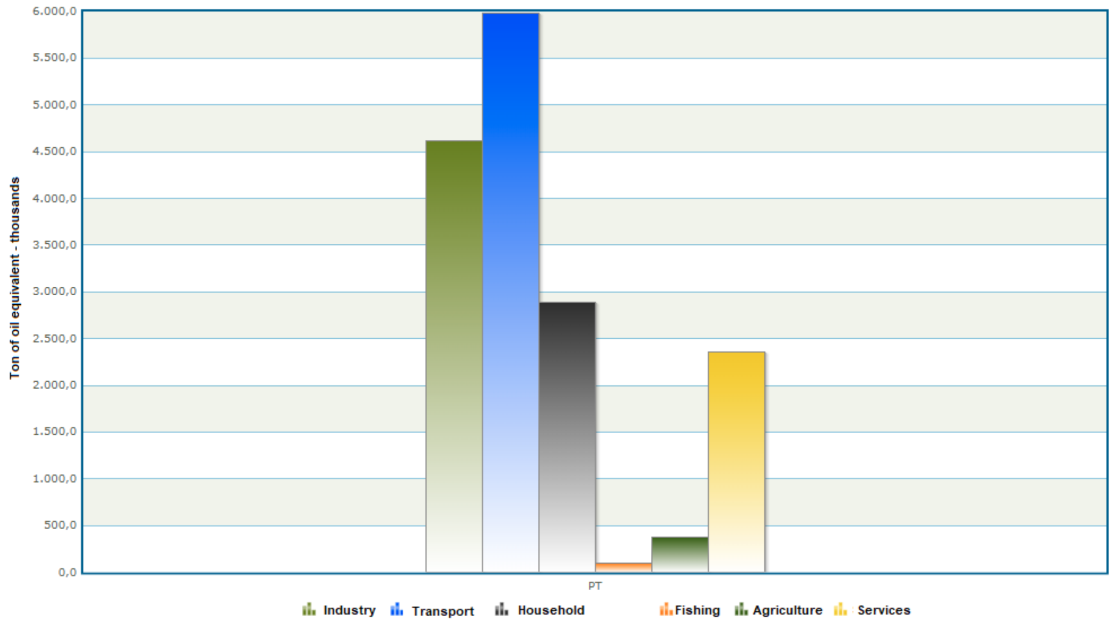


Figure 10: Final energy consumption by type of consumer sector in Portugal, 2019

Adapted, [8]

Concerning energy consumption in the residential sector, the use phase is considered the most relevant and causes the greatest environmental impacts. However, when the energy incorporated in the building is accounted for, i.e. all the energy necessary for the production, transport, application, maintenance, and disposal of materials used in the building's constituent elements, the environmental impact associated with the construction process is also quite significant. This makes the rehabilitation of the buildings desirable, both from a financial and an environmental perspective, as it avoids environmental impacts and the high costs associated with new construction that would replace the existing building[22].

About 25% of the European building stock was built in the middle of the last century, registering an age higher than that defined as the useful life of buildings, which in European countries is normally 50 to 60 years. Many of these buildings are important because of their cultural, architectural, and even historical context, but many of them have low energy performance and are degraded and in need of renovation interventions. They generally still use inefficient conventional systems, typically associated with high energy costs and a high rate of greenhouse gas emissions. Constructive interventions to improve their energy efficiency conditions can provide significant energy savings and emission reductions [22].

In the Portuguese context, the renovation of buildings represents only about 6.5% of the total activity in the construction sector, while the European average presents values situated at 37% [22]. According to the national population and housing census data, 2011 Census, around 34% of the Portuguese housing stock need renovation, which is a huge potential for the energy renovation of buildings. In this way, acting in this cause is not only a one-off necessity but must be part of a permanent agenda, where the constant improvement in the energy performance of existing buildings can contribute to energy savings and preservation of the environment, over generations [22].

2.4 Energy policies

Focusing on the concern with the rational use of energy and the reduction of emissions associated with it, several legal and regulatory measures have been adopted over time, to establish minimum levels of thermal performance for new and existing buildings [25]. Figure 11 shows some key milestones on this subject, over time.

In the Portuguese context, for example, it is strongly recommended that the security of energy supply should not be summarized only in reducing dependence on imports and increasing domestic production, but it requires a wide range of policy initiatives aimed, for example, at diversifying sources and technologies and increasing energy efficiency [20].

However, until 1990, there were no thermal regulations regarding the thermal behaviour and energy efficiency of buildings, nor in terms of the opaque envelope (roofs, walls, floors), translucent elements (windows, skylights) as well as equipment for domestic hot water and to maintain the comfort temperature in the interior space [26], [27].

Nevertheless, in 1990, based on the knowledge and experience acquired in other countries regarding energy conservation and the use of energy in buildings, the Regulation on Thermal Behaviour Characteristics of Buildings (RCCTE) was published, through the Decree-Law No. 40/1990 [26], [27].

This legal instrument imposed requirements on the design of new buildings and major renovations with the main objective of guaranteeing thermal comfort conditions without excessive energy consumption. This should be assured mainly through the improvement of the thermal quality of the building envelope through intervention in the project design and construction of buildings, constituting a significant step in the improvement of thermal comfort conditions ourselves [26], [27].

However, the requirements and recommendations are always being updated and since then several changes and new needs in terms of energy legislation have emerged, giving rise to a periodic evolution scenario, with the milestones described below [26], [27].

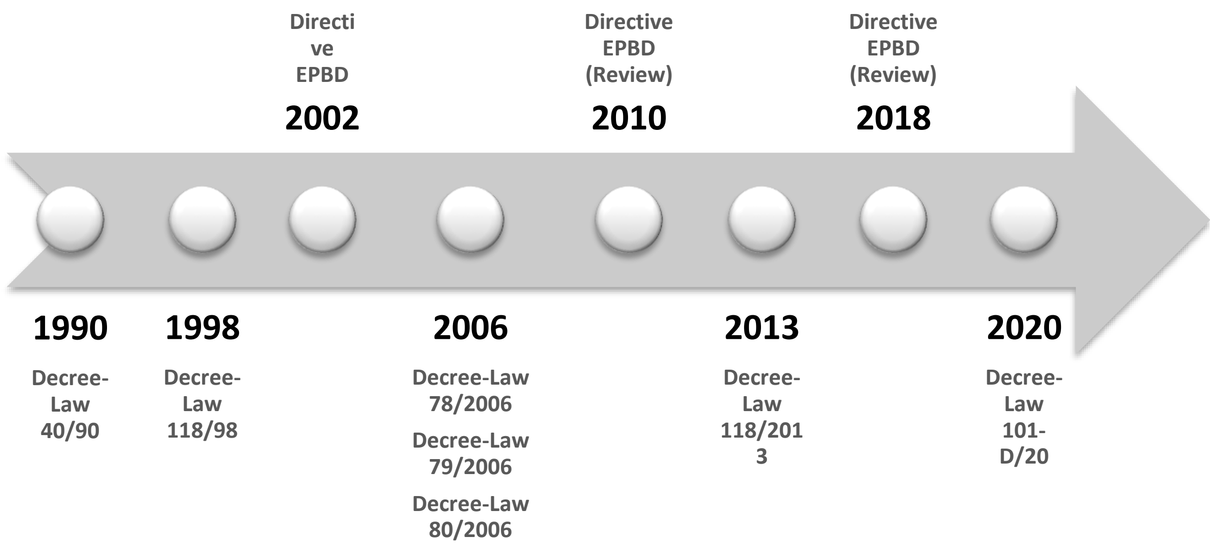


Figure 11 – Legislative framework

Adapted, [26], [27]

Because meeting the needs for thermal comfort and indoor air quality in buildings also involves the use of means of ventilation, heating, cooling, humidification, and dehumidification, it was published in 1992, with Decree-Law No. 156 /92, the Regulation on the Quality of Energy Systems for Air Conditioning in Buildings (RQSECE). This piece of legislation, however, was never applied, being amended and giving place in the Regulation of Energy Systems for Air Conditioning in Buildings (RSECE) through Decree-Law no. 118/98 [26], [27].

Although there was national attention to the theme of more sustainable construction as well as the installation of technical systems, in the European Union, there was a concern with final energy consumption in the buildings sector, residential and tertiary. It led to the publication of the European Directive 2002/91/EC4, transposed by all member states mainly during 2006. This directive imposes the establishment of minimum requirements for the energy performance of buildings (new or subject to major renovations), the energy certification of buildings, and the regular inspection of boilers and air conditioning installations in buildings [26], [27].

The mandatory transposition of the Directive 2002 into national law only took place in 2006, through the publication of 3 pieces of legislation. The Decree-Law no. 78/2006 approved the National Certification System for Energy and Indoor Air Quality in Buildings (SCE), through the need for training and creation of qualified experts to work at the level of the RSECE and RCCTE, which came into force in a phased manner through the publication of the Ordinance n.º. 461/2007. Decree-Law No. 79/2006 approved the Regulation on Energy Systems for Air Conditioning in Buildings (RSECE) and replaced Decree-Law No. 118/98. Finally, Decree-Law No. 80/2006 encompassed the Regulation on the Characteristics of Thermal Behaviour of Buildings, which revokes Decree-Law No. 40/1990 [26], [27].

However, subsequently, the Directive 2002 was republished through the European Directive 2010/31/EU, reformulating the first version, by promoting the continuation of the energy certification of buildings and especially the improvement of the previously imposed requirements [26], [27].

So, the pieces of legislation published in 2006 were revised, updated, and aggregated in a single decree-law, Decree-Law No. 118/2013, with the support of several Ordinances and Dispatches, which include the specific methodology for calculation, the contribution of renewable energy, the energy performance certificate template, climate data, primary energy conversion factors, etc. The Decree-Law thus includes the SCE, the Regulation on the Energy Performance of Housing Buildings (REH), and the Regulation on the Energy Performance of Commerce and Services Buildings (RECS) [26], [27].

Since then, buildings are now evaluated and subject to stricter requirements, which are mainly based on the pillars of thermal behaviour and systems efficiency, without forgetting the prevention of pathologies, indoor comfort, and the reduction of energy needs. Also, other factors play an important role in regulation, such as indoor air quality, shading, adequate natural light, and the use of energy from renewable sources, with emphasis on the use of the solar resource, abundantly available in Portugal [6], [28].

To develop a sustainable, competitive, safe, and decarbonized energy system until 2050, and to further reduce greenhouse gas emissions (by at least 40% by 2030, compared to 1990 values), increase the percentage of consumption of renewable energy, achieve energy savings in line with the Union's level of ambition, and increase Europe's energy security, competitiveness and sustainability, the European Union and the 2030 climate and energy framework for action set ambitious commitments published by the European Parliament and the Council of the European Union through Directive 2018/844 [29].

Thus, to ensure and promote the improvement of energy performance through the establishment of requirements applicable to its modernization and renovation, and to regulate the Energy Certification System for Buildings (SCE), transposing the Directive 2018/844 to the Portuguese legal order, the Decree-Law No. 101-D/2020 was published, which entered into force on July 1, 2021 [23].

nZEB: Nearly Zero-Energy Building

To support the renovation of the national stock of buildings into a highly decarbonized and energy-efficient one by 2050, each Member State must establish a long-term renovation strategy instigating that this transformation occurs cost-effectively, creating nearly zero-energy buildings (nZEB). The goal is to increase the number of buildings that fulfill current minimum energy performance requirements but are also more energy-efficient [6], [29].

According to Directive 2010/31/EU, the Nearly zero-energy building is defined for having a very high energy performance and the low amount of energy required should be covered to a very significant extent by energy from renewable sources, which can be produced on-site or nearby if there is reasonable justification [6].

Under the Community provision, Member States were required to ensure that, as of 31 December 2018, new buildings occupied and owned by public authorities were nZEB buildings, with the same obligation for all other new buildings, as of December 31, 2020 [30].

However, according to the Commission's Impact Assessment, to accomplish the Union's energy efficiency goal cost-effectively, it would be necessary that renovation occurs at an average rate of 3 % per year. Considering that every 1 % increase in energy savings reduces gas imports by 2,6 %, renovation of the existing building stock shows itself of great importance, because it can contribute actively to the Union's energy independence, and it has the potential to create jobs in the Union, mainly in small and medium-sized enterprises [29].

Then, major renovations of existing buildings provide a chance to take cost-effective measures to improve energy performance, and for reasons of cost-effectiveness, it is possible to establish a boundary in terms of minimum energy performance requirements to the renovated parts that have more relevance in the building, so far as this is technically, economically, and functionally viable [6].

Moreover, nZEB must have an efficient component compatible with the most demanding limit of economic viability levels that may be obtained with the application of the cost-optimal methodology, differentiated for new and existing buildings and different types [15]. In addition, it is noteworthy that the annual primary energy needs of nZEB must be supplied at least 50% by renewable energy sources [30].

2.5 Climate change

Climate change is defined as a stable and durable change in the distribution of weather patterns over periods. It could be a change in average weather conditions or the distribution of events around that average. It may be limited to a specific region or can cover the entire earth's surface [31].

Emissions of greenhouse gases should have peaked in 2015 and progressively decreased thereafter up to 50% by 2050. However, the progressive evolution of atmospheric CO^2 has grown, and it has recently reached an unprecedented high of 400 parts per million (ppm) [31]. In addition, other industrial gases threaten to deplete the planet's protective ozone shield in a way that is expected to dramatically increase the number of human and animal cancers, disrupt the ocean food chain, introduce toxic substances into the human food chain through industry and agriculture, and make groundwater out of cleaning range [2].

Besides, until the beginning of the next century, the 'greenhouse effect' and the rise of the average global temperatures may cause more negative impacts on the world, such as displacing areas of agricultural production, rising sea levels to flood coastal cities, and disrupting national communities [2]. The situation is so alarming that even if the greenhouse gas emissions stop immediately, the temperature increase will persist for centuries because of the effect of already present greenhouse gases in the atmosphere [14].

An increase in the global mean surface temperature is expected to range from 0.3 °C and 0.7 °C to 2.6 °C and 4.8 °C until 2100, if compared with a 1986-2005 baseline, according to the Intergovernmental Panel for Climate Change (IPCC) [16]. Besides, the results of modelling studies indicate that heat waves with greater frequency and severity tend to occur in the order of 5 to 10 factors in the probability of occurrence, considering 40 years [25].

In addition to the increase in external temperature, presented in Figure 12, the increase in solar gains also influences the predicted increase in internal temperature, since in the coming years, between 2020 and 2080, solar gains are expected to increase between 4 and 6% [20]. Unsurprisingly, it is expected for a drastic rise in cooling energy use and a moderate decrease in heating energy use [14].

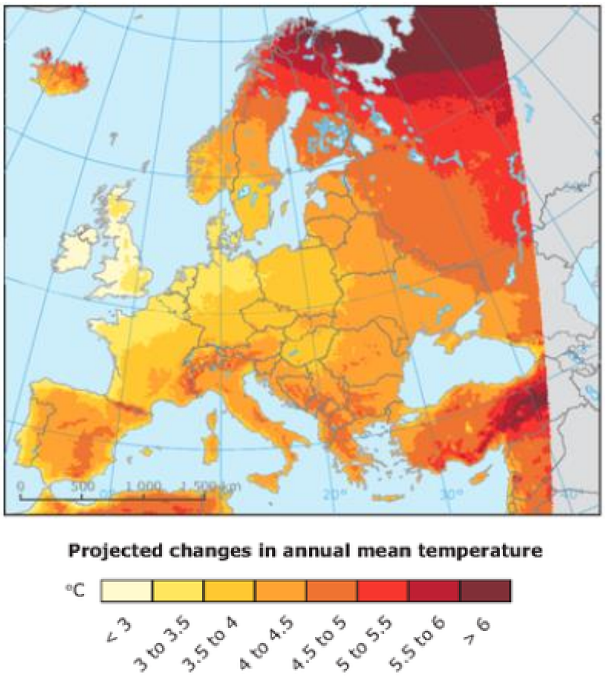


Figure 12: Projected changes in annual mean temperature for 2071-2100, compared to 1971-2000 (RCP8.5 scenario) [32]

As a result of these changes, several studies suggest that there are potential significant negative impacts to be expected in terms of discomfort and that existing buildings and their users will have to deal with conditions other than those which were considered when designed [19], differing according to the building type and function, constructive characteristics, as well as geographical location. During the 2003 European heatwave, for example, countries such as France, England, and Portugal registered an increased number of deaths related to abnormally high temperatures inside dwellings [25].

These combined views alert to the need to conduct thermal comfort and adaptation studies, mainly regarding the adequacy of thermal comfort standards in assessing indoor conditions in the future [25]. In this context, there is a particular need from property owners and facilities managers for estimates of the future energy demand for heating and cooling [13] and to balance mitigation and adaptation to climate change [25]

Unfortunately, recent analyses discussed at COP26 (2021 United Nations Climate Change Conference) show that the world is not even close to meeting the goals of limiting global temperature rise and that the greenhouse gas emissions that warm the planet will still be twice as high as necessary to keep the temperature rise below 1.5°C until 2030. The organizations believe that the main factor for the difference between the promises and the projections is still the production of coal and gas [33].

2.6 Energy Poverty

In response to future expectations of climate change, the installation of devices such as air conditioning, for example, tends to increase, which would lead to greater energy demand from buildings. This forecast deserves attention since the studies point to high levels of fuel shortages, which already exist in Europe, mainly in the countries of Eastern and Southern Europe. The concern is even greater when analysing the situation of more vulnerable families who may not be able to afford the rising fuel costs in winter and summer [25].

The need to alleviate energy poverty must then be considered when thinking about this issue, and the Member States must provide clear guidelines and establish measurable and targeted actions to promote equal access to finance. This should be targeted especially to social housing, consumers with an energy shortage, the worst performing segments of the national construction stock, and families subject to dilemmas of divided incentives while considering accessibility [29].

To guarantee a decent standard of living and the health of citizens, some essential services are needed, such as adequate heat, cooling, lighting, and energy to power appliances. Low-energy families experience inadequate levels of these services mainly due to a combination of low household income and high energy expenditure, inefficient buildings and appliances and specific household energy need. It is estimated that more than 50 million families in the European Union live in a situation of energy poverty [34].

Following Directive (EU) 2019/944 and the Governance Regulation, all Member States must calculate the number of families affected by energy poverty, considering the domestic energy services necessary to guarantee the basic standard of living in the relevant national context, existing social policy, and other relevant policies, as well as the Commission's indicative guidelines on indicators relevant to energy poverty [11].

In the latest data released by Eurostat, Portugal emerges as one of the countries in the European Union where people have fewer economic conditions to keep their homes properly heated, with 18.9% of Portuguese people in a situation of energy poverty [35].

However, to understand the level of energy poverty, it is important to know not only the incidence, through the number of people and/or families affected, but also the intensity, trying to understand the severity of the problem. For this, three types of indicators help to know the level of Energy Poverty in Portugal [12].

The first one is about the perception of families, which is done through surveys carried out to the population that evaluate themselves about the physical conditions and quality of where they live, and also about the economic capacity they have to satisfy the needs of energy consumption. The second talks about energy expenditure, also through surveys, but the aim here is to make a comparison between the family's energy expenditure and the available budget. Finally, the third indicator acts on the energy gap, by comparing the effective consumption of the house and the reference consumption that would be adequate to keep the family in a normative situation of well-being [12].

It is important to mention that energy poverty is a specific form of poverty-related to a series of adverse consequences for the health and well-being of people, manifesting through respiratory and cardiac diseases and interfering in the users' mental health, which is aggravated due to low temperatures and stress associated with inaccessible energy bills. Also, energy poverty has an indirect effect on many policy areas, including not only health but also the environment and productivity. Thus, facing this situation has the potential to bring several benefits, including less money spent by governments on health, reduced air pollution, better citizens' comfort and well-being, better family budgets, and increased economic activity [34].

CHAPTER 3: METHODOLOGY

To carry out the proposed study and fulfill the intended goals, it is necessary a sequence of processes, the use of different tools, and the consideration and analysis of different subjects, formulas, and concepts. The methodology used for this dissertation can be summarized in Figure 13, and the entire process involved is described in the current section.

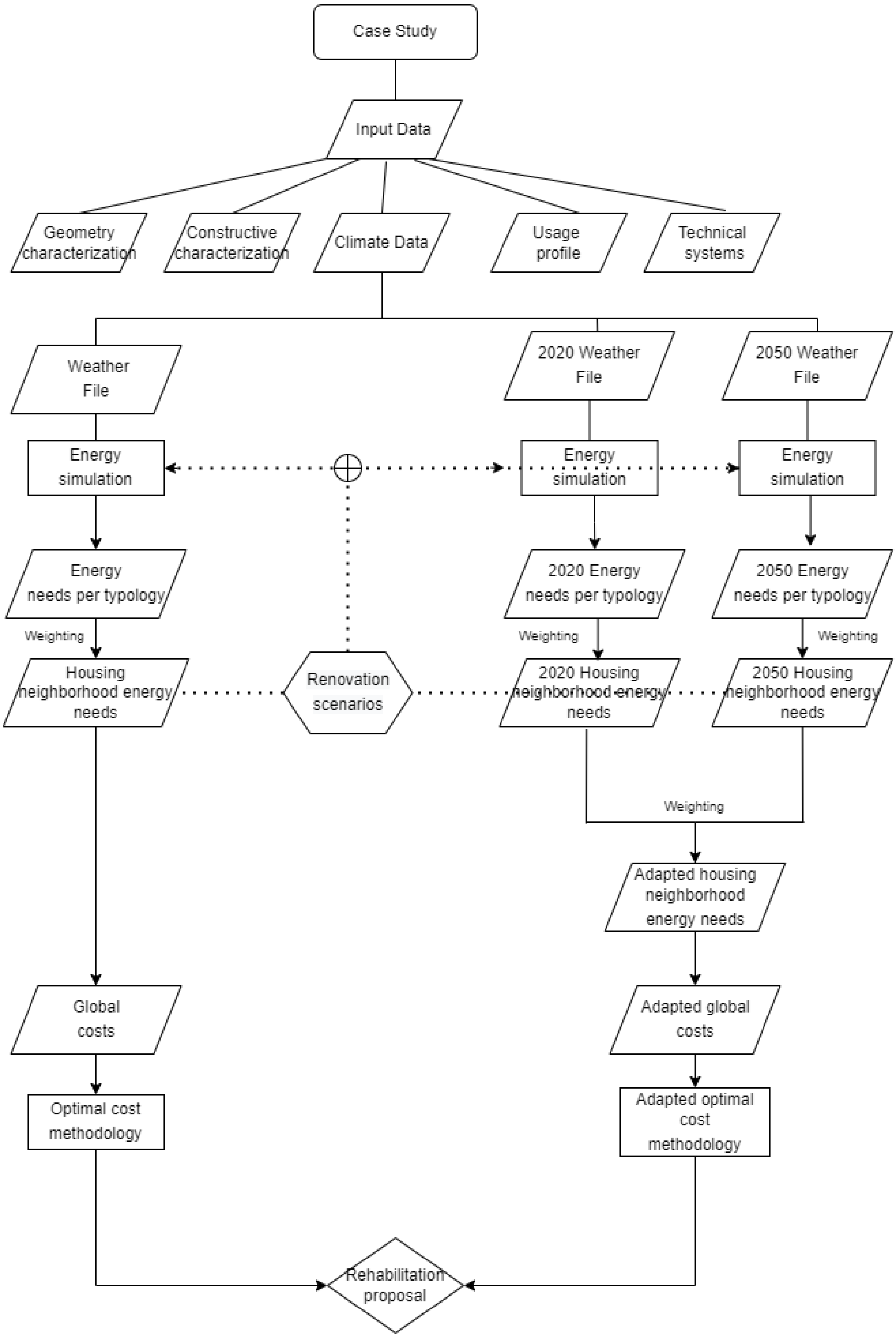


Figure 13: Dissertation methodology flowchart

3.1 Case study

Midrise apartments in the Mediterranean region are commonly very similar to each other, especially when it comes to social housing. Floors are usually made up of continuous concrete structures, while external walls are typically built with bricks (in the case of heavy facades) or blocks (in the case of light facades), the latter being less frequent. Walls usually have an internal air cavity and layers of plaster on the inside. The exterior cladding is mostly made up of traditional plaster or marble. The thermal performance of the envelope of these buildings is considered medium [36].

The methodology was applied in a case study that is representative of the Portuguese building stock, mainly in terms of the construction period and construction materials. It is also worth mentioning the fact of choosing a social neighbourhood, since these families are normally in a situation of energy poverty and more vulnerable to climate change projections and with greater challenges in terms of profitability, as already discussed [37].

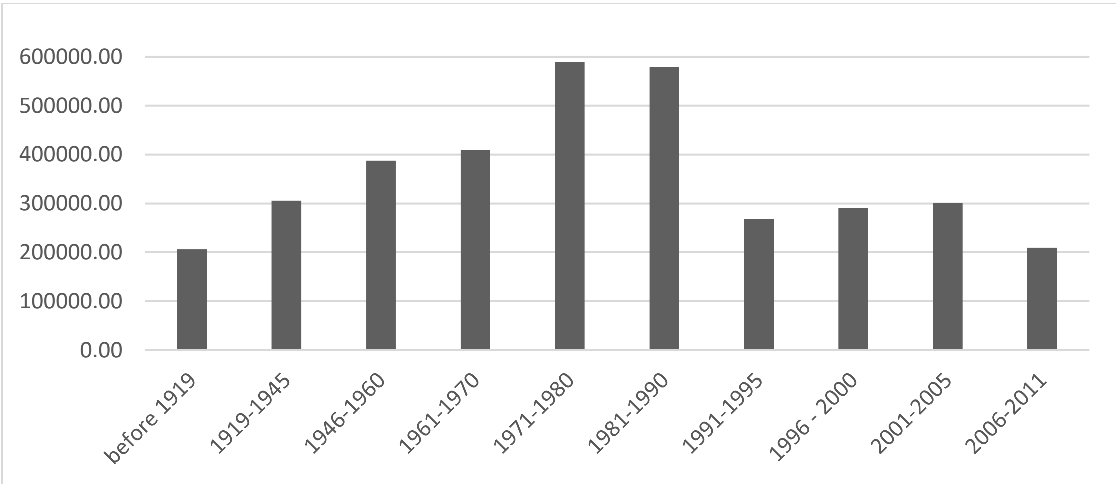


Figure 14: Number of classic buildings according to the construction period of the building in Portugal, 2011 Adapted, [37]

Buildings built from 1971 onwards constituted 63.1% of the buildings belonging to the Portuguese housing stock in 2011, with most of them dated between 1971 and 1980, as presented in Figure 14. Regarding the materials used in construction, in 2011, the largest part of the buildings had a reinforced concrete structure or masonry walls with concrete floors (40 % and 32 %, respectively). Regarding the exterior coating of walls, the vast majority had traditional plaster, marble, or exposed concrete (84%). Finally, when it comes to the roof, pitched roofs were the predominant type (49%) [37]. The graphics contained in Figure 15 show the most significant proportions regarding material, among the elements mentioned.

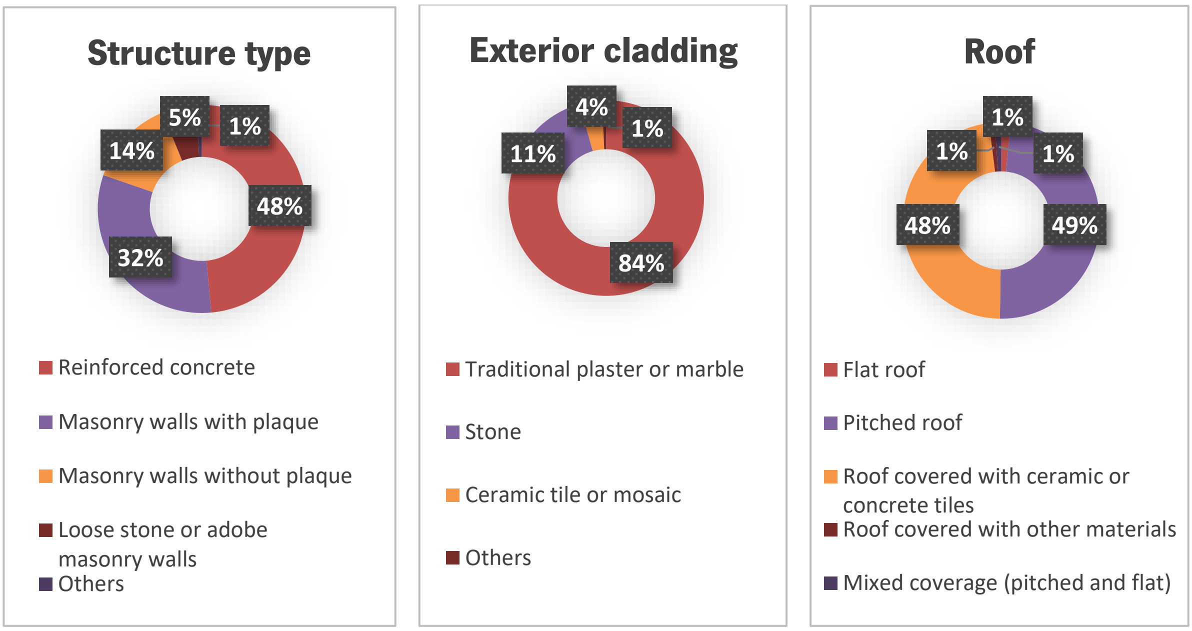


Figure 15: Proportion of classic buildings by materials, 2011

Adapted, [37]

Artificial heating and cooling are required in these social housing buildings to ensure comfortable indoor air temperatures throughout the year. In general, it is assumed that social housing buildings do not have built-in heating or air conditioning systems and rely only on natural ventilation [36].

In practice, what usually happens is that residents heat their apartments with portable electric radiators, which are in most cases energy inefficient and often not adequate to provide an even distribution of comfortable temperatures in homes. For cooling, in some cases, residents install room-sized air conditioners [36].

Buildings built before 2007 generally do not have mechanically controlled ventilation systems in bathrooms and kitchens, which contribute to the occurrence of pathologies, normally related to humidity, for example. However, the indoor air quality in these social housing buildings is usually not bad, due to the uncontrolled inflow of air through the building envelope (by infiltration) or due to the ventilation provoked by manual operation of the windows [36].

3.2 Energy simulation

To analyse the case study and fulfill the objectives proposed by this dissertation, it was necessary to assess the energy performance of the social neighbourhoodand the proposals for energy renovation that were analysed. The increasing importance that has been given to energy efficiency and building optimization has meant that different methodologies, approaches, and tools are developed and used to support energy simulation studies.

3.2.1 Modelling approach

Broadly speaking, there are two fundamental classes of modelling approaches used to estimate and analyse the overall energy use performance of the building stock: the top-down and bottom-up approaches (Figure 16) [38].

I. The top-down modelling approach works on an aggregated level, and it is generally aimed at adjusting a historical series of national energy consumption or CO^2 emissions data, to investigate, for example, the interrelationships between the energy sector and the economy at large. It can also be further classified as a top-down econometric and technological model [38].

II. Unlike the top-down modelling approach, bottom-up models represent the region or nation by extrapolating energy consumption calculations for individuals or groups of houses [38]. This approach can generate the thermal performance of a building complex with greater accuracy, because of the high granularity. Although the inclusion of micro-level input can be a disadvantage, due to greater difficulty in obtaining information and the consideration of many variables in the analysis, the ability to incorporate a high level of detail considering individual end-use energy consumption, offers the possibility to identify areas for improvement and the opportunity to rank various technical solutions and compare them and their combinations, considering the individual impact on energy consumption. For this reason, the bottom-up approach is widely used to assist profitability analysis, which is why it was the approach used for this study [36], [39].

The bottom-up approach can be further classified into two groups of methods: statistical and engineering [38].

a) Statistical methods are based on establishing relationships between end uses and energy consumption, and then use information and types of regression analysis to estimate the energy performance of representative dwellings of the residential stock [38].
b) Meanwhile, engineering methods are based on information such as housing characteristics, power ratings, use of equipment/systems, and/or heat transfer and thermodynamic principles, to then consider the energy consumption of end uses. Thus, this method allows for a greater level of detail, and it was the one chosen for this study [38].

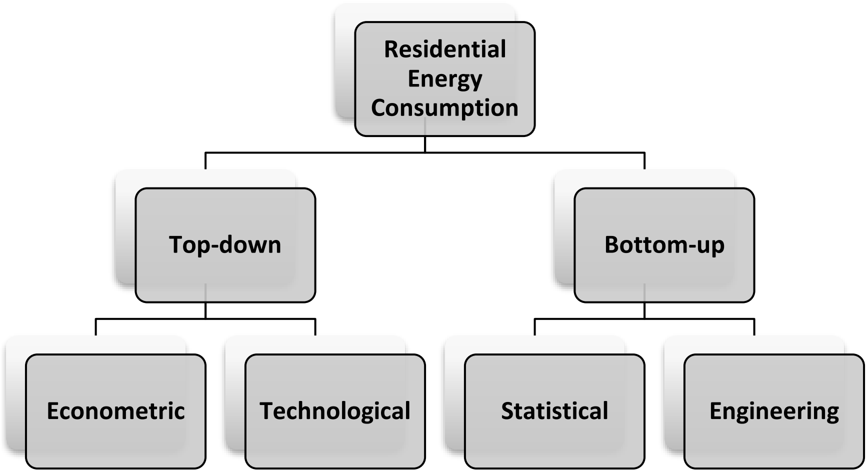


Figure 16: Modelling approaches

Adapted, [38]

3.2.2 Energy quantification method

Quantitative energy performance assessment methods involve the process of determining the amount of energy to use or energy performance indicators of the object under study. It is based on relevant information collected and introduced in the model and it can follow three main approaches: Calculation-based approach, measurement-based approach, and hybrid approach (Figure 17) [40].

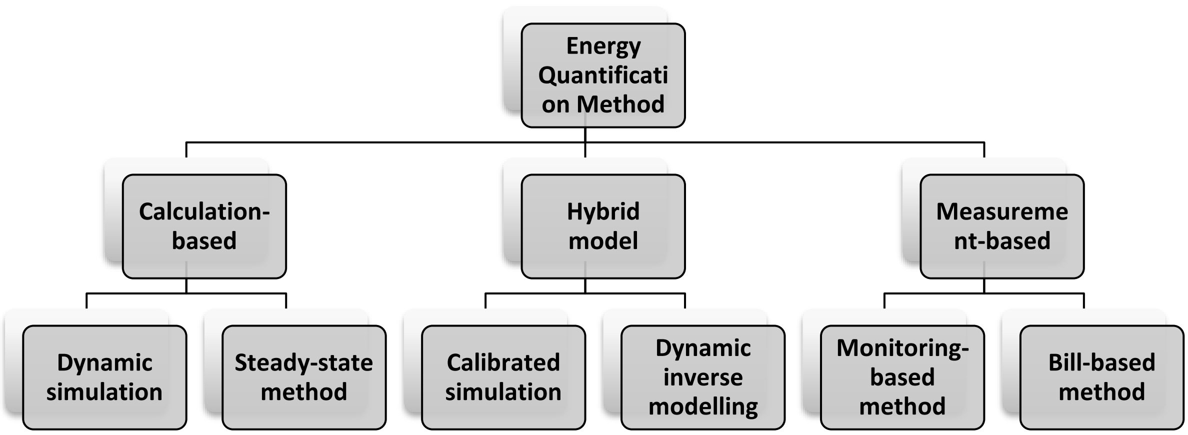


Figure 17: Energy quantification methods

Adapted, [40]

Both measurement-based and hybrid models require detailed energy monitoring data to carry out quantifications, the latter being the method normally recommended when all information is known, as it aggregates a calibration process through the use of monitoring data, then tending to be more accurate [40]. If there is no data available or they are unreliable due to the absence of heating and cooling systems. For example, the simulation is carried out using the calculation-based method, which was used in this study. It can be subdivided into two subcategories: dynamic simulation methods and steady-state methods [36].

I. Steady-state methods work through simplification of correlation factors, and they disregard construction dynamics, which reduces the complexity of the calculation but also brings limitations. The methodology uses, for example, a standard climate database with constant temperatures during the heating and cooling seasons, disregards more complex geometric shapes, such as domes and vaults, disregards lighting and the usage profile of the housing unit, among others [40].
II. Dynamic simulation methods, on the other side, are used to determine energy use in detail and take into account the effects of building dynamics. It analyses in detail the contributions of the thermal inertia of the walls, the outside temperature variability, solar radiation, natural ventilation, and occupant utilization. In addition, detailed data must be considered not only for the building properties but also for the climatic conditions [40] through a weather file that represents the typical weather conditions in the location of the building, at least on a time basis hourly [13].

Considering the above points, for the analysis of the defined case study and achievement of the proposed objectives, considering mainly that this dissertation also intends to analyse the influence of the variability of climate projections conditions for the future, dynamic simulation software is selected.

Dynamic Energy Simulation

A building is a complex thermodynamic object that accommodates ever-changing energy flows between the building's thermal zones and the exterior. Due to the complexity of the models, computer simulations can analyse the effects of different ECMs (Energy Conservation Measures) and their complex interactions more efficiently, comprehensively, and accurately than any other method [41].

Although dynamic energy simulation programs have the same main objective, each one of them uses a specific algorithm for calculations, has different input modes, and can produce outputs of different types. In general, the more powerful and complete the software is, the more detailed and necessary the data input [42].

Some building energy simulation programs feature not only the actual simulation engine but also a graphical user interface (GUI), which is used to prepare simulation input files for the former and to display simulation results. Advanced users of simulation programs generally edit their models manually using a text editor, while beginners often turn to GUI's. The engine is typically developed in public organizations such as government labs and universities, while GUIs are most often developed by commercial vendors. As a result, there are currently multiple GUIs for the same simulation engine. Although the choice of GUI implies the ease of use of the simulation program, it is the simulation engine that determines the reliability of the simulated results [41].

For this study, the US Department of Energy's 3rd Generation Building Dynamic Energy Simulation Engine was used: EnergyPlus (e+). The engine can be used for modelling buildings, heating, cooling, lighting, ventilation, and other energy flows, in addition to load calculations and modelling natural ventilation, photovoltaic systems, thermal comfort, water usage, and green roofs. EnergyPlus is validated by the standard benchmark test method for the evaluation of BESTEST (Building Energy Simulation TEST) / ASHARE STD 140 building energy analysis computer programs, one of the industry's most accepted methods for validating and testing the capabilities of these software [41].

DesignBuilder software (DB) was used in this study as the graphical user interface (GUI) for EnergyPlus. The tool is a mature product, also validated and tested by the BESTEST Standard Comparative Method / ASHARE STD 140, and it has quality control procedures that guarantee accurate results compared to the independent EnergyPlus engine. In addition to offering flexible geometry input and extensive and reliable component libraries (materials, schedules and activity profiles, HVAC system, etc.). The software presents results that can be displayed and analysed effectively in a comprehensive way. Finally, EnergyPlus is integrated into the DesignBuilder environment, which is advantageous, as it allows complete energy simulations to be performed without leaving the interface [41].

An important feature worth mentioning is that the DesignBuilder, like e+, follows the “model data hierarchy”. DesignBuilder also uses "data inheritance" through categories, which allows subcategories to be automatically populated through definitions made at higher hierarchical levels, as illustrated in Figure 18 [41].

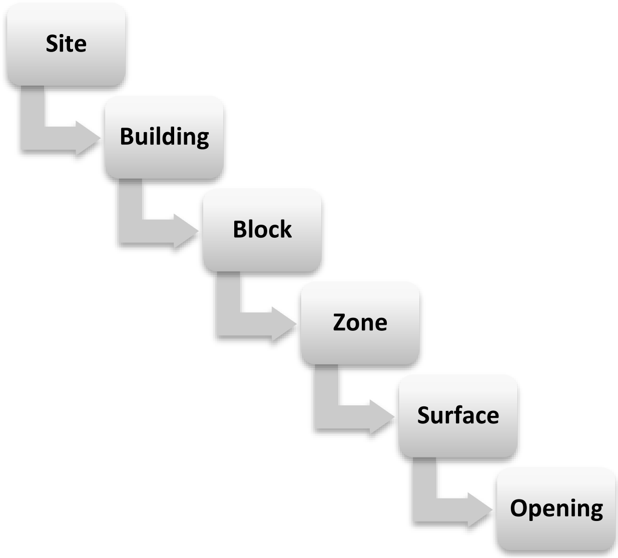


Figure 18: Model data hierarchy and data inheritance

Adapted, [41]

For example, for a building composed of several thermal zones, changes can be made to the configuration of the walls at the building level and thus the walls of all thermal zones are automatically updated. This feature makes data faster and more reliable as it automates the modelling process, reducing the number of individual and manual commands and definitions made in the model.

3.3 Input data

To estimate the neighbourhood's energy demand, a lot of different information has to be introduced in the model, as aforementioned, such as the building's location, construction form type, ventilation, occupancy, and weather parameters at the location of the building [13]. The level of detail of input data also depends on data availability, model purpose, and assumptions [38]. In this study, considering the goals and availability of data, the main input data influencing the energy model and improvement of the energy efficiency of the case study is divided as shown in Figure 19.

It is necessary to incorporate all the parameters together to understand a building's energy consumption, knowing that all variables related to the building and its use leads to simulations of the energy performance of buildings, which add algorithms and codes to the equation, making it even more complex, and giving rise to different possible values on a case-by-case basis [41].

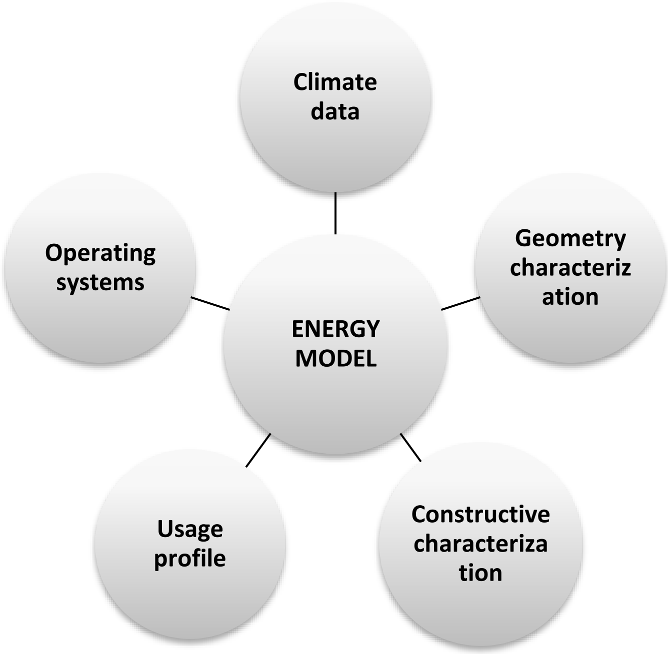


Figure 19: Categorized main input data for this study

3.3.1 Climate Data

Weather data

Site meteorological data is an essential input for the construction of energy, comfort, and daylighting simulations, providing the main environmental conditions needed to conduct the calculations. The location of the case study seriously affects the representativeness of the simulation outcomes [43].

When using dynamic simulation tools, some of the limitations of the degree-day method are addressed, as the heat losses and heat gains are calculated based on the particular building's thermal properties and internal gains on an hourly basis, and taking into account other weather parameters, which could affect the annual energy demand, such as solar gains, wind, humidity, etc. [13].

Typically, for the weather data, a representative year of hourly meteorological data is used to represent the typical regional climatic condition in which the object of study is located. Several methodologies have been developed over time to create this one-year weather data from historical weather records. The most commonly used methodology is the typical meteorological year (TMY), which was introduced in 1978 [44].

TMY consists of 12 separate months of data, each chosen to be the meanest month of the total years of measured data, through an empirical approach known as the Sandia method, which selects individual months of different years from the period of record [45].

For example, if there are 40 years of data, all 40 Januarys are examined and the one judged most typical is selected to be included in the TMY. The same procedure is repeated for the other months of the year, and then the 12 selected typical months are concatenated to form a complete year. Discontinuities at the month interfaces are smoothed for 6 hours on each side, due to the possibility of the existence of adjacent months in the TMY selected from different years [46].

The selection of the Sandia method considers nine daily indices consisting of [45]:

a. Mean dry bulb temperature;
b. Minimum dry bulb temperature;
c. Maximum dry bulb temperature;
d. Mean dew point;
e. Minimum dew point;
f. Maximum dew point;
g. Total global horizontal solar radiation;
h. Mean wind velocity;
i. Maximum wind velocity;

The dry bulb temperature is an indicator of heat, and it is the most commonly used air temperature property. It refers to the ambient air temperature, which is indicated by a thermometer not affected by the moisture of air [47].

Five candidates of each calendar year month are selected, with cumulative distribution functions (CDFs) for the daily indices that are closest to the long-term CDFs. What CDF does is provide the proportion of values that are less than or equal to a specified value of an index. The candidate CDFs for each month are compared to the long-term CDFs for each index using Finkelstein-Schafer (FS) statistics [45].

In this study, EnergyPlus “epw” format hourly weather data was used for simulations. This weather data format was originally developed for use with two major simulation programs EnergyPlus and ESP-r (Crawley et al. 1999) and nowadays is adopted as a standard format by many other building simulation tools. The file is text-based with comma-separated data and it is based on the data available within the older typical meteorological year version 2 format (TMY2) but has been reorganized to facilitate visual inspection [48].

The first eight lines contain location information such as longitude, latitude, time zone, elevation, annual design conditions, monthly average ground temperatures, typical and extreme periods, holidays/daylight saving periods, and data periods included. Then, the file is composed of 8760 lines of data, each corresponding to an hour of the year [48]. Some location information can also be visualized on an ASHRAE website [49], which contains the information in table form, with titles and indications. DesignBuilder also presents some of these indicators in the “Location” tab. These options can facilitate the understanding of the data for beginners who are not yet very familiar with the text-based file.

Energy Plus website provides the user with six weather data that are available for Portugal Continental: Bragança, Coimbra, Évora, Faro, Lisboa, and Porto (Figure 20). The file corresponding to the closest location of the case study chosen was used in the energy simulation.

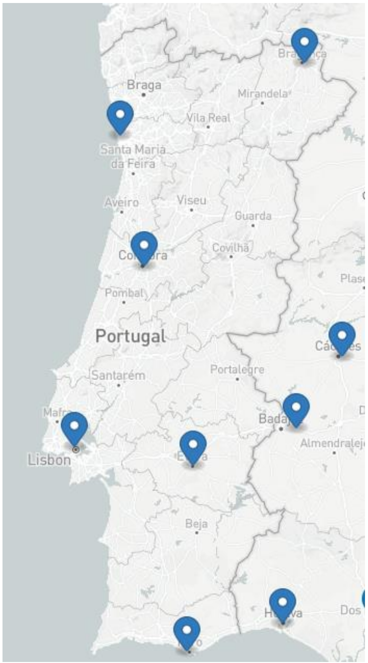


Figure 20: Epw weather data available for Portugal

Adapted, [50]

Climate zone classification

Climate zone classification is a way for designers and researchers around the world to identify in a simplified way some key characteristics concerning a specific region. The ASHRAE climate zoning classification is the one referenced in DesignBuilder through the weather file entered by the user. It’s widely used worldwide, and it is based on two main parameters: temperature and moisture [51].

First, the number associated with each zone tells how warm or cold it is, based on accumulated temperature calculations called degree days, which combine the amount of time and the temperature difference below some base temperature. Summing up, for heating and cooling, you add up the total number of HDD (heating degree days) or CDD (cooling degree days) for the whole year, and that tells you how hot, cold, or mild the climate is. The number zone based on this parameter ranges from 1 to 8, depending on the number of HDD and CDD, where zone 1 is the hottest of all and zones and zone 8 is the coldest one [51].

Second, ASHRAE classifies how moisture impacts the climate zones, considering mainly precipitation and annual mean temperature: in a nutshell, it is classified into moist (A), dry (B) or marine (C) [51]. The distribution of the different climatic zones around the globe is presented in Figure 21.

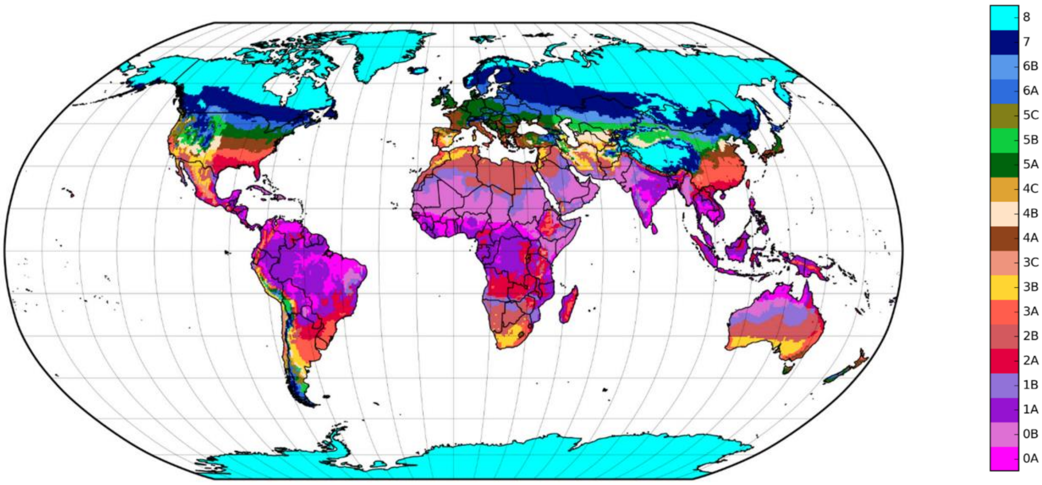


Figure 21 ASHRAE climate zones

[51]

However, it is also important to classify in which winter and summer climate zone the case study belongs according to Portugal's climate zoning, especially because it was used as a reference during the process of defining alternative energy renovation solutions detailed in the next section, as the choices must comply with local regulation.

For that, first, it is necessary to verify in Dispatch 15793-F/2013 in which NUTS III the case study corresponds. Then, using the reference values and slopes for adjustments in altitude for the heating season present in table 4 of the same document, for the region in question, the number of degree-days (GD) at the base of 18 °C can be calculated, with the corresponding altitude correction. In possession of this result, it is then possible to identify in which winter zone the case study is classified, following Table 1.

Table 1 – Criteria for determining the winter climate zone

GD ≤ 1300	**1300 < GD ≤ 1800**	**GD > 1800**
I1	I2	I3

Adapted, [52]

Similarly, using the reference values and slopes for altitude adjustments for the cooling season present in table 5 of the same Dispatch, for the region in question, the average outdoor temperature corresponding to the conventional cooling season ($\theta ext,\ v$) can be calculated, with the corresponding altitude correction. In possession of this result, it is then possible to identify in which summer zone the case study is classified, following Table 2.

Table 2 - Criteria for determining the summer climate zone

$\theta ext, v$ ≤ 20 °C	**20 °C < $\theta ext, v$ ≤ 22 °C**	**$\theta ext, v$ > 22 °C**
V1	V2	V3

Adapted, [52]

Future weather data

Obtaining present climate data is based on the observation of climatic parameters and the application of statistical methods for understanding existing trends. On the other hand, for future climate, future scenarios and climate model projections should be used [14].

Until recently, most weather data used in energy simulations consisted of purely historical readings. But, as more emphasis is placed on developing optimal performance and considering the influence of climate change on that behaviour, using traditional "typical year" climate data to project tomorrow's buildings that have to perform into future weather conditions is no longer a viable option [43].

This understanding has led scientists to make processes to predict future climate in different locations, without loading the ecosystem with more environmental degradation [13]. For this purpose, building energy simulation (BES) is an important support tool, through a robust meteorological dataset that defines the external boundary conditions that the construction faces during its lifetime [14], which must be accomplished using a future weather archive that incorporates climate change projections [13].

In this context, the creation of future weather files is usually approached in two ways, according to Herrera et al., 2017 [31]:

I. by combining climate projections with a weather generator to allow the creation of typical future weather years data;

II. or by a mathematical transformation (morphing) of the time series of existing current weather files using climate change forecasts;

The morphing method is most used in research on the impact of climate change on building energy use in the U.S.A, in Canada, Australia, Asia, and in Europe, using as input different GCMs (General Circulation Models), climate change scenarios, future time slices [24].

However, it is important to emphasize that anthropogenic global climate change would cause changes in atmospheric characteristics on a large scale. Thus, to fill the gap between the data that the climate modelling community can currently provide and the data required by the research community, it is necessary to reduce the scale of the climate projections of the GCMs, which can be done through the process of downscaling [53].

According to the IPCC, as stated by Brekke et al. [53] "downscaling is a method that derives information from a local to a regional scale (10 to 100 km). Downscaling of climate projections is the process of transferring the result of the general circulation model (GCM) to a more precise spatial scale that is more significant for analysing local and regional climatic conditions". It is a common practice for the operational weather forecast to correct the model outputs at subgrid scales [54].

One of the main techniques used for downscaling is the statistical method, which works through an empirical relationship between large-scale circulation variables and local climatic variables. After determining this relationship and based on the future climate variables of the GCM, the future regional climate variables are then predicted [55]. It is important to highlight that this methodology assumes that the current relationship between the large-scale circulation and local climate remains valid under different forcing conditions of possible future climates.

To obtain the future climate files used to analyse the resilience of the proposed renovation solutions in this study, the CCWorldWeatherGen is chosen. It is a Microsoft® Excel-based tool that uses a morphing methodology to create future weather datasets in Energy Plus Weather format (EPW) for multiple locations around the world. The tool was created by the Sustainable Energy Research Group at the University of Southampton and uses the Hadley Center Coupled Model 3 (HadCM3) global climate model with IPCC A2 emission scenarios [14].

HadCM3 A2 was chosen by the research group because at the time of development it was the only climate model that had all the necessary climate variables for the metamorphosis procedure. The model provides as input to the morphing the monthly value of relative changes over the period 1961–

1990 and generates future weather datasets for 3-time intervals: 2001–2040 (referred to as '2020'), 2041–2070 (referred to as '2050') and 2071–2100 (referred to as '2080') [14].

The main advantage of CCWorldWeatherGen is that it is a free online option, which makes it widely used. However, the main disadvantage involves the possible differences in the reference period between HadCM3 and EPW data, which can lead to inaccuracies in the tool results [14]. However, the results of previous studies have already shown that different downscaling tools used for the same purpose, including for example other well-known tools such as WeatherShift and Meteonorm, predicted the future energy performance and comfort analysis of buildings in a very similar way [14], [55]. Thus, it is believed that the chosen instrument meets the objectives established for this study

Possible emission scenarios for the next 100 years

The Special Report on Emission Scenarios (SRES) developed by the International Panel on Climate Change (IPCC) defines a family of possible emission scenarios for the next 100 years, based on economic, social, technological, and environmental assumptions, which can directly alter the energy performance results of buildings, and therefore must be known [56]. Figure 22 illustrates these driving forces and scenarios.

Ideally, the most assertive way to perform the resilience analysis would be through a sensitivity analysis considering different climate projections, but due to the limitations of the available tool for generating future weather files, only the A2 storyline, and scenario family is considered. It describes a very heterogeneous world, where the underlying theme is the preservation of local identities and self-reliance (Figure 23). A continued increase in the global population is expected through the slow convergence of fertility patterns across regions. Concerning economic development, it is mostly oriented towards the region and economic growth per capita and technological changes are more fragmented and slower compared to other scenarios [56].

Despite the limitation, it can be said that the A2 represents a business as usual scenario and can be considered a valuable and likely development path with significance for the built environment [57]. Furthermore, in terms of global surface warming, for example, Figure 24 shows more significant differences in 2100 between significant SRES scenarios, however, during most of the analysis period of the study in question (2022-2052) it is possible to verify that the differences are not that significant.

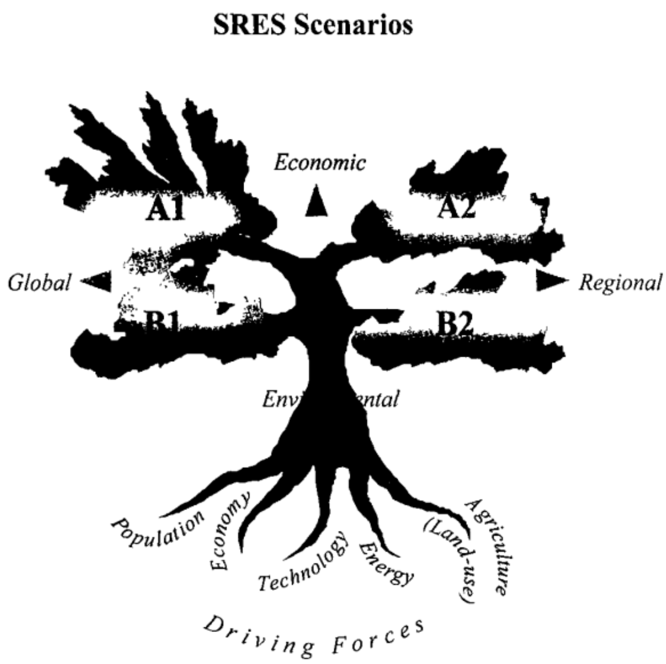


Figure 22: Driving forces for the different SRES scenarios by IPCC

[58]

Set			SRES					Total
Family		A1			A2	B1	B2	
Scenario Group	A1C	A1G	A1B	A1T	A2	B1	B2	
Globally Harmonized Scenarios[a]	2	3	6	2	2	7	4	26
Other Scenarios[b]	1	0	2	1	4	2	4	14
Total Scenarios	3	3	8	3	6	9	8	40
(Different Models Used)	*(3)*	*(3)*	*(6)*	*(3)*	*(5)*	*(6)*	*(6)*	*(6)*
			Scenario characteristics:[c]					
Population growth	low	low	low	low	high	low	medium	
GDP growth	very high	very high	very high	very high	medium	high	medium	
Energy use	very high	very high	very high	high	high	low	medium	
Land-use changes	low–medium	low–medium	low	low	medium/high	high	medium	
Resource availability[d]	high	high	medium	medium	low	low	medium	
Pace and direction of technological	rapid	rapid	rapid	rapid	slow	medium	medium	
change favoring	coal	oil & gas	balanced	non-fossils	regional	efficiency & dematerialization	"dynamics as usual"	

Figure 23: SRES scenarios by IPCC

[56]

Making projections over such a long period is a difficult task and the different outcomes of different scenarios reflect this uncertainty. Some demographers, for example, are already trying to understand the impact of the pandemic situation on fertility. Although they can identify a few changes in the growth trajectory for the short-term, how fertility rates and population numbers will change in the longer term is more difficult to predict and involves serious controversy. Regarding population trajectory around the world, according to Leontine Alkema [59], a statistical modeler at the University of Massachusetts

Amherst, “it’s kind of an impossible exercise and so we do the best we can and it’s good that different groups use different approaches,” she says.

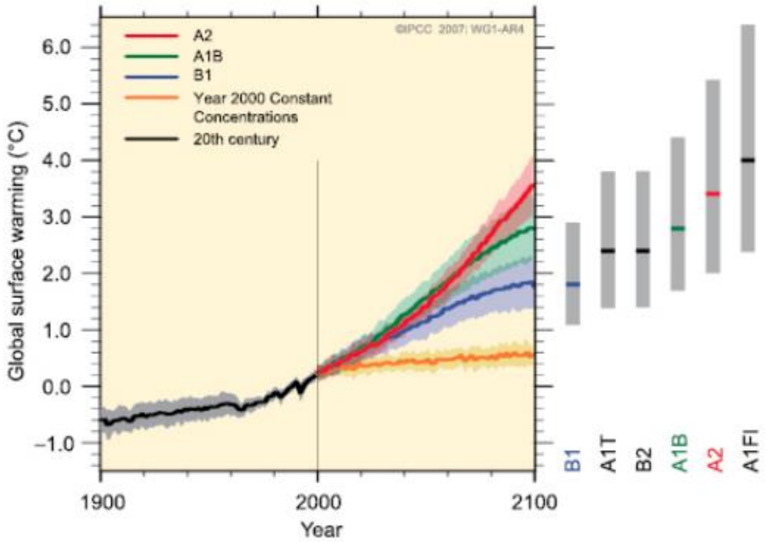


Figure 24: Multi-model average temperature increase concerning significant SRES scenarios [58]

3.3.2 Geometry characterization

Residential energy models can be built on a single thermal zone, building, neighbourhood, city, state, region, or nation. However, the larger the scale of the object of study, the more information is attached to the model, which results in greater time to complete the energy simulations, in addition to the time it takes to build the model itself [38]. For this reason, for the analysis of the chosen social neighbourhood, the main characteristics that vary between apartments within the neighbourhood and that influence the thermal behaviour of the dwellings were defined so that they represent the entire object of study with reduced computational time.

For the orientation of the apartments, the one predominant in the neighbourhood was used as an input in the energy model. The orientation of the house and its facades, impacts interior comfort, whether in the winter or summer [60], and influences on radiation, which results from the relationship between the energy of solar radiation that passes into the space and the external energy that falls on the window, impacting on the energy balance through the variable of internal gains [61]. In general, for Portugal, the south orientation is characterized by strong sun exposure, contrary to north exposure [60].

Regarding apartment size and number of rooms, a predominant typology in the neighbourhood was used as a reference apartment for the simulation. The dwelling was modelled as a single thermal zone, which is understood by EnergyPlus as a volume of air in which the thermal conditions are homogeneous [62]. The main focus of the modelling was on the envelope characteristics, as the energy performance of these elements is important, to improve the building's energy performance and approaches to the reachable co-benefits [63]. Internally, only the partition walls were modelled as "hanging partitions".

Hanging partitions are partitions that do not connect at both ends with other walls or partitions in the model, and they do not create thermal zones. They appear in light blue in the model so they can be differentiated, and they are translated non-geometrically in EnergyPlus as internal thermal mass [64], used to specify the construction and area of items that although are not important geometrically, can impact heat transfer values [65]

Regarding the position of dwellings inside the building and the different boundary conditions originated, the outcome of previous studies shows that this parameter has a significant impact on the variation of the quantity of primary energy from heating and cooling needs before and after the application of energy renovation scenarios. For example, the results of several modelling studies indicate that houses located on the upper floors of multi-residential buildings are more vulnerable to overheating when compared to houses on other floors of the same building [36].

Then, a selection was made of the most significant typologies for the modelling. Because the thermal losses through the roofs are the highest, at least one top-floor apartment should be considered in the simulation, so the impacts of the renovation measures on the roof can be detected on the model. In addition, due to walls and floors in contact with the ground having an impact on the thermal performance as well, at least one ground floor apartment is taken into account. Finally, because of the high number of adiabatic surfaces on middle floor apartments, at least one of them is also analysed [36]. However, due to the differences between an edge and a middle floor apartment, caused mainly because of heat transmission through the facade, for each of three cases, one dwelling of each position (edge and middle) is considered, originating six different typologies to be distinguished, as shown in Figure 25 [36].

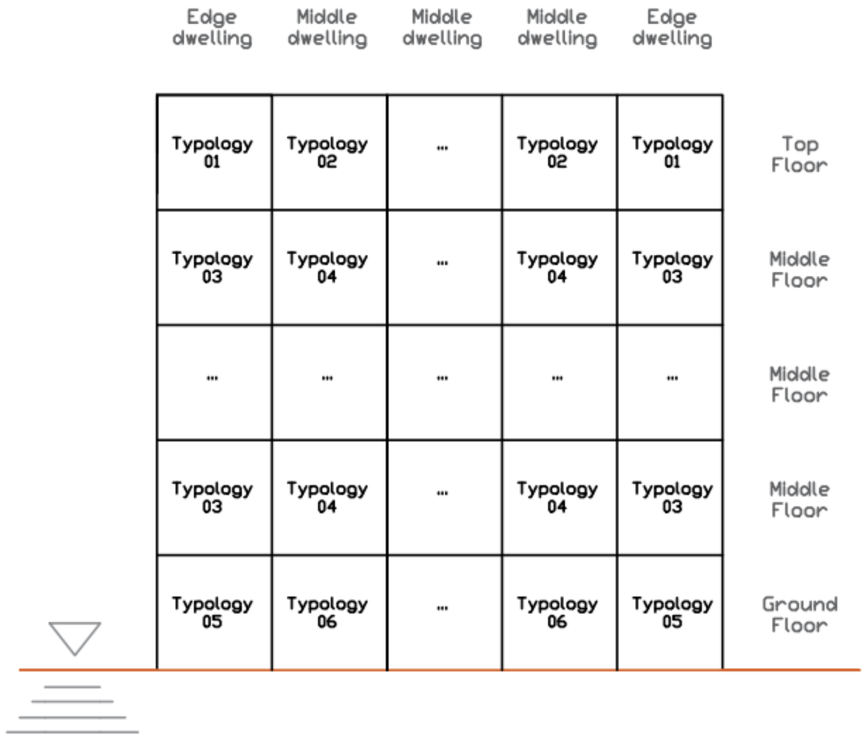


Figure 25: Typologies regarding boundary conditions

Boundary conditions are determined automatically by DesignBuilder based on its position. This is the default setting where external surfaces above the ground plane are considered to be in contact with outside conditions while the ones below the ground plane are considered to be adjacent to the ground. However, it is recommended that all boundary conditions be checked and set differently, when necessary [66].

It is even possible to settle surfaces as adiabatic, meaning that heat is not transferred to its outer surface, which is often used in thermal modelling to represent surfaces that are between two zones under similar conditions, which was used in this study for surfaces between dwellings of the building [66]. The software also identifies semi-exposed surfaces assuming the constructive characterization stetted by the user for these surfaces, which occurs in the case of the ones between a standard and a semi-exterior unconditioned zone.

For clarity, a Standard zone in DesignBuilder is a type of zone within the main envelope and is usually cooled and/or heated and occupied, such as the reference dwelling itself. On the other side, the Semi-exterior unconditioned zone is unoccupied, neither heated nor cooled, such as roofspaces, sunspaces, crawlspaces, parking lots, etc [67].

3.3.3 Constructive characterization

The constructive characteristics of existing technical solutions in a building and proposals for energy renovation are extremely important for the thermal behaviour of the building and occupant comfort level, being a crucial factor in the choice of materials.

For opaque surfaces, the most used parameter to identify them is the thermal transmittance, widely known as the U-value. It defines the ability of an element to transmit heat when no dynamic or static external forces are applied to it. It is computed as the quantity of heat that flows through a unit area in unit time per unit difference in the temperature of the individual environments between which the structure intervenes [68]. The lower the U-Value is the less likely heat is to transfer from one side of the element to the other, and therefore, the better that element is as an insulator [69].

When there is a difference in temperature between the inner and outer faces of a dwelling, the heat transmission through the surface depends on the resistance that each layer of material presented in the element imposes on that transmission (R1, R2, and R3 in Figure 26). In addition to this resistance, two microscopic air layers that are found on the faces of the element also affect heat transmission (Rsi and Rse) [70].

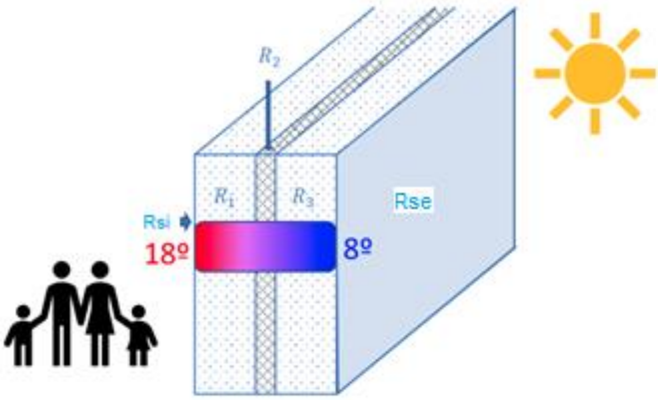


Figure 26: Thermal transmission coefficient of opaque elements

[70]

The U-Value is calculated as a sum of the thermal resistances (R-Values) of the layers that make the element plus the inside and outside thermal resistances, also known as surface resistances. The calculation of U-value is indicated in standard EN ISO 6946 and can be briefly accessed through Dispatch 15793-K/2013 [71]. The Equation for elements made up of several materials in layers of constant thickness is shown in Equation 1.

Equation 1 – U-value for opaque elements in layers of constant thickness

$$U - value = \frac{1}{\Sigma R + Rsi + Rse} \text{ [W/(m}^2\text{.°C)]}$$

[70]

On what:

R - Thermal resistance of layer, [m².°C/W];

Rsi - Interior thermal resistance, [m².°C/W];

Rse - Exterior thermal resistance, [m².°C/W];

The thermal resistance of the layer depends on the thermal conductivity of the material "λ" and the thickness of the layer "e". The thermal resistance of building material is obtained through Equation 2.

Equation 2 - Thermal resistance of each layer of building material

$$R = \frac{e}{\lambda} \text{ [W/(m2.°C)]}$$

[70]

Regarding thermal conductivity, as this is a characteristic of the material itself, this data can be obtained in the technical sheet to be provided by the manufacturer, but there is also information listed in ITE-50 by LNEC for typical values on thermal transmission coefficients of building envelope elements.

For the cases of elements composed of non-homogeneous materials, such as hollow brick perforated and lightweight slabs of concrete blocks, the manufacturer tests the material as a whole and provides the material's thermal resistance value in the technical sheet [72].

Regarding surface resistances (Rsi and Rse), they shall be defined following the EN ISO 6946 or following the typical values defined by ITE-50 or Dispatch 15793-K/2013 [71]. These values depend on convection phenomena and the direction of heat flow (horizontal, vertical ascending, and descending) [70].

DesignBuilder uses construction components to model heat conduction through building elements and other opaque parts of the envelope, as presented in Figure 27. The component can be selected on the Construction tab to define the thermophysical and visual properties of the various inner and outer surface elements of the building. The user can enter the reference U-value for each construction category of the model or describe the layers and materials and let the program calculate them [73].

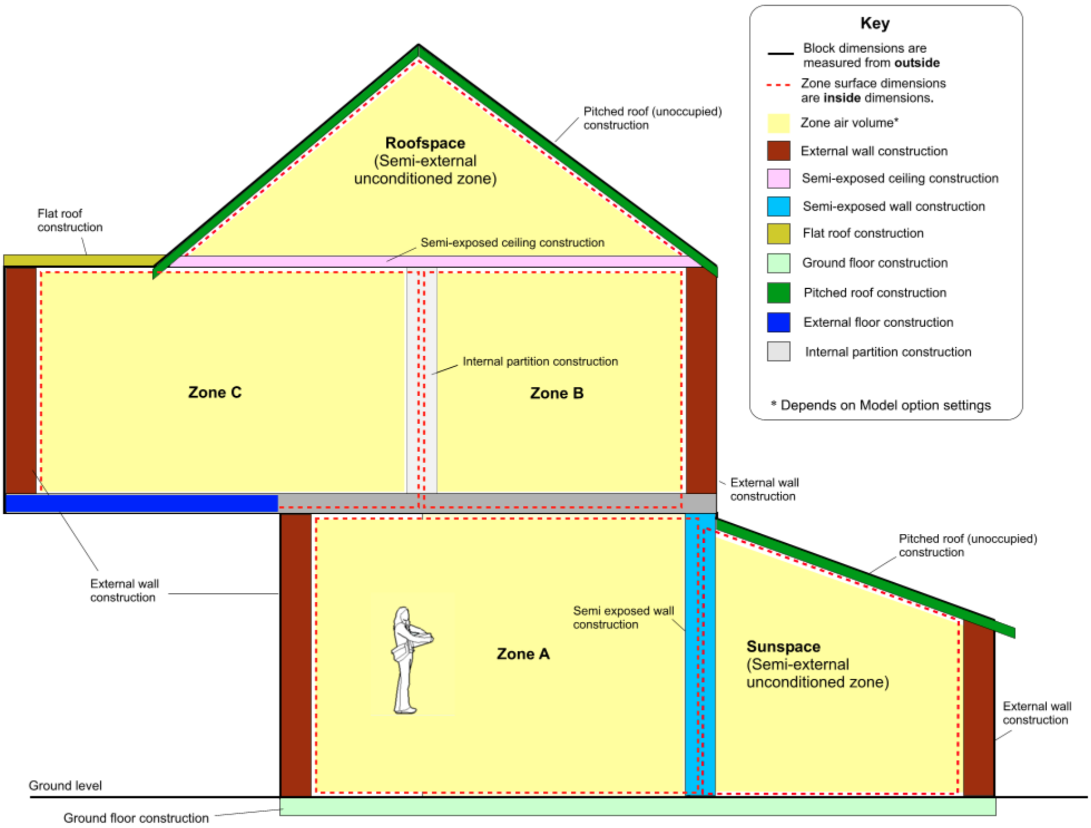


Figure 27: Schematic diagram showing construction locations

[74]

For example, in the Construction tab, the user can define for the "building level" that the exterior walls will be formed by a certain material with a certain thickness, and then the DB calculates the corresponding U-value, according to the energy code, and apply this setting to all exterior walls of the model. If for some reason there are differences in the constitution of a specific wall, it must be selected individually and then the change in the constructive characteristic will be made at the "surface level".

For this study, the U-values that will be indicated in the next section are calculated by DesignBuilder. However, it is important to highlight an exception for the pitched roof. The software describes U-values separately for the elements of a pitched roof - a value for the semi-exposed ceiling construction and a value for the pitched roof (which in this case would be just the sloped surface). So, in this case, despite normally introducing material layers into the Construction Tab of the model and allowing DB to calculate the U-value, the corresponding values for the complete solution were those referenced in this study, through the typical values defined in the ITE-50, to subsequently carry out verifications in terms of the minimum requirements established by the national regulation, as per ordinance 379-A/2015.

It is noteworthy that layers that have a minimal influence on the thermal behaviour of the solutions and that were present both in the reference solutions and in the renovation proposals, such as painting layers, weren't modelled in the program, considering that they would not influence the objective of the study. For example, considering that the entire apartment was modelled as a single thermal zone and that the definition of the construction solution for the floors was made for the entire housing unit, only one type of floor covering was defined for the entire apartment instead of distinguishing the specific coverings for the wet and dry areas. The same logic was applied to wall covering, for the same reason.

Thermal bridges

A thermal bridge is a localized discontinuity in the thermal envelope of a building that usually occurs when the insulation layer is interrupted by a more conductive material. They are responsible for the increase in heat transfer caused by the decrease of resistance in these places of the building [75].

The existence of thermal bridges in the envelope of buildings has negative implications on energy consumption, especially regarding energy needs for heating, due to the increase of thermal loss to the outside, besides increasing the risk of occurrence of certain pathologies, mainly related to humidity [76].

DesignBuilder calculates a total linear thermal bridge at junctions per zone by multiplying the length of each of the bridge categories, through the external dimensions of the zone, for the Psi of the category. The default Psi values used in DB are based on BRE IP 1/06 values degraded by the greater of 0.04 W/mK or 50% [77].

Linear thermal bridges are also known as non-repeating thermal bridges and they describe the heat transfer that occurs at junctions between elements. This can include, for example, junctions at corners, where external walls join with the floor, or where external walls are bridged by lintels, jambs, or sills where window or door openings are installed, as illustrated in Figure 28 [78].

Full thermal bridge out-of-zone transmission is included on the EnergyPlus model using a single standard surface called "WallExterior" per zone, with no film resistance applied. To avoid affecting shading calculations, these surfaces are located in the model below the building. Their area is fictitious and is calculated so that the total conductance is the same as the sum of the linear bridging transmittance based on the known conductance of the construction [77].

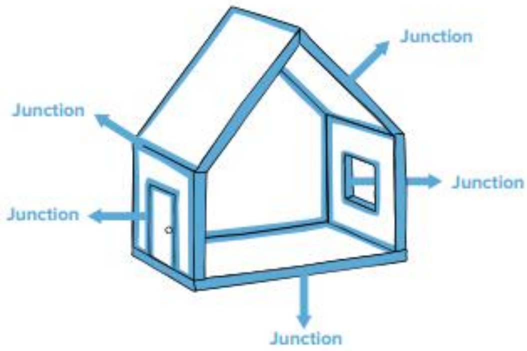


Figure 28: Examples of thermal losses due to linear thermal bridges at junctions

[75]

The thermal bridges that occur between structural elements, as in the case of the meeting of exterior walls with intermediate floors (Figure 29), are responsible for negatively influencing the thermal behaviour of the housing unit, however, they are considered in the study quantitatively only linearly and not flat, as described above. Nevertheless, it is known that some solutions are recommended to reduce these thermal losses and this was qualitatively considered in the choice of renovation solutions. For example, the Dispatch 15793-E/2013 alerts to the fact that if the solutions can guarantee the absence or reduced contribution of thermal bridge areas, for example through the use of measures such as continuous thermal insulation from the outside, it can be considered that the U-value is not increased by the bridging thermal losses [79].

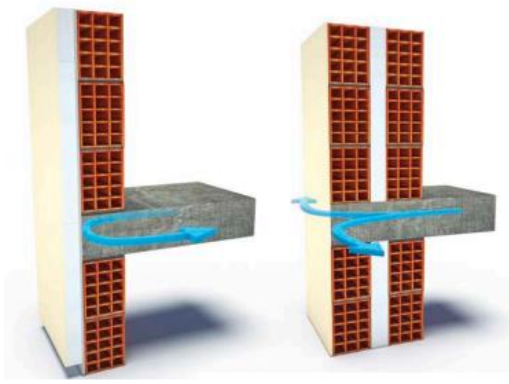


Figure 29: Case example for heat flow through the facade, according to the position of the thermal insulation

[80]

Glazed elements

The choice of windows materials has a major influence on the amount of heat that goes both in and out of the building passively. The U-value of a single-window "Uw" can be calculated using Equation 3, according to ISO 10077-1 [81] (Figure 30). Typical values for the complete solution can also be found in ITE-50.

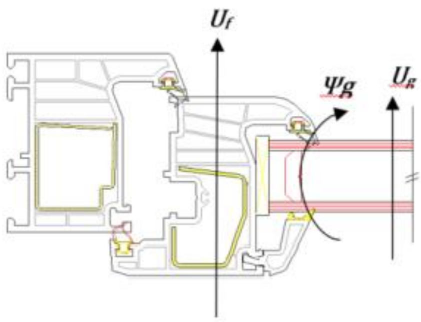


Figure 30: Thermal transmission coefficient of windows

[70]

Equation 3 – U-value of a single-window

$$Uw = \frac{AfUf+AgUg+lg\Psi g}{Af+Ag} \text{ [W/(m2.°C)]}$$

[70]

On what:

Af: area of the frame, [m²];

Uf: thermal transmittance of the frame, [W/(m².°C)];

Ag: area of the glazing, [m²];

Ug: thermal transmittance of the glazing, [W/(m².°C)];

lg: perimeter of connection between the frame and the glass, [m];

Ψg: linear thermal transmittance due to the combined thermal effects of glazing and frame, [W/(m.°C)];

The equations presented refer to external vertical windows. If the opening is interior or in the horizontal position, it is necessary to carry out the correction, considering the surface resistances.

The values of "Ψg" for different types of material frames and glazing are tabulated in the same ISO mentioned above. The areas "Ag" and "Af" were calculated according to the glazed fraction established by Dispatch 15793-K/2013, according to the frame in use, and the dimensions of the openings [71].

In the case of glazed openings that have solar protection, a reduction in "Uw" is considered when the shading device is active, through the increase of thermal resistance caused by the element, known as "Un" and calculated following Equation 4.

Equation 4 – U-value of a single-window with solar protection activated

$$Un = \frac{1}{\frac{1}{Uw} + \Delta R} \text{ [W/(m2.°C)]}$$

[70]

On what,

ΔR: additional thermal resistance due to activated sun protection, [m2.°C/W];

"ΔR" varies according to the type and material of the sun protection and air permeability. Typical values can be consulted at ISO 10077-1.

With the "Un" value obtained, it is possible to calculate the new U-value representing the window, called "Uwdn", which corresponds to the weighting of the thermal transmission coefficient of the window without a solar protection device and with closed shutters. Devices are normally considered to be active for half of the day, according to REH. For this study, the fraction of time mobile shading devices are activated was specifically determined following Dispatch 15793-K/2013, depending on the solar orientation of the facade, and the final value of "Uwdn" was weighted accordingly:

For the openings oriented to the north in the model under analysis in this study, mobile solar protection devices were disregarded, to maximize the use of solar radiation, as recommended in the same document aforementioned.

For glazing elements, other properties are also important besides the U-value, and they must be analysed to ensure good thermal behaviour, such as Visible Transmittance (VT) and Solar Heat Gain Coefficient (SHGC) or g-value.

The visible transmittance distinguishes the amount of light that windows allow through. This value is important since it diminishes the amount of energy used for lighting during the day. The visible transmittance relates only to the visible sunlight spectrum (380-720 nanometers), which is transmitted through the glazing of a window, door, or skylight [82].

A higher VT transmits more visible light than a lower VT. It is a factor to consider during construction and especially renewing older buildings. In warm places, for example, it is sometimes better to have a lower VT value due to the amount of heat that glaring adds to the building's interior. In DB, a fractional value from 0 to 1 must be imputed in the model and it is the rated value for visible transmittance at normal incidence [83]. The coefficient shall be presented by the manufacturer and consulted on technical datasheets.

The solar transmittance of glazing elements is usually characterized in the United States by the solar heat gain coefficients (SHGC) and in Europe by g-values. In essence, these both represent the fraction of incident solar radiation transmitted by a window and they range between 1 and 0, where zero indicates no solar heat gain and 1 the maximum possible solar heat gain. DB uses the concept of SHGC for windows characterization [84].

The solar coefficient of the glass applied in the openings for a normal solar incidence on the surface, i.e. "gvi", must be provided by the manufacturer. The g-value can also be consulted within the typical values indicated in table 12 of Dispatch 15793-K/2013. The coefficient can also be calculated using the method described in EN 410 [71].

As with the U-value, the g-value also has its value changed due to the use of solar protection devices, as they influence solar transmission. The global solar factor "gt" with solar protections fully activated is calculated through the following Equations 5 and 6.

For single glazing:

Equation 5 – gt for single glazing elements

$$gt = gvi \, \Pi \frac{gtvc}{0.85}$$

[70]

For double glazing:

Equation 6 – gt for single glazing elements

$$gt = gvi \, \Pi \frac{gtvc}{0.75}$$

[70]

On what:

gtvc: solar factor of the glazed element with current glass and a sun protection device, permanent, or fully activated mobile, for a normal solar incidence on the glass surface, according to Table 13 of Dispatch 15793-K/2013;

3.3.4 Usage profiles

In energy simulation, the effective operating period of a building that reflects the behaviour and human presence per hour is defined by Usage Profiles. These profiles refer, for example, to the fraction of lighting equipment that is active and the time that windows are opened during the day. These data sets have a significant effect on the energy needs of a building, especially because of the influence it has on internal gains and heat transfer by ventilation [85].

However, it is difficult to have accurate information about real schedules and uses for each dwelling of a neighbourhood and these uncertainties in simulation inputs may have an impact on outputs [86]. To introduce input variables in this simulation model, it was prioritized pre-defined profiles and recommended by accredited entities, taking into account the type of building under study. In the case of the adoption of empirical and typical values, such as for ventilation, they were made based on the concepts and considerations described as follows. It is also important to highlight that this data remains the same in the reference and renovation scenarios studied so that it is expected that the possible variations resulting from the actual use and schedules didn't significantly affect the choice of the renovation proposal that was made at the end of this study.

Internal gains

In a dynamic simulation, internal gains are defined every hour and account for all heat sources that contribute to the natural heating of the space, so it does not account for an auxiliary heating system. It results from heat dissipation by equipment, lighting devices, and people's metabolism inside the thermal zone [86]. It is important to emphasize that including these internal gains in heating sizing simulations leads to under-sizing the systems. So, the general rule is to avoid including any internal gains in heating sizing simulations for any schedule to be used to control internal gains [87].

Definitions of schedules can be used as input in DB in three different ways [87], [88].

a) "7/12 schedules" considers a unique daily variation defined using profiles for each day of the week and each month of the year;

b) "Day schedule" is a special type that defines the profile for a single day;

c) The "compact schedule" was the one used in this study, mainly because it is a more flexible definition that uses a slightly modified version of the standard EnergyPlus "Schedule:Compact" text-based data format.

The Compact Schedule shall contain the elements "Through (date)", "For (days)", "Interpolate (optional)", "Until (time of day)" and "Value". The value is recommended to be a fraction in the range between 0 and 1 [87].

For example, if it is defined that in an apartment the number of people is equal to 4, it is possible, through the compact schedule, to define an occupancy factor for a specific interval of time different from the maximum value imputed. Then, the code for this example shown in Table 3 informs that between 06:00 and 18:00 for weekdays, the calculation of occupant metabolism to be considered in internal gains shall take into account only 2 people instead of the maximum value of 4 defined to the rest of the day.

The code exemplified in Table 3 also informs EnergyPlus that this variable influences the thermal zone calculations only during the cooling season ("For: SummerDesignDay Until 24:00, 1,") while for the rest of the year it will be disregarded ("For: AllOtherDays Until 24:00, 0,").
In addition to defining the schedules, other information is needed to contemplate the internal gains of the thermal zone.

Table 3 – Example of a compact schedule

```
Schedule:Compact,
Occ_Residential,
Fraction,
Through: 31 Dec,
For: Weekdays,
Until: 06:00,      1.00,
Until: 18:00,      0.50,
Until: 24:00,      1.00,
For: Saturday,
Until: 08:00,      1.00,
Until: 18:00,      0.50,
Until: 24:00,      1.00,
For: Sunday Holidays,
Until: 08:00,      1.00,
Until: 18:00,      0.50,
Until: 24:00,      1.00,
For: SummerDesignDay,
Until: 24:00,      1,
For: AllOtherDays,
Until: 24:00,      0     ;
```

Because values of internal loads resulting from heat dissipation by equipment and lighting can vary a lot depending on the quantity of equipment, quality, material of lighting, time of use, etc., then typical values for medium internal loads were used for this purpose, referenced in ordinance 349-B/2013.

However, heat gains due to people's metabolism were additionally calculated separately. Recent census studies recommend that the total number of occupants is based on two persons for the first bedroom, plus one person for each additional bedroom, which corroborates with the expression recommended in Dispatch n.° 15793-I/2013 [89], [90].

Equation 7 – Total number of occupants, according to number of bedrooms

$$T0 \rightarrow 2\ occupants$$

$$Tn \rightarrow n + 1\ occupants$$

[90]

On what:

"n" is the number of bedrooms;

Regarding metabolism, DesignBuilder expresses the physical activity of humans as "met", which amounts to 58.2 W.m². One met is an average metabolic rate for a person seated at rest. The average body surface area for adults is considered as 1.8 m², therefore 1 met is equivalent to approximately 100 W of total heat emission. The software suggests the user to a metabolic rate of 1 for an adult man, 0.85 for a woman, and 0.75 for a child, which corresponds to 100 W, 85 W, and 75 W, respectively. The factor is then multiplied by the number of people in the thermal zone to find a total contribution corresponding to an occupation [91].

The fraction of time mobile shading devices are fully activated in the cooling station "Fmv" also modifies the internal gains that occur through the window, as mentioned before in previous sections. In this way, the amount of time they were used was defined depending on the window orientation, according to the values tabulated in the Dispatch 15793-K/2013.

To maximize the use of solar radiation during the winter, mobile solar protection devices are considered to be fully open.

Air renovation

Regarding ventilation, the impact on energy demand occurs due to heat transfer corresponding to the renovation of indoor air, which can be mainly influenced by infiltration, natural and mechanical ventilation [90].

Air infiltration is the unintentional leakage of air through a building due to small openings, joints, or imperfections that may exist in the structure, such as cracks around doors and windows or between cladding sheets. This parameter is closely dependent on the construction, materials, and condition of the building. Older buildings usually present higher infiltration rates than new buildings, especially because the last ones use to have a more airtight envelope, mainly due to the higher requirements implemented with its construction time [92]. For infiltration, a constant ACH value (air changes per hour) under "Airtightness" on the "Construction tab" shall be imputed in DesignBuilder [93].

Natural ventilation is characterized by the airflow flowing through a building resulting from the designed provision of specified routes such as openable windows, ducts, shafts, etc, as illustrated in Figure 31. Because these areas are usually larger than the imperfections mentioned above, they usually have a greater influence on the heat transfer of the dwelling than infiltration. Both natural ventilation and infiltration depend on the natural forces of wind and gravity [92].

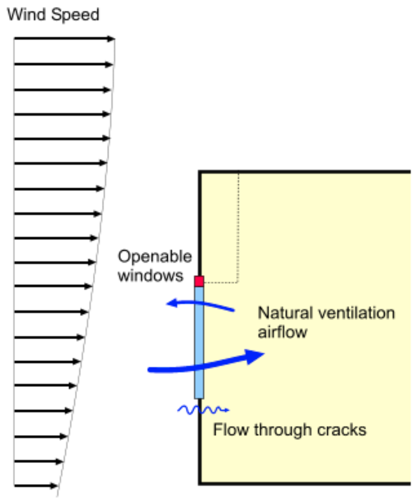


Figure 31: Natural ventilation airflow

Adapted, [93]

During the cooling season, natural ventilation can have a favourable effect on the indoor temperature, depending on the time of the day. This happens especially because the indoor temperature uses to be higher than the outdoor temperature, mainly during the night, so in these conditions the entry of outside air through the opening of windows or other openings placed in the facades tends to reduce the cooling needs and improve its thermal comfort conditions, being one of the reasons why natural ventilation at night is usually recommended during this time of the year [62].

The Regulation on Energy Performance of Housing Buildings (REH) defines the comfort temperature for the cooling season of 25˚C, which ideally should be ensured at all hours. However, due to the thermal amplitude during the day and unpredictable weather conditions, it is usually not possible to achieve it naturally in current residential buildings, during the entire period of the cooling season, without generating energy costs [62].

During the heating season, opening windows is not advisable, as the temperature inside the dwelling is generally higher than the temperature outside, so, it is usually recommended that windows if manipulated, stay open for a minimum period. The minimum daily outdoor temperature in this season is often less than 10˚C while the indoor temperature recommended by the REH as comfort is 18˚C. This difference makes it difficult to maintain comfort conditions throughout the heating season. To alleviate the drop in interior temperature, it is common to use some type of heating system inside the dwellings in winter, which results in energy costs [62].

The Scheduled approach used in DesignBuilder requires that the natural ventilation rate is explicitly defined for each zone in terms of a maximum ACH value. A range of control options is provided, such as the definition of ventilation setpoint temperatures, which can be made to prevent windows are opened depending on established limits of indoor or exterior temperatures (minimum or maximum range of control). The natural ventilation flow rate and programming data are accessed in the "HVAC tab", which encompasses airflow through windows, vents, and external doors. The opening extension of the windows can also be changed, which may vary, for example, according to the type of opening of the windows (sliding window, tilting window, etc.) [93].

It is essential to mention that even during periods of the day when the windows are not opened, it is necessary to ensure the minimum air renovation required, which corresponds to the sum of the air flows admitted to the building divided by the useful interior volume of it. For residential buildings, the hourly air renovation rate calculated following the provisions set out for this purpose in the Dispatch of the Director-General for Energy and Geology must be equal to or greater than 0.4 ACH [94].

Regarding mechanical ventilation, it also impacts the balance of the airflow inside an apartment, as it is characterized by the renovation of air promoted by mechanical fans, that ensure, in a controlled and uninterrupted way, the flow of air between outside air inlet openings and the air extraction openings connected to ducts. There are systems with mechanical insufflation and extraction and systems with extraction fans only [95].

Mixed ventilation is the combination of two types of conditions, natural and mechanical, being characterized by the existence of individual extractors (exhausters, bathroom extractors) connected to individual ducts. In Portugal, 96% of existing residential buildings have natural/mixed ventilation with extractors in the kitchen and toilets [95].

3.3.5 Technical Systems

For the sizing and definition of the use of technical building systems to calculate heating/cooling needs, the basic EnergyPlus ZoneHVAC method was used: "IdealLoadsAirSystem", within the configuration of "Simple HVAC". HVAC stands for Heating, Ventilation, and Air Conditioning systems [96]. The ideal load is the amount of heat that must be added or subtracted from a thermal zone for it to maintain the air temperature at a certain level, which for this study follows the comfort temperatures mentioned in the previous section (18˚C for the heating season and 25˚C for the cooling season), following guidance from REH [97].

However, the space load does not correspond to its energy use, which requires further conversion according to the efficiency of the equipment. The efficiency "η" represents the ratio of energy provided by a unit relative to the amount of input required to generate it. So, systems with higher values are more efficient, if comparing this only variable. It is worth mentioning that for air conditioning equipment, usually the energy efficiency is measured using the Energy Efficiency Ratio (EER) for cooling and Coefficient of Performance (COP) for heating [98].

In the absence of HVAC equipment or project specification in the building, for the calculation of heating and cooling needs, default technical systems and their coefficients must be assumed, according to the guideline of ordinance 349-B/2013 [79], [99].

3.4 Energy needs

3.4.1 Useful energy

I. Heating and Cooling

In possession of all inputs and after running the energy simulation through DesignBuilder, the results calculated by EnergyPlus for sensible heating and cooling were obtained for each of the six typologies described in section 3.2.2. These values correspond to the nominal annual useful energy needs for heating and cooling, known as "Nic" and "Nvc", respectively. The energy needs are expressed as [kWh/ m^2.year] and they are the results of the main parameters that influence energy needs in each of the correspondent seasons (Figure 32), such as the heat transfer by transmission through the building envelope [kWh], heat transfer from air renovation [kWh] and useful thermal gains resulting from gains through glazed openings, lighting, equipment and occupants [kWh], normalized by the useful interior floor area of the building “Ap”, measured by the interior [m^2] [90].

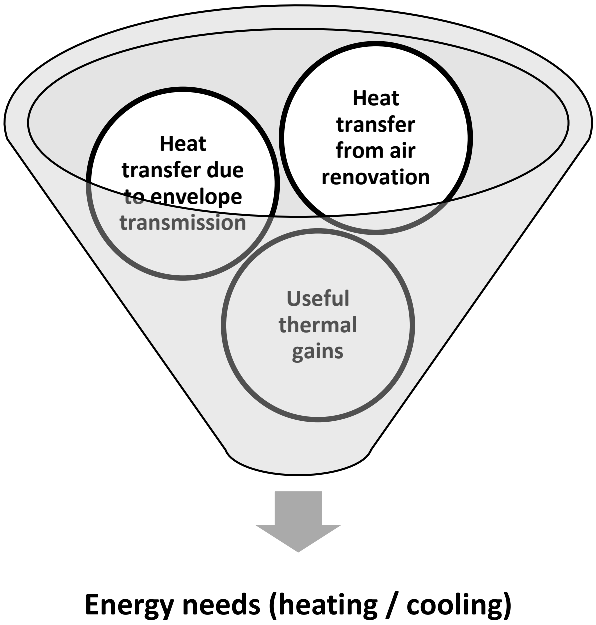


Figure 32: Parameters influencing heating/cooling energy needs

II. Domestic Hot Water (DHW)

The calculation of the energy use required for the preparation of Domestic Hot Water (DHW) for one year was made on Microsoft® Excel, following Equation 8, according to Dispatch 15793-I/2013.

Equation 8 – Annual energy needs for DHW

$$Qa = (MAQS * 4187 * \Delta T * nd)/3600000 \quad [kWh/\text{year}]$$

[90]

On what:

ΔT: temperature increase necessary for the preparation of DHW, which has a reference value of 35°C.

nd: the annual number of days of consumption of DHW of residential buildings that are considered as 365 days for effects of calculation.

In residential buildings, the average daily consumption of reference is calculated according to Equation 9:

Equation 9 – Average daily consumption of DHW

$$MAQS = 40 \times n \times feh \text{ [liters]}$$

[90]

On what:

n: conventional number of occupants of each autonomous fraction;

feh: Water efficiency factor, applicable to showers or shower systems with water efficiency certification and labelling. Because the apartments do not include showers or shower systems with label A or higher, it is considered feh equal to 1.

Neighbourhood weighted useful energy needs

The result of each portion of energy needs ("Nic", "Nvc" and "Qa") for each of the six typologies was weighted according to the number of apartments presented in the neighbourhood for each typology, according to Equation 10.

Equation 10 – Neighbourhood weighted energy needs

$$w.en = \frac{\sum en,x}{\sum n,x} \quad [\mathrm{kWh/\ m^2.year}]$$

On what:

w.en: weighted energy need, [kWh/ m^2.year];

en,x: energy need for typology "x", [kWh/ m^2.year];

n,x: number of dwellings of typology "x" in the neighbourhood, [units];

3.4.2 Primary energy

The process of converting primary energy to useful energy involves losses due to the transformation and conversion processes involved in the energy flow [100]. The conversion of final energy to useful energy related to the technical systems depends on the efficiency of each one of them "η", while the conversion of primary energy into useful energy depends on the conversion factor "Fpu", which varies according to the energy source (electricity, gas, etc.) [90]. Figure 33 illustrates this process.

"Fpu" values can be found in Dispatch 15793-D/2013, assuming a value of 2.5 for electricity, regardless of whether it is from a renewable source or not, and 1.0 for all others [90]. Meanwhile, the efficiencies of technical systems are defined as the useful energy output (benefit) divided by energy input (cost) and it is usually a value provided by manufacturers, but it can also be calculated through this relationship in possession of both data [101]. In the case of systems that are not specified in the project or installed, the applicable default solutions indicated in Ordinance 349-B/2013 must be considered [90].

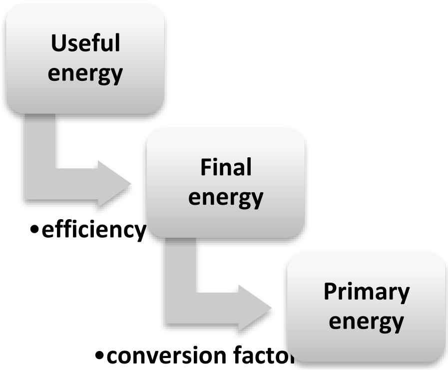


Figure 33: Conversion process between primary and useful energy

Adapted, [94]

The calculation of the nominal primary energy needs of residential buildings results from the sum of the specific nominal primary energy requirements related to the different uses: heating, cooling, DHW production, and mechanical ventilation, deducted from any contributions from renewable energy sources. According to Dispatch 15793-I/2013, the calculation can be made following Equation 11 [90].

Equation 11 – Annual nominal primary energy needs

$$Ntc = \sum_j \sum_k \left(\frac{fi,k*Nic}{nk}\right) * Fpu,j + \sum_j \sum_k \left(\frac{fv,k*\delta*Nvc}{nk}\right) * Fpu,j + \sum_j \sum_k \left(\frac{fa,k*Qa/Ap}{nk}\right) * Fpu,j + \sum_j \frac{Wvm,j}{Ap} * Fpu,j - \sum_p \frac{Eren,p}{Ap} * Fpu,p \qquad [\mathrm{kWh/\ m^2.year}]$$

[90]

On what:

Nic: useful energy needs for heating, supplied by the k system, [kWh/ m^2.year];

fi,k: parcel of useful energy needs for heating supplied by the k system;

Nvc: useful energy needs for cooling, supplied by the k system;

fv,k: parcel of useful energy needs for cooling supplied by the k system;

Qa: useful energy needs for DHW preparation, supplied by system k, [kWh/.year];

fa,k: parcel of useful energy needs for DHW supplied by the k system;

nk: efficiency of system k, which takes the value of 1 in the case of systems based on renewable energy sources, except for solid biomass burning systems where the efficiency of the burning system must be used;

j: all energy sources including those of renewable origin;

p - sources of renewable origin;

Ener,p: energy produced from renewable sources p, [kWh/year], including only consumed energy;

Wvm: electric energy necessary for the operation of the fans, [kWh/year];

Fpu,j, and Fpu,p: conversion factor between useful energy and primary energy, [kWhep/kWh];

δ: equal to 1, except for the use of cooling which can take the value 0 whenever the factor of use of thermal gains is higher than the respective reference factor, which represents the conditions in which the risk of overheating is minimized;

Renewable energy

The contribution of renewable energy must be quantified following the recommendations provided in dispatch 6476-H/2021.

A. Solar thermal systems (ST)

For the study in question, the "Eren" of solar collectors' systems was obtained using the SCE.ER, a Microsoft® Excel-based tool provided by the Director-General for Energy and Geology. First, it is necessary to introduce data in the file, such as the location and occupancy of the dwelling (number of rooms and people), so the minimum systems requirements can be simulated, according to Decree-Law 118/2013. Only then the type of solar collector (thermosiphon or forced circulation) and its characteristics are defined, so the "Eren" of the chosen system is calculated.

The functioning method for both is the same, that is, a collector transforms heat into thermal energy by capturing the sun's radiation, normally for heating water, for example [102].

The thermosyphon system is usually indicated for general buildings due to its ease and independence of operation, as the circulation of water between the collector and the tank occurs by gravity because of the thermosyphon effect, hot water rises to the tank and the cooler goes down to the collector. Note that the tank is insulated to prevent losses [102]. On the other hand, for the forced-solar system, it is essential to install the collectors on the lid and bottom of the tank, requiring a pump for the transport of water. This system typically requires more material and therefore costs are typically higher [102]. Figure 34 exemplifies these two methods.

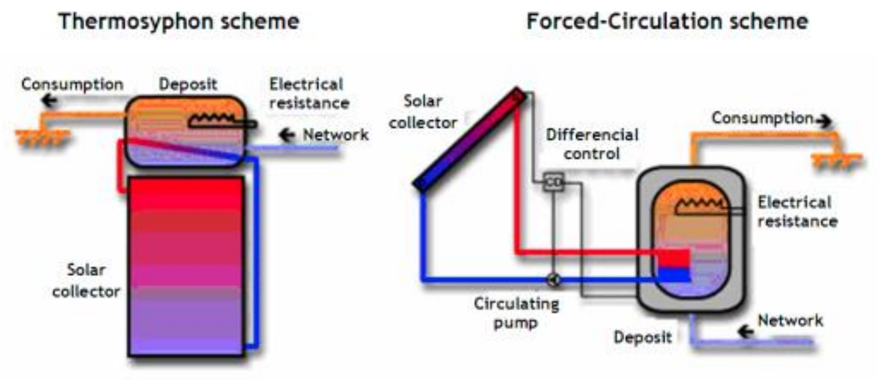


Figure 34: Thermosyphon x forced-circulation schemes

[102]

B. Solar Photovoltaic Systems (PV)

Photovoltaic modules are usually made of silicon and convert solar energy into electrical energy. They are connected to inverters to carry out the conversion of direct current (DC) into alternating current (AC), for harmonization with the housing energy supply [103].

For the photovoltaics (PV) contribution, the Photovoltaic Geographical Information System (PVGIS) by the European Commission - EU Science Hub was used, which is a tool available online. The tool also requires the input of information related to the location of the object of study, as well as the installed peak PV power [kWp], which depends on the number of modules used in the building and the power of each one of them [104]. It encompasses both system options: off-grid and on-grid, as shown in Figure 35.

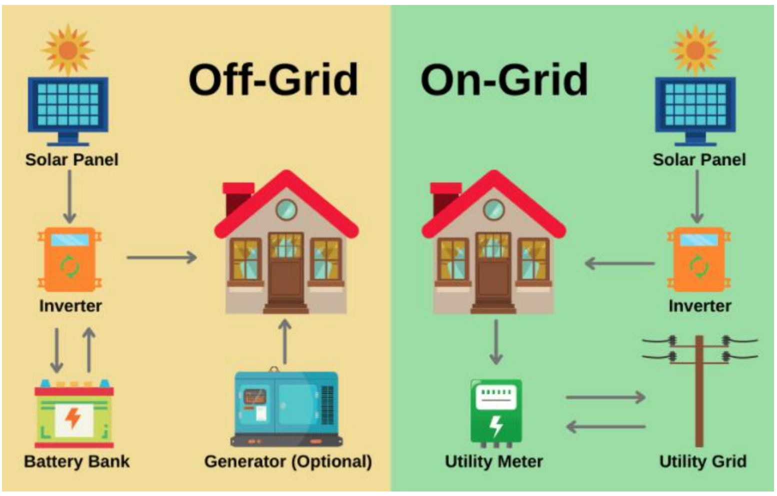


Figure 35: Off-grid x on-grid solar systems

[105]

In the case of on-grid systems, they are connected to the utility grid. This means that when the energy demand is greater than that supplied by the panels, for example on cloudy days or at night, the electricity is then supplied by the grid. Likewise, if PVs produce an excess of unconsumed electricity, it is sent to the grid in the form of alternating current to power other homes. The utility meter is used to control these energy flows and subsequent adjustment of energy bills [103].

On the other hand, for people who yearn for complete independence, as in the case of homes in more remote locations, you can opt for the off-grid option, where the system has no connection to the utility's electricity grid. In this case, then it is necessary to use a battery to store the energy produced by the solar system [103]. It is important to highlight that the "Eren" values resulting from the simulation always consider only the self-consumption contribution to the primary energy calculations.

C. Aerothermal or geothermal heat pump systems

Heat pumps offer an energy-efficient alternative. They use electricity to transfer heat instead of generating it. During the heating season, heat pumps transfer heat from the outside to the interior, while during the cooling season, they reverse flow by transferring heat from the interior to the exterior.

There are three main types of heat pumps: air to air, water source, and geothermal. They collect heat from the air, water, or soil outside the housing unit and concentrate it for indoor use. The most common type is the aerothermal heat pump, which works by transferring air [106].

The renewable contribution of heat pump, aerothermal or geothermal type systems, is determined following what is defined in Annex VII of Directive 2009/28/EC, but it can only be considered when the value of the Seasonal Performance Coefficient (SPF) is greater than 2.5 [107].

Equation 12 – Annual renewable contribution of heat pump

$$Eren = Qusable * \left(1 - \frac{1}{SPF}\right) \quad [\mathrm{kWh/year}]$$

[107]

On what:

Eren: energy produced from renewable sources for self-consumption in the building's regulated uses [kWh/year];

Qusable: useful energy for the use of heating, cooling, or preparation of DHW supplied by heat pumps [kWh/year];

SPF: it corresponds to the seasonal coefficient of performance, SCOP, SEER or SCOP, DHW or, in its absence, the nominal coefficient of performance, COP, EER or SCOP, DHW, respectively;

Note: heat pumps need equipment such as radiators or convectors as indoor units for fluid circulation.

For any other system to be considered in renewable contributions, the Dispatch must be consulted, and the calculation methodologies described must be considered.

3.5 Renovation scenarios

3.5.1 Renovation measures

The reference scenario to be compared with the energy renovation proposals must foresee intervention without improvement of the thermal behaviour, according to Delegated Regulation (EU) n. 244/2012, by European Commission. So, the renovation proposals for the base scenario were made in the sense of maintenance of the neighbourhood, using typical measures in Portugal for this purpose.

Regarding the energy renovation measures to improve the thermal behaviour, as previously discussed, and because of the greater impact on the building's energy performance, they focus on the envelope of the blocks. Some studies have shown that the measures that are part of the most relevant improvements in energy renovation include additional insulation on the roof, additional insulation on the facade, and intervention in the openings of the envelope [108]. Usual solutions in Portugal were tested for these, and the layers and solutions common to all tested variants, such as paintings, weren't included in the DesignBuilder, same as the reference scenario, as previously discussed.

Energy renovation measures to be chosen shall range within the limit values defined by the thermal regulation. Thus, the tabulated values of Ordinance No. 379-A / 2015 for the maximum U-value were consulted according to the climate zone to which the case study belongs. It is noteworthy that for elements in contact with unconditioned zone, the "btr" (loss reduction coefficient) must be calculated following EN ISO 13789, or through the parameters listed in Dispatch 15793-K/2013, which involves the degree of ventilation of the space, volume, and the relationship between "Ai" and "Au" (sum of the areas of the elements that separate the conditioned and unconditioned zone, and the sum of the areas of the elements that separate the non-useful space from the outside environment, respectively).

The maximum g value "gtmax" was also verified for glazing, according to Ordinance 349-B / 2013. To define the "gtmax", in addition to the climate zone information, it is also necessary to classify a housing unit concerning thermal inertia.

The concept of thermal inertia can be expressed as the material capacity to store heat and delay its transmission [109]. According to Distatch15793-E/2013, the determination of the thermal inertia class can be done by performing calculations based on the surface mass values of the solutions and coatings implemented in the building, depending on its location in the building, installation, positioning, thermal insulation, and characteristics of surface coating solutions [71].

To clarify, if the facade has thermal insulation from inside the building, for example, the vertical parameter that supports the wall (a row of bricks, for example) wasn't counted in the calculations as it did not contribute to heat absorption, contributing to low thermal inertia. On the other side, if a facade does not have insulation or if it is insulated from the outside, the entire mass surface of the vertical parameter will contribute to heat absorption, consequently influencing the fraction towards a classification with greater thermal inertia.

As an alternative to the calculation of surface masses, the interior thermal inertia class can be provided also according to the qualitative parameters, based on the solutions and coatings implemented in the building and the typical behaviour of the materials, following the requirements tabulated in 15793-E/2013 and described below.

I. Low thermal inertia

If the following solutions are cumulatively verified:

- Dropped ceiling in all rooms or wooden floor or a light slab (roof);
- Floating or wooden floor covering;
- Thin wooden partition or interior partition in plasterboard or without interior partition;

II. High thermal inertia

If the following solutions are cumulatively verified, without the application of thermal insulation inside:

- Floor and ceiling in reinforced or pre-stressed concrete;
- Ceiling covering in stucco or plaster;
- Floor covering - ceramic, stone, parquet, industrial type carpet without piles, excluding floating floor solutions;
- Interior partition walls in masonry with stucco or plaster coatings;
- Exterior walls of masonry with interior coatings of stucco or plaster;

- Interior walls (staircase, garage, ...) in masonry with stucco or plaster interior coatings;

III. Average thermal inertia

- If the requirements to classify the thermal inertia class as high or low are not met;

It is noteworthy that in the final analysis of the renovation proposals (optimal cost of the renovation packages considering different systems), all analysed scenarios must comply with Ordinance 98/2019, therefore renewable energy systems in nZEB buildings must supply at least 50% of annual primary energy needs [30].

Furthermore, it is noteworthy that following the guideline of Decree-Law 118/2013, solar collector systems must be installed for DHW, if there are technical conditions that allow it (coverage area and sun exposure). However, as an alternative, other systems for the use of renewable energy can be considered that guarantee, on an annual basis, energy equivalent to the solar thermal system.

The choice of renovation measures to be tested will depend on the particularities of the case study, such as the climatic zone, existing construction solutions, technical systems adopted, etc. Thus, the more specific considerations and particularities will be made in section 5.1.

3.5.2 Cost-optimal methodology

The next step for the analysis is the application of the cost-optimal methodology, according to Delegated Regulation (EU) n. 244/2012. It consists of the comparison of renovation scenarios with a reference case, called "anyway renovation" measures, which is used to establish the threshold for the cost-effectiveness of renovation scenarios. The renovation scenarios consist of packages of renovation measures that include improvements not only in the building envelope but also in the Building Integrated Technical Systems (BITS) [110].

Every scenario that presents a lower energy demand and lower costs than the reference case, is considered cost-effective, and the comparison is made considering the life cycle of the building [111].

To approximate an existing building subject to renovation to an nZEB, based on the aforementioned premises, it is possible to generate a cost-optimal graph to assist in deciding on different possible technical solutions, so that the x-axis describes the use of primary energy and the y-axis describes the results related to the expected global cost for each renovation solution proposed, which is represented for each point shown in Figure 36 [112]. Cost-effective measures are those located below the line defined by the reference renovation. The cost-optimal level corresponds to the measure of improvement that provides a building's energy performance at the lowest global cost over the building's life cycle [111], i.e. 30 years for renovation, which is the case of this study, and 50 for new buildings, in Portugal [7], [112].

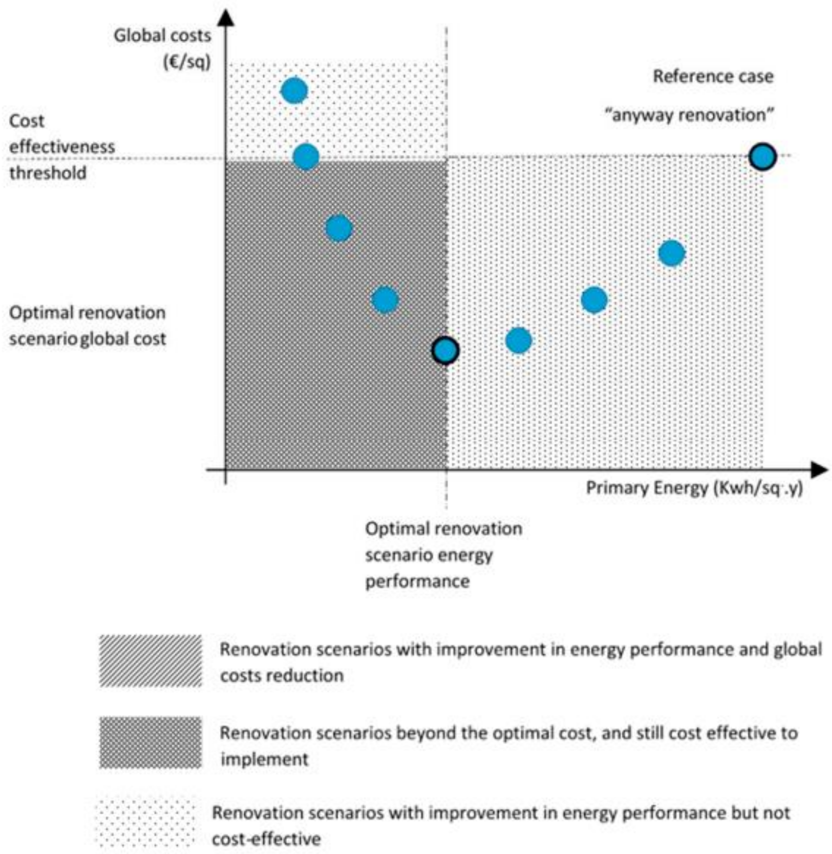


Figure 36: Effectiveness threshold and identification of the cost-optimal renovation scenario [113]

It is worth mentioning that the improvement proposals can and should be combined in packages, after all, it can create more synergistic effects than the case of measures proposed in isolation, leading to better results in terms of costs and energy performance. For this reason, the renovation measures tested generated a first graph that was used to assess the results and choose the reasonable combinations to be tested in the next phase. This was done to reduce computational time without the need for crossing between all measures, which would lead to an unfeasible number of scenarios to be analysed. Then, a second graph was generated with the isolated measures and the packages, and finally, the passive proposals tested in the last phase with the different technical systems and renewable energy were defined [112].

Calculation of global costs

The fundamental steps of the cost-optimal methodology are shown in Figure 37. After obtaining the energy needs, according to the procedures already described in section 3.4, it is now necessary to determine the costs associated with the renovation scenarios.

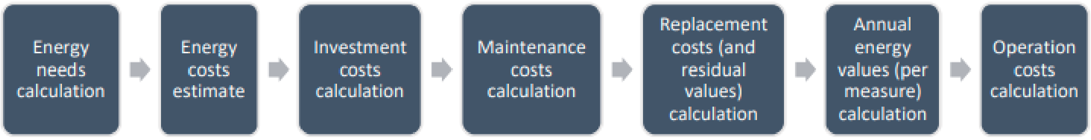


Figure 37: Fundamental steps of the cost-optimal methodology [114]

The calculation of the costs can encompass a macroeconomic perspective, which includes the costs and benefits of energy efficiency investments for the society, or a strictly financial viewpoint, which comprehends only the investment itself [112], [115].

The financial perspective considers the initial investment costs, the fees related to the project, the purchase of building components, connections to suppliers, facilities, surveys, and taxes. It can also include support schemes and incentives. However, since they can change very quickly, it is permissible to exclude subsidies and incentives [112], [115].

Some studies demonstrate that although the macroeconomic perspective usually requires more efficient buildings, the results between this and the financial perspective are usually similar in terms of the cost-optimal range [116], [117]. For this study, the private perspective was used to achieve the proposed objectives.

The global cost encompasses initial investment costs, which correspond to all costs incurred up to the moment when the building or building component is ready to use, but also the running costs, which includes replacement costs, meaning investments for the periodic replacement of a building component; energy costs, including energy price, capacity tariffs, and grid tariffs; operational costs, relating to insurance, cyclical regulatory costs, utilities (excluding energy costs) and taxes; and maintenance costs, which includes inspections, adaptations, cleaning, repair, and consumables. The earning from energy produced can also be considered, and when plausible, global costs should also cover disposal costs. It also considerers the residual value of the solutions, which means how much the solution is worth at the end of the building's life cycle [112], [115]. It can be calculated using Equation 13.

Equation 13 – Global costs

$$C_g(\tau) = C_I + \sum_j \left[\sum_{i=1}^{\tau} \left(C_{a,i}(j) * R_d(i) \right) - V_{f,\tau}(j) \right]$$

[115]

On what:

τ - Calculation period

$Cg(\tau)$ - Global cost (relative to the initial year $\tau 0$) in the calculation period

CI - Initial investment cost for a measure or set of measures j

$Ca,i(j)$ - Annual cost in a year i for a measure or set of measures j

$Rd(i)$ - Discount factor for year i, based on the discount rate r and p the number of years [(1/(1+r/100))p]

$Vf,\tau\ (j)$ – Residual value of measure or set of measures j at the end of the calculation period

The investment and maintenance costs were obtained from the price database widely used for budgeting in civil construction works, i.e. Price Generator, by CYPE [111]. However, for measures regarding technical systems, considering that values can vary considerably according to specifications, brand, efficiency, etc., whenever possible, the price of the equipment itself or others with similar characteristics was checked on commercial websites and replaced in the corresponding item of the cost composition provided by the Price Generator. The intention is to get as close as possible to a more assertive choice since the economic parameter, in this case, does not only involve an analysis of the feasibility of using construction solutions, but rather a choice criterion with a direct impact on the final renovation proposal. In such cases, labor and other costs will remain at those of CYPE.

Residual values comprise the corresponding value of the solution in the last period of the life cycle of the building under analysis, through a straight-line depreciation [22]. For example, if the useful life of the equipment is 20 years, and the life cycle of the building is 30 years, it is necessary to replace it after 20 years of $\tau 0$, but at the end of the cycle the equipment will still have 10 years of expectation of reasonable functioning. Thus, for this case, the investment cost of the equipment would be diluted by its useful life and multiplied by the number of years of the remaining life. The result is then deducted from the overall cost as described in the equation above. For the study in question, typical values for technical systems and solar energy use were considered, i.e. 15 years for general HVAC systems and 20 years for common DHW heaters and renewable systems [118].

The replacement cost involves the same investment cost but enters the solution's financial flow again in the year in which it has its useful life ended. In the example above, an investment cost in $\tau 0$ and another equal in year 20 would be added to the file. Finally, the energy costs correspond to the annual value of final energy for each scenario under analysis.

It is important to remember that these calculations are based on the present net value methodology, which was made using Excel. In practice, what is intended to be compared corresponds to the sum of initial investments with the amount that would be necessary today to support all future expenses, considering the valuation of that amount at an interest rate corresponding to the discount rate [112]. . A discount rate is applied to this global cost that reflects the degree of risk of the investment for the future [111]. In Portugal, the usual value ranges from 3% to 8% with a prevalence of 6%, as presented in Figure 38, which was the rate considered in this study [119].

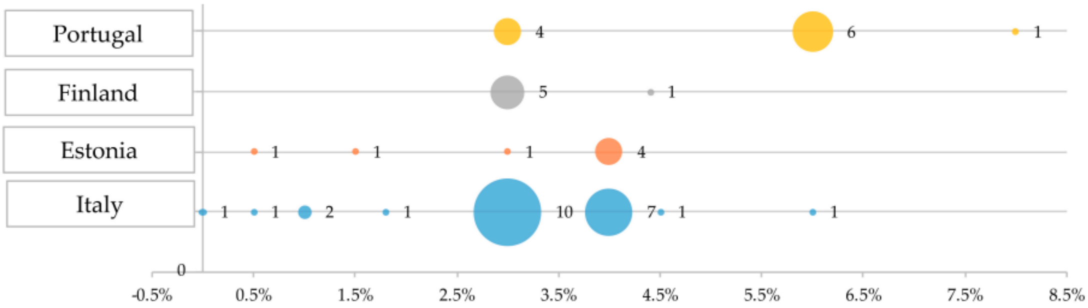


Figure 38: Typical values of the discount rate by country

[119]

Energy Prices

For current energy prices, values were considered from real bills from the same region of the case study and similar consumption profile, and/or by consultation of the websites of energy supplier companies in Portugal. However, in addition to this information, it is also necessary to predict the fluctuation that these prices suffer in future years, throughout the life cycle of the case study. For this, some considerations were made and presented below.

The economic recovery in 2021 put pressure on commodity markets and consequently on energy prices. In addition to immediate contributing factors, some analysts predict that the world may be entering a new supercycle, i.e. an extended period during which strong demand and some supply constraints lead to high prices for energy and other commodities (Figure 39). The International Energy Agency (IEA) further points to the impending mismatch between the world's strengthened climate ambitions and the availability of essential minerals that are necessary to realize those ambitions [120].

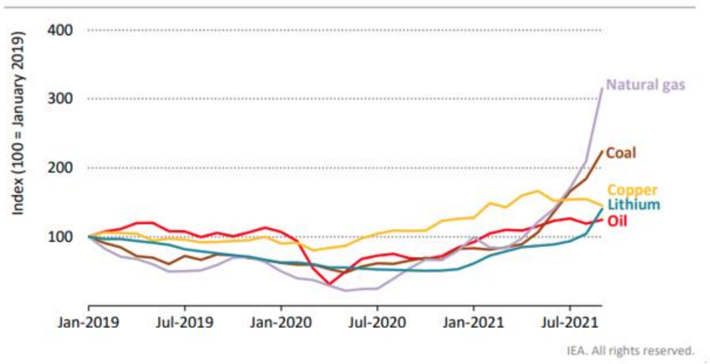


Figure 39: Monthly price indicators for selected commodities

[120]

On the other side, the prediction of a broad-based supercycle spanning energy and other commodity markets may be overstated. As there is an increase in demand for minerals and metals for solar panels, electric motors, wind turbines, and transmission lines, for example, there is also a tendency to ease pressure on traditional fuel markets. So, scientists do not foresee an extended period of high-priced commodities, but there is still great room for volatility and price spikes given the various mismatches between current investment trends and possible demand patterns [120].

The IEA presents in World Energy Outlook 2021 different scenarios for the projection of natural gas prices, among others, as shown in Figure 40.

			Net Zero Emissions by 2050		Sustainable Development		Announced Pledges		Stated Policies	
Real terms (USD 2020)	2010	2020	2030	2050	2030	2050	2030	2050	2030	2050
IEA crude oil (USD/barrel)	92	42	36	24	56	50	67	64	77	88
Natural gas (USD/MBtu)										
United States	5.2	2.0	1.9	2.0	1.9	2.0	3.1	2.0	3.6	4.3
European Union	8.8	4.2	3.9	3.6	4.2	4.5	6.5	6.5	7.7	8.3
China	7.9	6.3	5.3	4.7	6.3	6.3	8.5	8.1	8.6	8.9
Japan	13.0	7.9	4.4	4.2	5.4	5.3	7.6	6.8	8.5	8.9
Steam coal (USD/tonne)										
United States	60	43	24	22	24	22	25	25	39	38
European Union	109	50	52	44	58	55	66	56	67	63
Japan	127	69	58	50	67	63	73	63	77	70
Coastal China	137	89	61	51	72	66	77	65	83	74

Figure 40: Fossil fuel prices by scenario

[120]

Ideally, a sensitivity analysis should be carried out considering these different scenarios, but considering the time limitation, the opposite points mentioned above, and the uncertainty about future levels of demand reflected in the scenarios, the most intermediate scenario between "stated policies" and "sustainable developments" and others, i.e. “announced pledges”, was used in this study for the projection of the natural gas prices, in order not to overestimate or underestimate the price projection. It is noteworthy that as the thermal performance is improved, it is expected that among the final energy renovation packages, the energy consumption for such is much lower since the goal is to reach nZEB, thus, the energy price tends to occupy lesser importance in this analysis, as it tends to correspond to a less significant parcel of the global cost.

Finally, after defining the scenario, the values presented for 2020, 2030, and 2050 serve as a basis for linear interpolation in Excel. Then, the evolution percentages are obtained, which are then applied to initial energy costs, to be able to predict costs yearly. The procedure is the same for different types of energy.

Regarding electricity, the "EU Energy, Transport and GHG Emissions - Trends to 2050" by European Commission was used to estimate the variation of electricity price, following the guideline of Delegated Regulation (EU) n. 244/2012. The report presents a scenario for different sectors, where after 2020, average electricity prices remain stable until 2035 and then are expected to decline moderately until 2050. In addition to the normal restructuring investments in electricity supply increasingly present, the decrease is estimated to occur due to lower technology costs resulting from technological progress and learning over time, along with a slowdown in gas price increases [121].

The price evolution for households was used in this study, as it corresponds to the object under analysis. As for natural gas, linear interpolation was done in Excel to obtain the electricity price corresponding to each year within the life cycle of the social neighbourhood under analysis. The points considered were the values for the 5-year projection presented in Figure 41.

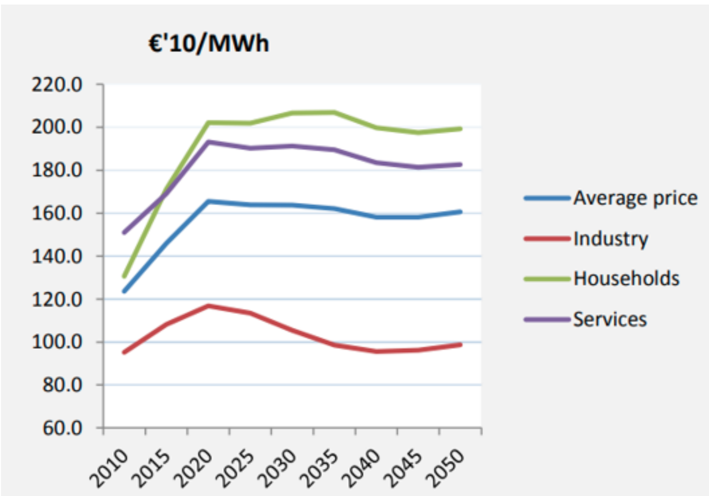


Figure 41: Price of electricity (pre-tax) by sector

[121]

3.5.3 Resilience methodology

The standard application of the cost-optimal methodology considers a fixed value for the useful energy throughout the building's life cycle, and consequently a fixed value for the primary energy. In addition, global cost despite projecting the evolution of the unit price of energy also considers a fixed amount of final energy for the entire life cycle of the building under analysis. This is non-ideal since, for example, a study performed in 2021 considers for the energy cost during the year 2050 an energy consumption that is based on climate files generated using data from years (or even decades) ago, i.g. the climatic file for Porto, 2009 ASHRAE Handbook, uses measurements from the 80s, 90s, and beginning of the 2000s to create the TMY file.

Considering this limitation and all the points previously discussed concerning the projection of climate change, this study suggests adopting a variation of the cost-optimal methodology to analyse the resilience of the solutions proposed in the present for the future. Before the methodology adaptation it was required to perform the following steps in order:

I. Initially, the EPW weather file was converted for the years 2020 and 2050. The procedure described in section 3.3.1 to generate the future weather file through CCWorldWeatherGen will be performed.

II. Then, the simulations that were tested for each of the measures and renovation packages that were chosen in the conventional methodology, were repeated in DesignBuilder considering the new climatic characteristics.

III. Finally, the new results of "Nic" and "Nvc" for the six typologies understudy were weighted according to the procedure already described in section 3.4.2 and using equation 10. In possession of the representative energy needs for heating and cooling for the social neighbourhood under study, both for 2020 and for 2050, linear interpolation was made in Excel to estimate the values corresponding to each year present in the interval of the life cycle of the case study. In this case, considering that the $\tau 0$ for this study was 2021 and the range of the optimal cost analysis was from 2022 to 2051, the same rate calculated for the useful energy variation between 2049 and 2050 was extrapolated and used to obtain the 2051 values.

Adaptation of the cost-optimized methodology was based on two main changes. The first consists of adapting the global cost calculation, using different values of energy consumption per year to calculate the total energy cost. Figure 42 illustrates the proposed procedure, using the energy needs for cooling as an example.

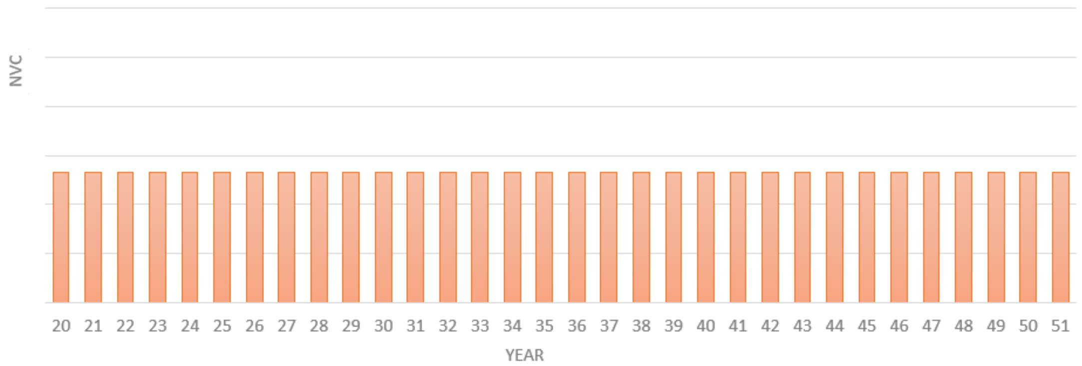


Figure 42: Neighbourhood representative Nvc (fixed), based on weather file obtained from measurements from previous years

Instead of using the fixed values above, obtained from past weather data, the energy cost of each year was considered the different estimated values of “Nvc” for each year, as shown in Figure 43, is multiplied by the estimated unit price of energy for each year, as is already done in the conventional methodology.

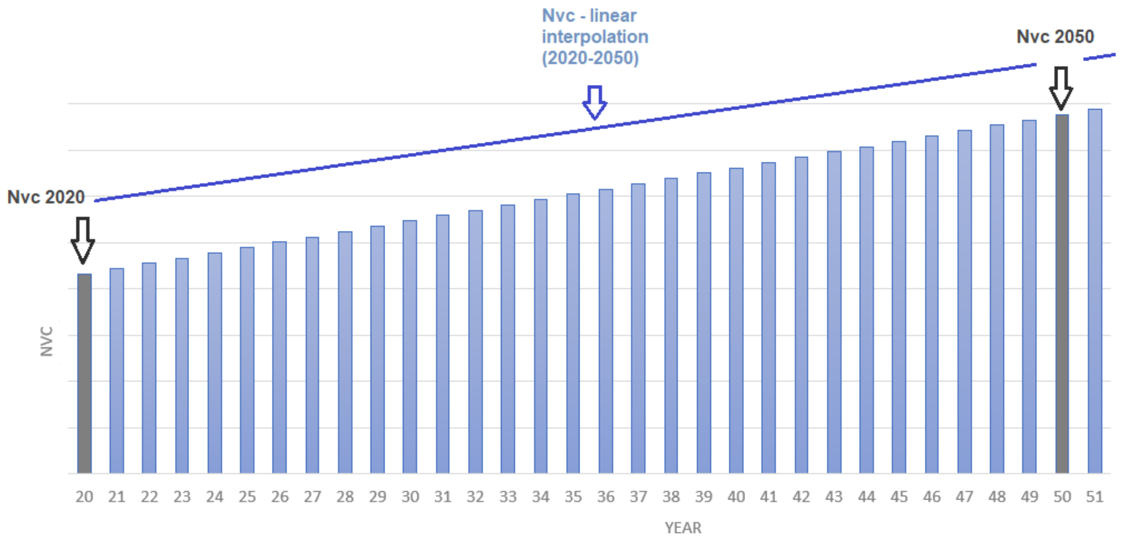


Figure 43: Neighbourhood representative Nvc (per year), based on future climate projection

Note: these graphics are merely illustrative of the proposed methodology, and do not necessarily correspond to the actual evolution rate of the exemplified parameter.

The second proposed adaptation to the methodology is the use of the average of the interpolated individual values mentioned above for the useful energy of heating and cooling, to calculate the primary energy that appears in the cost-optimal graph. That is, the value of "Nvc" (as for "Nic") that was used in

Equation 11 is the one shown in green in Figure 44, different from the standard methodology that would use the orange values illustrated in Figure 42.

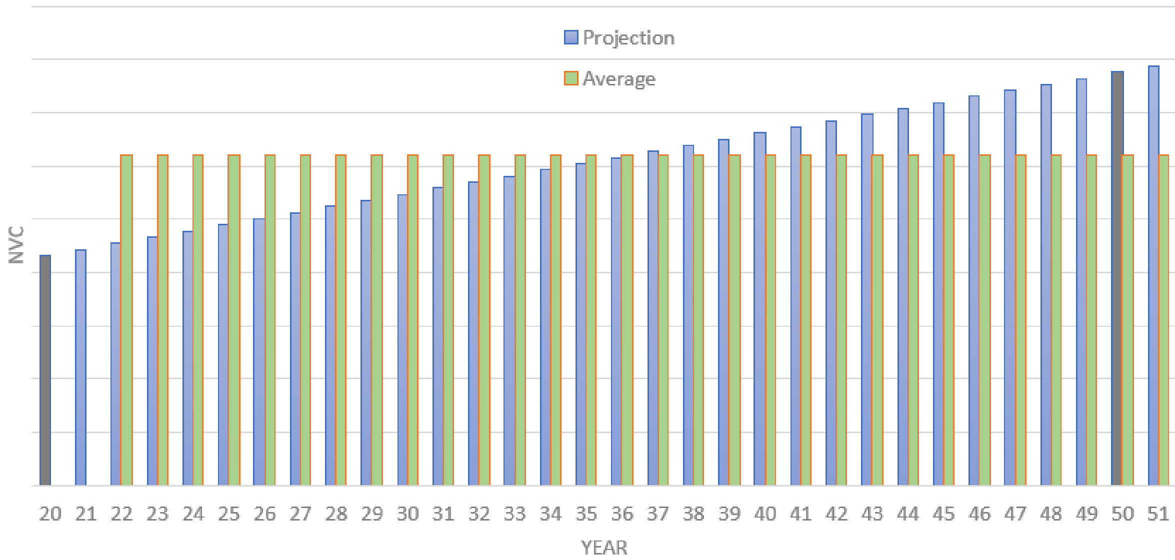


Figure 44: Neighbourhood representative Nvc (per year and average), based on future climate projection

The values referring to the demand for useful energy to DHW remain the same, as they vary mainly according to the number of inhabitants. However, analysing Equation 08, it is noted that one of the expression's inputs involves the necessary temperature increase for the preparation of DHW so that there is a possibility of a future change in the currently recommended reference value, i.e. 35 °C. However, sufficient quantitative criteria were not found to change it, so it was decided to keep the values equal.

Finally, with all the useful energy parcels obtained, the calculation of the global cost and the primary energy is remade for all the proposals considered in the study, and the new cost-optimal graphs are generated.

It is noteworthy that climate changes predicted for the future may alter the behaviour and efficiency of technical systems, but not enough data have yet been found to estimate these changes. In the case of solar systems, for example, its contribution must remain constant throughout the period, because although solar radiation is expected to increase, the external temperature also increases, tending to cause less efficiency of photovoltaic panels [19].

CHAPTER 4: THE CASE STUDY

This section describes the case study used to apply the methodology proposed in section 3, to meet the goals established in section 1. For that, the Santa Tecla neighbourhood was chosen (Figure 45), which is a typical example of a social housing neighbourhood in the Mediterranean region. It is a multifamily building complex built in 1979, located in Braga – north of Portugal (41.55, -8.41, and 181 meters above sea level). Like most social housing in the country, the building was constructed with lower-quality materials, and it was designed with requirements that do not meet the current thermal regulation. The neighbourhood is in a degraded state and it has several pathologies [36].

Figure 45: Santa Tecla social neighbourhood
[122]

4.1 Input data

4.1.1 Climate Data

Weather data

Among the options offered by the EnergyPlus website for climatic files in mainland Portugal, the option of Porto was chosen for the study (WMO station identifier - 085450) as it is the closest location to the neighbourhood under analysis. The design conditions refer to Climate Design Data 2009 ASHRAE Handbook, coordinates 41.23, -8.68, 73 meters above sea level, and belong to the GMT zone. Monthly Design Dry Bulb temperatures range between 17.4 °C and 33.3 °C for the coldest month, i.e. January, and the warmest month, i.e. August, respectively (considering a 99.6% chance of more extreme weather occurring) [47].

4.1.1.1 Climate zone classification

Concerning the parameters listed in section 3.3.1 for the ASHRAE climate zoning classification illustrated in Figure 46, and considering that the Santa Tecla neighbourhood is located in Braga, north of Portugal, it is classified as a 3C zone, which is a warm – marine zone with CDD10°C ≤ 2500 and HDD18°C ≤ 2000 [51].

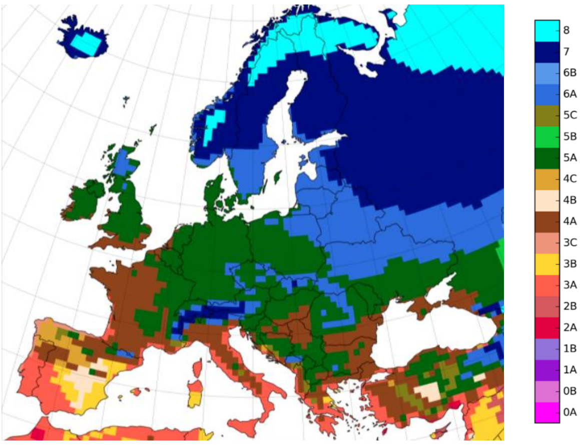


Figure 46: ASHRAE climate zones: Europe

[123]

Regarding the Portugal zone classification, first, it was verified that the municipality of Braga is included in NUTS III of Cávado. Then, the calculation of the number of degree-days (GD) at the base of 18 °C and the average outdoor temperature corresponding to the conventional cooling season ($\theta ext, v$) were made, including the altimetric correction. As a result, the case study can be classified as part of winter zone I2 and summer zone V2. The location of the case study in Portugal as well as the different summer and winter zones are illustrated in Figure 47 below.

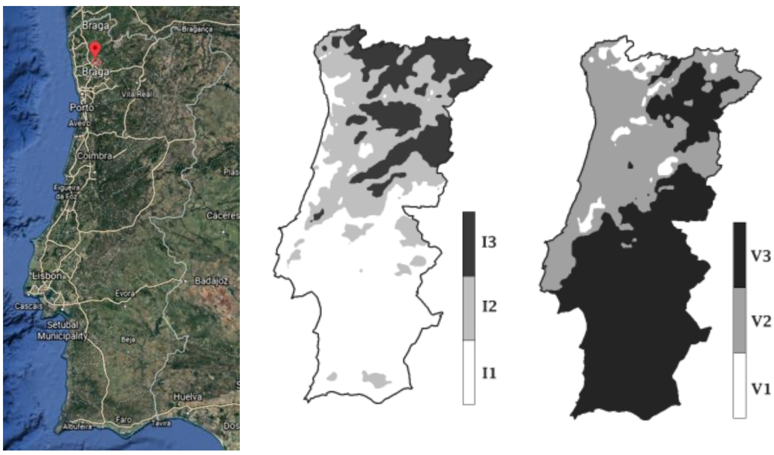


Figure 47: Location of the Santa Tecla neighbourhood, and Portugal climate zones on the continent, respectively

[52], [124]

4.1.2 Geometry characterization

The housing neighbourhood consists of 160 apartments with different kinds of geometry and orientation, divided between four mid-rise blocks (Figure 48), each one with five floors: a top floor, three middle floors, and a ground floor [36].

Figure 48: Santa Tecla: panoramic view

[124]

Blocks 01, 02, and 03 are the ones with more dwellings: 48, 40, and 56, respectively. Block 04 is the smallest one, with only 16 apartments. The most occurring orientation for the majority of building positions has one facade south-facing (195° approximately) and the other one north-facing (15° approximately), which is the orientation of blocks 02 and 03 that total 96 of the 160 units of the complex. So, this is the cardinal orientation input in the model.

Regarding geometry, it is noted that all apartments with the same number of bedrooms have the same geometry. There are 80 dwellings with three bedrooms (T3), 40 with two bedrooms (T2), and 40 with four bedrooms (T4). Then, considering the most occurring typology in the neighbourhood, a T3 with 79.5 square meters is the reference dwelling used for the modelling, as shown in Figure 49 [36].

To perform the modelling in the DB, the available "DWG" files were consulted. The apartment is modelled as a single thermal zone, and the corridor adjacent to the floor is a semi-external unconditioned room and it is also modelled in DB. Compartmentation walls are designed as hanging partitions, as seen in Figure 49.

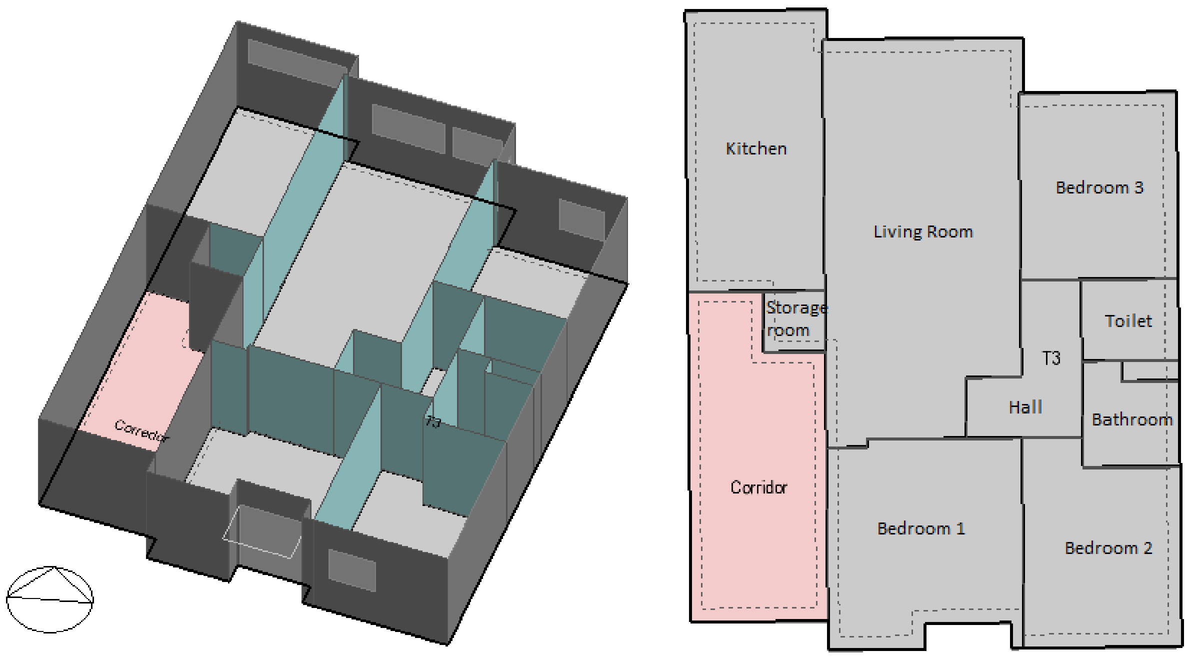


Figure 49: Reference dwelling model: floor plan

The dwellings have a pitched roof that includes a horizontal slab, an unoccupied and unheated space (semi-external unconditioned room), and a slope with 11°. The constructive element is presented below in Figure 50.

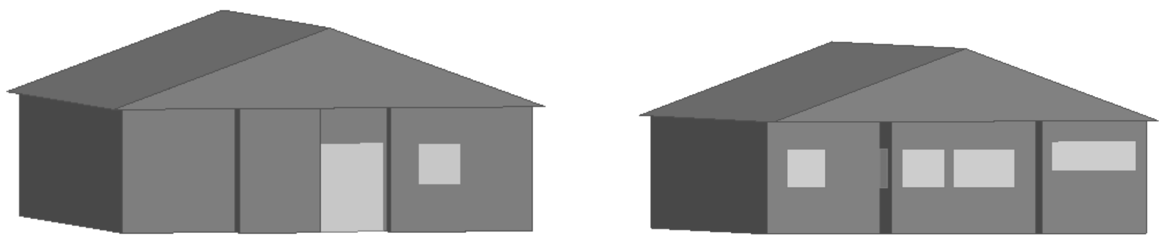


Figure 50: Reference dwelling model (typologies 01 and 02): front + side elevations, and rear + side elevations, respectively

Regarding the openings, each apartment has 7 windows totalling 9.43 square meters of opening, oriented as described in Table 4.

Table 4: Windows by cardinal orientation

ID	Window opening area (m²)	Cardinal orientation
J1	3.00	S
J2	0.95	S
J3	0.95	N
J4	0.71	E
J5	1.05	N
J6	1.52	N
J7	1.64	N
Total: 9.43 m²		

Representative typologies of dwellings by position in the building

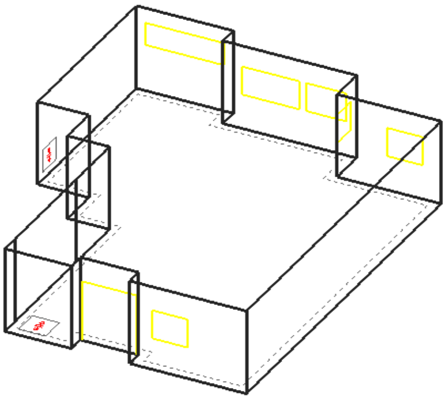
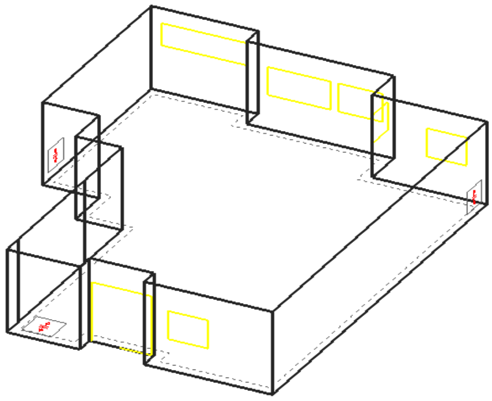
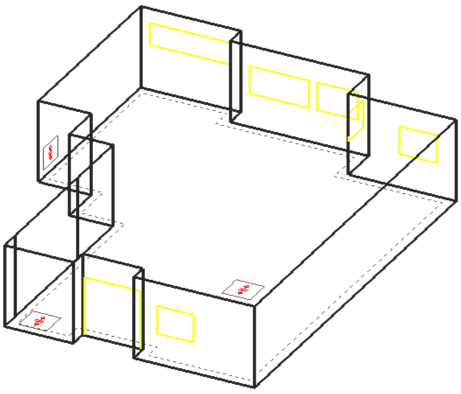
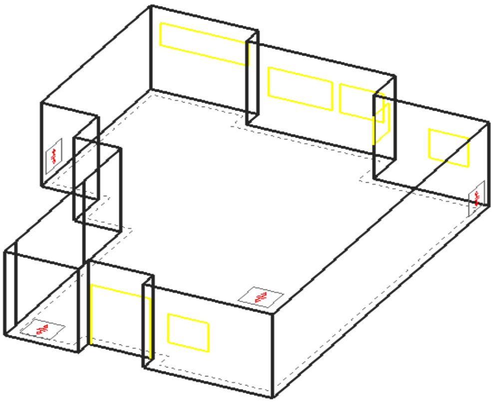
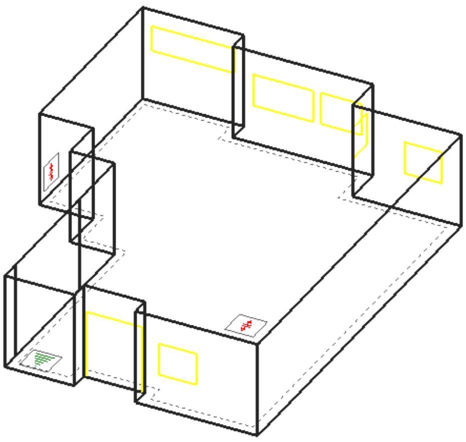
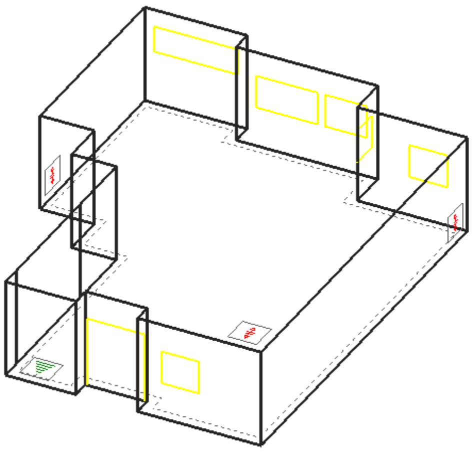
The housing units were categorized according to the positions they occupy in the building, due to the influence of the different boundary conditions, as described in section 3. For the Santa Tecla social neighbourhood, the quantities corresponding to each typology are presented in Table 5:

Table 5: Quantity of each representative typology of dwellings by boundary conditions

Typology	Position	Quantity
01	Top floor at the edge	8
02	Top floor in the middle	32
03	Middle floor at the edge	16
04	Middle floor in the middle	64
05	Ground floor at the edge	8
06	Ground floor in the middle	32
	Total	160

The representation of the typologies by boundary conditions, as considered in the dynamic simulation software, can be seen in Table 6.

Table 6: Representative typologies of dwellings by boundary conditions

	Edge	**Middle**
Top Floor	Typology 01 	Typology 02 
Middle Floor	Typology 03 	Typology 04 
Ground Floor	Typology 05 	Typology 06 

Subtitle: Adjacent to ground Adiabatic

4.1.3 Constructive characterization

The construction solutions of the main building elements are described in Tables 8 to 10. The type of interaction the surface has concerning the boundary condition is presented in colour (Table 7).

Table 7: Boundary condition subtitle

	Adjacent to exterior
	Adjacent to semi-external unconditioned room, i.g. surfaces between dwelling and corridor
	Adjacent to ground
	Adjacent to the interior, i.g. surfaces between dwellings of the same building
	Compartmentation

Table 8: Constructive characterization of the main building elements

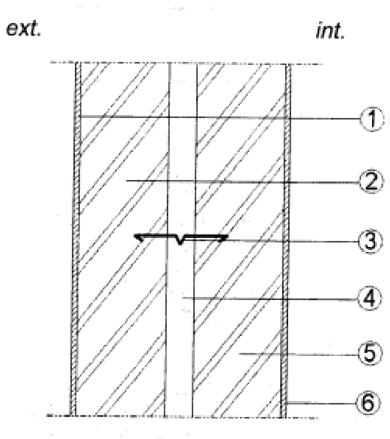
Bldg. element	Illustrative scheme	Solution description	Value
Facade		1: Gypsum plastering (1 cm) 2: Hollow brick pane - Brick (15 cm) 3: Cloth binding stirrup 4: Air gap: R=0.11 m^2K/w 5: Hollow brick pane - Brick (11 cm) 6: Gypsum plastering (1 cm)	U-value= 0.84 $W/(m^2 °C)$ (calculated DB)
Window		- Wooden frames (no grids), without a thermal break (high air permeability considered) - External PVC shutters (activate 60% of the time) (15793-K/2013) and single glaze: 6 mm - Uw=5.10 $W/(m^2 °C)$ (ITE-50) - Un=2.40 $W/(m^2 °C)$ (Eq. 4)	Uwdn=3.48 $W/(m^2 °C)$ (calculated) g-value= 0.84 (15793-K/2013) VT=0.89 (tech. sheet [125])

Table 9: Constructive characterization of the main building elements (cont.)

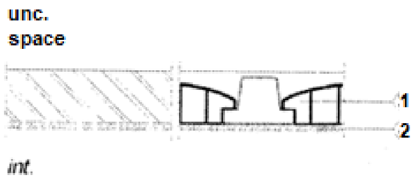
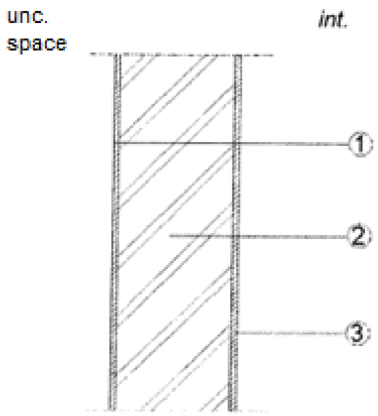
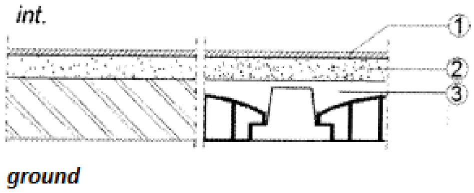
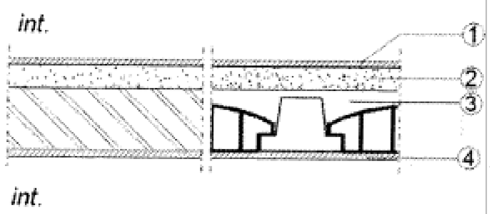
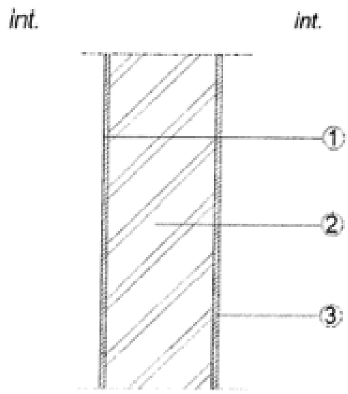
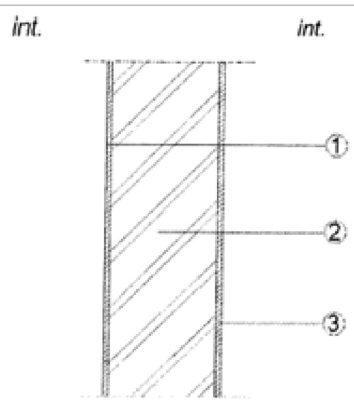
Bldg. element	Illustrative scheme	Solution description	Value
Roof		1: Concrete cast, dense, reinforced (15 cm) 2: Ceiling cladding – gypsum plastering (1 cm)	U-value= 1.40 W/(m²°C) (ITE-50)
Wall		1: Gypsum plastering (1 cm) 2: Hollow brick pane - Brick (22 cm) 3: Gypsum plastering (1 cm)	1.05 W/(m²°C) (calculated DB)

Table 10: Constructive characterization of the main building elements (cont.)

Bldg. element	Illustrative scheme	Solution description	Value
Floor		1: Timber flooring (2 cm) 2: Cement, plaster, mortar | cement plaster, sand aggregate (3 cm) 3: Concrete cast, dense, reinforced (15 cm)	N/A
Floor		1: Timber flooring (2 cm) 2: Cement, plaster, mortar | cement plaster, sand aggregate (3 cm) 3: Concrete cast, dense, reinforced (15 cm) 4: Ceiling cladding – gypsum plastering (1 cm)	N/A
Wall		1: Gypsum plastering (1 cm) 2: Hollow brick pane - brickwork, inner leaf (10,5 cm) 3: Gypsum plastering (1 cm)	N/A
Wall		1: Gypsum plastering (1 cm) 2: Hollow brick pane - brickwork, inner leaf (10,5 cm) 3: Gypsum plastering (1 cm)	N/A

Note: the balconies of bedroom 01 have an overhang and are represented in the DB due to the influence they may have on solar obstruction, excluding top floors that do not have apartments on top of them.

4.1.4 Usage profiles

Internal gains

Using equation 09 and considering that the representative dwelling for this study has three bedrooms, it is assumed that four people live in each apartment. Dividing the number of people for the useful area, i.e. 79.5 square meters, the occupancy density corresponds to 0.05 people/m^2. Regarding metabolism, considering there is a different kind of occupancy in the building, the most intermediate factor was the one used, i.e. 0.85, which in this case corresponds to a total heat gain of 85W per person, as described in section 3.3.4.

For the schedule, a template for a residential occupancy from the DB library under the ASHRAE 90.1-2007 category was considered, named “Residential Occ”, as per Annex 1.

Additionally, it was considered average internal gains referring to equipment and lighting of 4 W/m2, according to ordinance 349-B/2013.

For the lighting schedule, a template for residential lighting from the DB library under the ASHRAE 90.1-2007 category was considered, named “Residential Lighting”, as per Annex 1. Meanwhile, regarding equipment, it was adapted the suggested “24/7” schedule, i.e. a factor of 1 all the time, 24 hours in the day, and 7 days in the week, but excluding winter days (Annex 1).

As described in Table 4, the windows of the dwelling are north, south and east oriented. Following the guideline from Dispatch 15793-K/2013, the north-oriented windows were considered without sun protection device, while the fraction of time mobile shading devices are fully activated in the cooling station “Fmv” for the others corresponds to 60%. It was considered in DB that they are activated between 07:00 and 21:30, to reduce solar gains.

Air Renovation

Considering that the social neighbourhood was built in the 70s and, unlike more modern buildings, it has relatively high rates of uncontrolled air inflow into the building envelope, a common air infiltration value was adopted for this housing profile, i.e. 1 ACH [25], [36].

The standard schedule suggested in DB for that is "24/7", and it was the one used for that purpose (Annex 1).

Regarding natural ventilation through windows, and considering the concepts and recommendations described in section 3.3.4, it was considered in the model that during winter the windows are closed, while during the summer, nocturnal ventilation is adopted, from 20:00 to 23:00.

To avoid a profile inconsistent with reality, a limiting condition in terms of outside temperature was added, so that the described schedule is only considered when the outside temperature does not exceed 25 °C, otherwise, the windows are considered closed.

To minimize pathologies related to humidity and improve air quality, it is recommended to adopt at least individual extractors in the kitchen and bathroom, which are generally the rooms in the housing unit most prone to this problem. Then, a typical extractor for its use was adopted, i.e., a bathroom extractor fan with a flow rate of 86 m^3/h [126] and a kitchen extractor fan of 450 m^3/h [127] (Annex 2).

However, because the apartment was modelled as a single thermal zone, it was necessary to weigh the flow to enter a single value in the software, but considering the different schedules provided for each of the devices aforementioned. Knowing that the sum of the airflow values results in 536 m^3/h, this is the value inputted in DesignBuilder. For the bathroom extractor fan, it was assumed that it is used for an hour in the morning and an hour at night, while in the kitchen the equipment considers use for an hour and a half at night. Then, during the time interval where only the first one is used, it is considered a factor of use of 0.15 in the schedule, to obtain the correspondent flow rate. Similarly, a factor of use of 0.85 is considered for the time interval where only the kitchen extractor fan is activated.

4.1.5 Technical Systems

There is no standard HVAC equipment installed in the social housing, but as they must be assumed to carry out the comparative analysis with the primary energy of each scenario in the following sections, as already mentioned in section 3.3.5, default considerations have to be made, following Ordinance n. ° 349-B/2013 guideline.

I. Heating

For heating, an electric heater was considered (COP=1) [99]. The equipment is the solution adopted by some of the residents in the neighbourhood when they have financial availability, because it is relatively cheaper than the others considering the acquisition cost, despite not being very efficient.

For the compact schedule, the "*Dwell_DomCommonAreas_Heat*" for residential spaces was used in the HVAC tab in DesignBuilder, as per Annex 1.

II. Cooling

For the cooling system, an air conditioning Multi-split system with air-to-air exchange was considered (EER=3.00) [99], end-use is also electricity.

For the compact schedule, the "*Dwell_DomCommonAreas_Cool*" for residential spaces was used in the HVAC tab in DesignBuilder, as per Annex 1.

III. DHW: Domestic hot water

Still considering the systems by default and that the electric power of each dwelling is less than 10kw, a gas heater with an efficiency of 82% was adopted for DHW [99]. It was also assumed that insulation is applied in the distribution piping of DHW, as recommended [99].

4.2 Energy needs

4.2.1 Useful energy

I. Heating and Cooling

After carrying out the energy simulation for each typology of the reference model, the software generates the energy needs for heating and cooling as an output. The results correspond to the total need for the apartment, so they are divided by the usable area, i.e. 79.5 m², to obtain the "Nic" and "Nvc" results shown in Table 11. Equation 10 is then used to weigh energy needs by typology, to obtain the representative average value of useful energy needs for heating and cooling, for the social neighbourhood.

Table 11: Annual useful energy demand (heating and cooling) for the reference model

Typology	Position	Quantity	Nic (kWh/ m^2.year)	Nvc (kWh/ m^2.year)
01	Top floor at the edge	8	57.24	8.90
02	Top floor in the middle	32	53.95	9.29
03	Middle floor at the edge	16	19.49	3.78
04	Middle floor in the middle	64	15.19	4.07
05	Ground floor at the edge	8	17.61	1.56
06	Ground floor in the middle	32	14.85	1.64
Neighbourhood weighted useful energy needs:			**25.53**	**4.71**

Analysing figure 32 and the main parameters influencing the heating and cooling needs, it is possible to say that the heat transfer due to envelope transmission is the major difference between these typologies, as the heat transfer due to air renovation and the internal gains should not present a great difference among them.

For example, the results demonstrate, as expected, that the top floors dwellings present a higher energy demand than the other typologies, because of the heat transfer due to the roof, especially in this reference scenario where there is no insulation in it, so the gap tends to be even higher. It is also possible to note that edge dwellings present higher needs than the middle ones because they have more surfaces in contact with outside conditions, which entails higher heat transfer.

II. Domestic Hot Water (DHW)

Considering Equations 7, 8, and 9, the calculation of the energy demand for DHW "Qa" can be made, which brings as a result 2377.29 kWh/year for each dwelling. Then, by dividing this value for the useful area, an energy demand of 29.9 kWh/ m^2.year is obtained.

4.2.2 Primary energy

Considering Equation 11, the default systems described in section 4.1.5, and the useful energy needs that were obtained in the previous topic, the annual final energy use, and the annual primary energy use for the reference model "RI" are calculated. The main data and results are shown in Table 12.

Table 12: Annual primary energy for the reference scenario

ID	Nic	η	Nvc	η	Qa/ m²	η	Final energy	Fpu	Fpu	Fpu	Primary energy
RI	25.53	1	4.71	3	29.90	0.82	**63.57**	2.5	2.5	1	**104.21**

Note: The values presented for Nic, Nvc, Qa/m², final energy, and primary energy are in (kWh/ m².year).

Analysing the results of the useful energy needs, it is possible to see that, as expected, the need for heating is much greater than that for cooling, a common thermal behaviour for the location of the case study. It is also noted that the demand corresponding to DHW presents significant values, which is directly influenced by the number of inhabitants in the apartment, i.e. four people. The chart presented in Figure 51 allows a clearer visualization of the proportions of each parcel of the energy useful need.

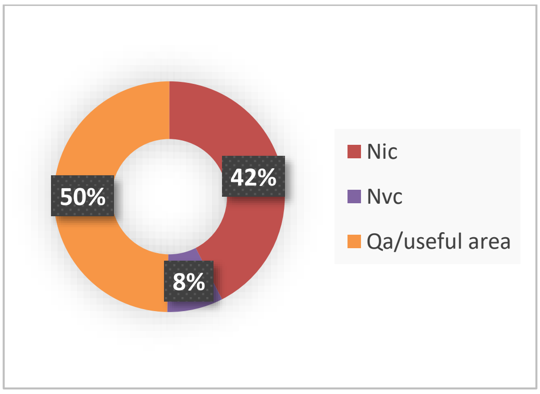


Figure 51: Proportion of each parcel of the energy useful need, for the reference model

CHAPTER 5: COST-EFFECTIVENESS AND RESILIENCE ANALYSIS

This section describes both the individual renovation measures proposed and the energy renovation packages tested. Then, the conventional and adapted cost-optimal methodologies are applied to the defined case study. Finally, the results and respective cost-effectiveness and resilience analyses are demonstrated throughout this section.

5.1 Cost-optimal analysis

5.1.1 Passive renovation measures

The general measures of renovation considered for the reference scenario correspond to the maintenance of the social neighbourhood. It does not impact the thermal behaviour of the building, as already described in section 3.5.1., and it includes the following measures:

- Facade: repairing cracks, cleaning and painting the facade
- Roof: cleaning the sloping roof and gutters
- Windows: repair and painting
- Indoor water pipes: replacement in bathrooms and kitchens

If the energy renovation measures constructively influence the maintenance measures, only one of them was considered, e.g. for measures involving a solution with ETICS, the complete solution was considered including the specific paint recommended for that type of intervention, so the maintenance measure for painting the facade presented above was disregarded.

As described in section 3.5.1, to meet the minimum requirements established by the thermal regulation and to optimize the process, it was verified, for the choice of insulation of opaque elements, which minimum thickness meets the established maximum U-values for the climate zone of the case study.

For double exterior walls, considering the maximum U-value of 0.40 for the “I2” zone, according to Ordinance No. 379-A/2015, the minimum thickness of thermal insulation to be added that meets the stipulated value is 60 mm (the solution was tested in the DB and the corresponding U-value is 0.35, for λ of 0.038). Initially, three individual measures were defined for the application of ETICS on the facade:

Expanded polystyrene EPS (λ of 0.038) with 60, 80, and 100 mm. The construction solution chosen to represent the renovation proposal encompasses the ETICS Morcem Insulation system “GRUPO PUMA” of thermal insulation for the exterior of the existing façade, as illustrated in Figure 52 [128].

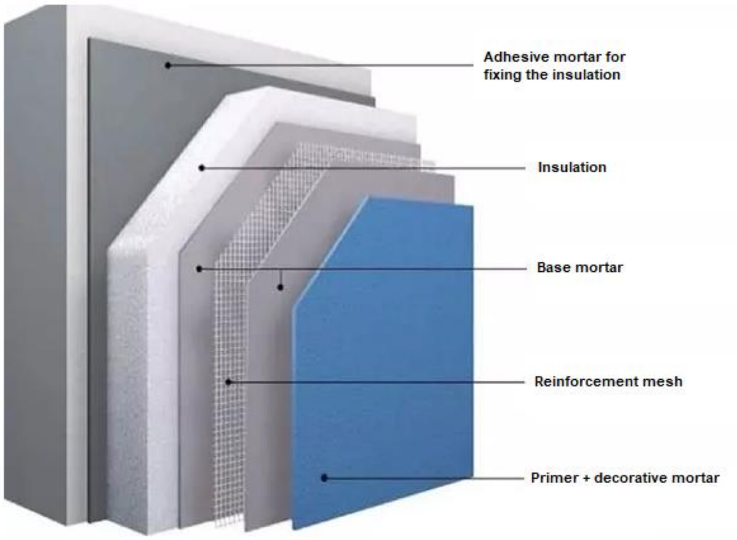


Figure 52: Representative scheme of the ETICS renovation measure

Adapted, [129]

It is important to highlight that it is necessary to carry out a study on the status of the support that receives the system, before its execution, and to determine the necessary actions to arrange a correct preparation of the base support. The proposed solution, then, includes the previous preparation of the external support [128].

It was also decided to test a solution with the insulation applied inside the building, to verify possible changes between the solutions, since their expected behaviour may vary according to the present and future scenario. However, it is expected that the solution of insulating from the inside will continue to show worse thermal behaviour concerning a greater chance of the emergence of thermal bridges.

Due to the availability of interior space in the apartments, only the measure with the smallest thickness of thermal insulation was considered, that is, 60 mm. The construction solution chosen to represent the renovation proposal involves the direct interior lining of the plasterboard with built-in insulation (“KNAUF” system). The system comprises, in a simplified way, the application of thermal insulators directly on the wall with KNAUF adhesive mortar, in addition to the application of the joint compound. Finally, the paint layer is then applied, as illustrated in Figure 53 [130].

Note: despite the paint layers being considered in the construction solution in terms of their acquisition cost, they were not added to the software, as happened with the reference model, for the reasons already explained above. This applies to all construction solutions.

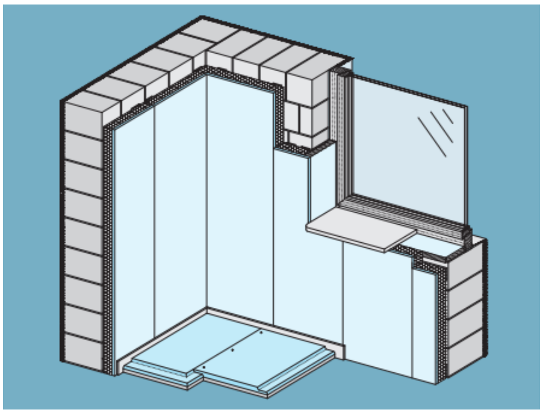


Figure 53: Representative image of the exterior wall with insulation from the inside [130]

Concerning the roof, the volume of the unconditioned space above the horizontal slab is less than 50 m^3, and the relationship between the sum of the areas of the elements that separate the interior space from the unconditioned space (Ai) and the areas of the elements that separate the last one from the exterior (Au) ranges between 0.50 and 1.00. Therefore, following Dispatch15793-K/2013 and considering the space as strongly ventilated, the adjustment factor "btr" has a correspondent value of 0.90.

Then, following Ordinance No. 379-A / 2015, the maximum U-value for this element for the "I2" zone corresponds to 0.35. It was verified through the ITE-50 that for a λ of 0.037, the minimum thickness for continuous insulation to be added to a solid horizontal slab, to meet thermal requirements, is 100 mm (the corresponding U-value is 0.33). Thus, three renovation measures were also defined for the pitched roof: mineral wool – MW (λ of 0.035) with 100, 120, and 150 mm.

The application of thermal insulation on the horizontal slab rather than on the sloping element was chosen because it tends to present a superior thermal behaviour than the last, as detected by several studies carried out for the region of the case study [36], [131]. The choice of insulating over the roof slab instead of from the inside of the building is mainly because it prevents condensation on the surface of the ceiling with which it is in contact and reduces the chance of thermal bridge's appearance [132]. Besides, it encompasses greater ease regarding generating fewer inconveniences in the renovation process for the residents.

The construction solution chosen to represent the renovation measure encompasses the energy renovation of a pitched roof over an uninhabitable space, with thermal insulation from the inside ("URSA IBÉRICA AISLANTES" system) [133]. It is also recommended to apply a vapor barrier, as illustrated in Figure 54, to minimize problems related to pathologies arising from moisture [134].

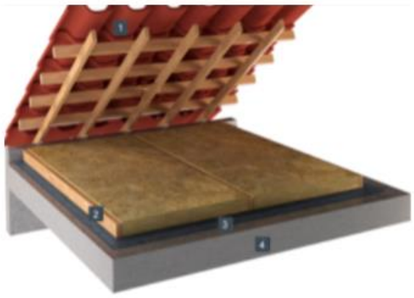


Figure 54: Representative scheme of the roof renovation measure

Adapted, [135]

To reduce heat transfer through the openings of the envelope, by increasing resistance, the renovation measures chosen for the windows encompass double glazing (4 – 16 – 4) instead of the single glazing that appears in the reference scenario. It is noteworthy, however, that the orientation of the facade in which the windows are inserted is also a criterion that influences the choice of glass, as it impacts greater or lesser entry of solar radiation, and consequently the thermal gains through glazing.

It is recommended, for example, that south-facing windows have solutions composed of glass with low emissivity (low-e), as presented in Figure 55, to combine thermal insulation with protection against solar radiation, as this orientation for Portugal corresponds to a lot of sun exposure [60]. This characteristic of glasses results from the addition of a metallic layer on one of its sides, capable of reflecting a large part of the sun's rays that would enter the environment, working as a barrier to control the transfer of temperatures between the external and internal environment without, however, prevent the passage of natural light, as the low-emission glass has high transparency. This solution is also capable of preventing heat from escaping from the environment as the coating would reflect the heat to the interior, which in this case would be the expected behaviour for the winter, by reducing the heat loss [136], [137].

Analysing Table 4, it can be noted that the two main l orientations for Santa Tecla are north and south. Considering that the cost-optimal methodology involves the economic parameter, and taking into account that low emissivity glasses are usually more expensive [137], the two types of window glasses are proposed to be tested in the analysis: standard and low emissivity glass.

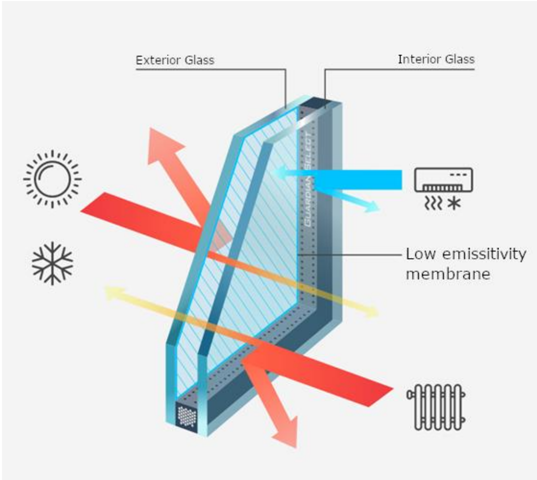


Figure 55: Illustrative scheme of a Low-e glass window

Adapted, [138]

Regarding the frame material, typical results of the combination of these two glasses with different usual frame materials were analysed: aluminium frame with thermal break, wooden frame, and PVC frame. Based on the results, the three solutions with the highest probability of presenting good thermal behaviour were chosen, i.e. lower values of "Uw": the wooden frame with low emissivity glass, and the PVC frame with both glass options [60].

To introduce these solutions with more specific characteristics into the DB, instead of applying the typical solutions of the ITE-50 as done for the reference solution, the final U-value of the window was adjusted based on the technical characteristics of the glass and the window frames, as per Equation 3. As the openings have different dimensions, the value corresponding to each of them was calculated in Excel, but considering that the results did not vary so much, and to minimize the modelling time by defining this input for the "building level" and not for each "opening level" every time a new renovation measure was modelled, it was decided to use the most unfavourable final value among the windows to represent all of them, which in this case is the highest U-value since for this parameter the regulatory limit is maximum, not minimum.

The individual values calculated for the three renovation measures and all windows can be seen in Annex 2, and the final result defined for each one of them and suitable in the DB model can be seen in Table 13, besides the corrections due to the use of sun protection devices, according to the procedure described in section 3.3.3. The values referring to the "gvi" and "VT" were obtained from the datasheets of the glasses presented in Annex 2. The solar factor, as well as the U-value, was also corrected according to the blinds used, following what was established in Equation 6. The "Uf" values were also obtained from the document provided by the manufacturer, as per Annex 2.

It is noteworthy that all alternative solutions are under the maximum allowed limit, which for zone “I2” and openings not facing north is 2.4 W/(m²°C) for the U-value, according to Ordinance No. 379-A / 2015. For verification of the maximum g-value, it is considered that the dwelling presents high thermal inertia since the constituent materials of the building fit into the categorization proposed by Dispatch 15793-E / 2013 and depress in section 3.5.1. Thus, and considering that Santa Tecla is inserted in the “V2” zone, the limit for the solar factor was also fulfilled, i.e. 0.56.

Table 13: Main parameters of renovation measures for windows

Construction solution	**Uw W/(m²°C)**	**Uwdn W/(m²°C)**	**gvi**	**gt**	**VT**
PVC frame and double glass (low e)	1.82	1.51	0.64	0.03	0.82
Wood frame and double glass (low e)	2.17	1.75	0.64	0.03	0.82
PVC frame and double glass (standard)	2.66	2.07	0.79	0.04	0.83

After running the simulations of all the above variations, new “Nic” and “Nvc” values were obtained from the software for each of the six typologies being analysed in the study. Then, the same procedure already described through Equation 7 and section 4.2.1 was repeated for weighting the values, and the new representative values of “Nic” and “Nvc” for the social neighbourhood were obtained. The value of the useful energy requirement for DHW remains the same because it does not vary with construction solutions, but mainly with the number of inhabitants. To calculate the values of primary energy need, using Equation 11, the same default systems defined for the reference scenario were also considered, to first understand the individual effects of each proposed passive measure.

The renovation measures are summarized in Table 14 with results of the primary energies for each scenario, and the reduction compared with the reference dwelling. As can be seen, the renovation measures that presented the best performance in terms of primary energy were the roof solutions, with a reduction in the order of 20 % in the facade, and finally the windows. This greatest contribution is probably related to the issue of top apartments having the highest energy needs due to heat transfer through the roof. In this case, the addition of insulation proved to be the most significant measure, in terms of primary energy.

In addition, making a comparative analysis between the absolute values of useful energy of heating and cooling, as per Annex 3, the insulation in the facade, despite presenting a reduction in heating needs, implies an increase in the need for cooling. This usually happens due to the outcome that a very insulated envelope can have, by making heat dissipation difficult, and causing an increase in the interior temperature [139]. However, even so, considering that the greatest energy parcel needs for the case study in question are heating, the proposed solution still has positive results in terms of primary energy.

Table 14: Renovation measures and primary energy results

ID (cost-opt. file)	Constructive element	Renovation measures	Primary energy (kWh/m².year)	Δ from Ref.
RI	-	Reference scenario	**104.21**	**-**
Var 01	Facade	Maintenance + Exterior wall: ETICS EPS 60 mm	**93.05**	**10.71%**
Var 02		Maintenance + Exterior wall: ETICS EPS 80 mm	**91.70**	**12.00%**
Var 03		Maintenance + Exterior wall: ETICS EPS 100 mm	**90.69**	**12.98%**
Var 20		Maintenance + Exterior wall: EPS 60 mm from the inside	**93.91**	**9.88%**
Var 29	Roof	Maintenance + MW 100 mm in the horizontal slab of the pitched roof	**84.09**	**19.33%**
Var 30		Maintenance + MW 120 mm in the horizontal slab of the pitched roof	**83.61**	**19.78%**
Var 31		Maintenance + MW 150 mm in the horizontal slab of the pitched roof	**83.11**	**20.25%**
Var 38	Windows	Maintenance + PVC frame and double glass (low-e)	**98.16**	**5.81%**
Var 39		Maintenance + Wood frame and double glass (low-e)	**99.46**	**4.56%**
Var 40		Maintenance + PVC frame and double glass (standard)	**98.28**	**5.70%**

Because the methodology under study encompasses not only the primary energy but also the economic pillar, the cost-optimal calculations initially will be performed in the next subsection, and only then packages of renovation measures combining the individual measures will be proposed.

Cost-optimal graph

To obtain the global cost of each renovation measure, it is necessary first to obtain the values of each package involved in its calculation, as described in section 3.5.2.

The complete budget with the initial investment and maintenance costs obtained through the CYPE Price Generator is in Annex 3, however, some considerations need to be mentioned.

As for primary energy, the weighting of the different typologies was done for the investment and maintenance costs, to represent an average value for the social neighbourhood, whenever possible, so that the two axes of the cost-optimal graph compare corresponding situations.

Thus, the procedure for obtaining these costs for renovation measures involving the roof, for example, was based on the calculation of the intervention for all the blocks, and then the value was diluted for all housing units, i.e. 160 apartments. Similarly, the Ing of the cost of facade renovations was also made, after all the values would vary according to the typology, as each one of them has different areas of the external walls. The measurements were taken through the DWG file provided.

For the electricity price, an energy bill from October 2021 of an apartment in Braga with four residents and 5.75 kva power was used, considering not only the energy price per kWh but also the fees involved in it (DGEG, IEC, and CIEG). The total cost corresponding to the consumption of the month was then calculated and the result was divided by the kWh consumed in the period, to find a final cost/kWh, plus applicable taxes. The final result found for the current electricity price was 0.24 €/kWh.

The same logic was followed to obtain the price of natural gas, considering level 1 of consumption, and the result obtained after the increase in taxes was 0.08 €/kWh. In addition to this unit price, the annual costs with the Fixed Tariff Term and Tax Subsoil Occupation were also considered separately in global costs, i.e. 20.62 € and 1.07 €, respectively.

Finally, with all the results obtained for the renovation measures, i.e. annual primary energy and global cost, the cost-optimal charts were assembled and can be seen in Figure 56.

Analysing the result of the individual renovation measures, it is noted that the measures involving the windows are not below the cost-effectiveness threshold, that is, the improvement in thermal performance caused by them follows an increase in the global cost concerning the base maintenance scenario. However, considering that the construction element has characteristics that do not meet the regulatory limit (U-value greater than the maximum allowed), it is still recommended at least one of the solutions be considered in the renovation packages. Considering that the three solutions for window renovation are almost on the same vertical line and have similar primary energy values (the wooden frame solution still has a slightly higher value than the PVC options), the one with the lowest cost was the one tested on renovation packages, i.e. PVC frame + double glass (standard).

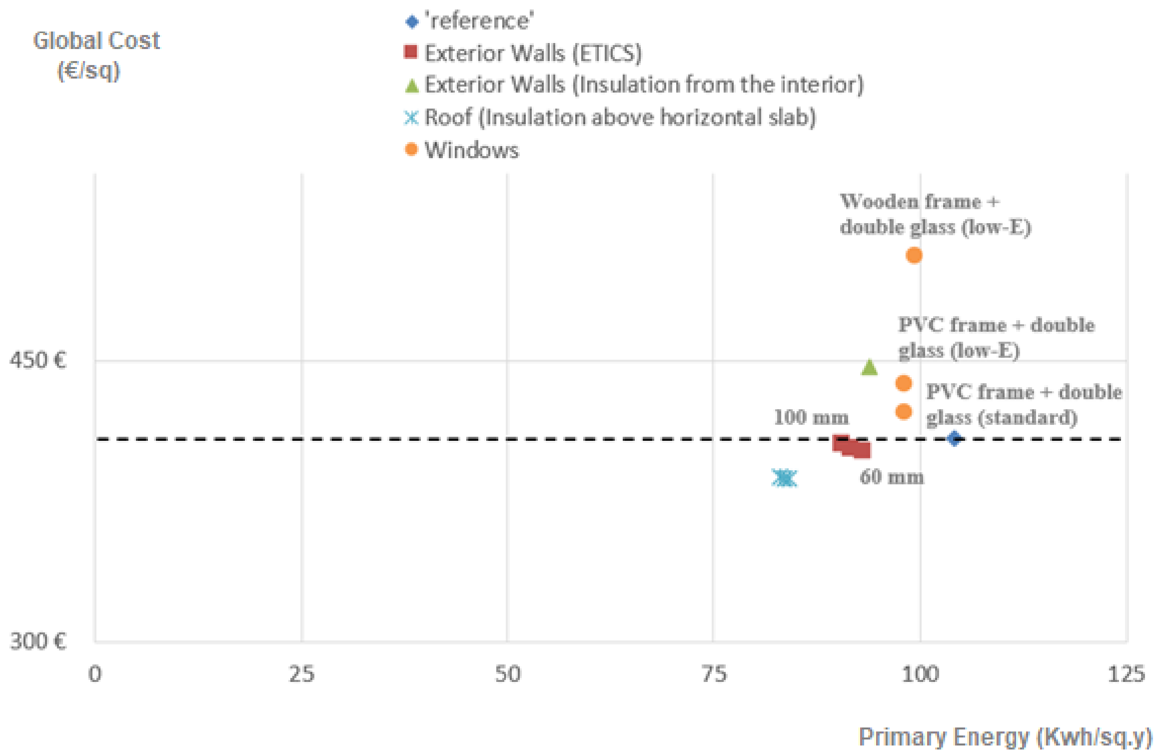


Figure 56: Cost-optimal graph for the renovation passive measures

Regarding the proposed roof measures, the values presented are very similar, both in terms of primary energy and global cost, as can be seen in the graph. Thus, and to minimize computational time, only one of the solutions was considered for the renovation packages. Since the values are similar, the solution with the smallest thickness was used, i.e. 100 mm, to consume less material in the renovation process. It is worth mentioning that in addition to having presented a greater reduction in terms of primary energy, it also had a lower associated global cost, corresponding in this case to the optimal cost solution among the individual renovation measures.

Finally, concerning the exterior walls, it is noted that the solution with insulation of the facade by the interior has higher associated primary energy and even greater global cost, compared to the exterior insulation solutions, and because of that, it was not considered in the next phase for the combinations of measures. Regarding the thickness of the insulations for ETICS, as the solutions behave inversely proportional to the two axes under consideration, it was decided to analyse the three measures in the renovation packages, as these differences can influence the objective of finding the cost-optimal solution but also the nZEB since they do not always refer to the same solution.

5.1.2 Renovation packages

I. Package of passive renovation measures

It is noteworthy that in this second phase, considering that the final renewable solution will probably encompass one of the packages described in this section, due to the more synergistic effect expected, in this phase, it is necessary to rehabilitate the elements that do not meet the regulatory limits. Thus, analysing the construction solutions described in Table 9, it is necessary to verify the U-value of the wall in contact with the stairwell/corridor.

The corridor space can be considered as strongly ventilated, due to the permanent openings it has. Considering that its volume is in the range between 50 and 200 m^3, it is concluded that its "btr" is above 0.70, following Dispatch15793-K/2013. Thus, the maximum admissible U-value for the wall between the apartments and the corridor, considering the thermal zone of the social neighbourhood, is 0.40 W/(m^2.°C). The minimum necessary thickness of insulation to be added to meet the established requirement is 60 mm (λ = 0.035), which is the solution adopted for the construction element for all renovation packages. The new U-value calculated is 0.39 W/(m^2.°C), and the construction solution can be represented as similar to the exterior wall with insulation from the interior, as described in Section 5.1.

Considering all the above points, the proposed renovation packages in terms of passive solutions can be seen in Table 15. The simulations were performed in DesignBuilder, where the new "Nic" and "Nvc" values were obtained. With these results and still using the systems by default, then the new primary energy calculation was made for each package. The results, as well as the % reduction concerning the reference scenario, are also shown in the aforementioned table.

As expected, the synergy between the individual measures resulted in much better results in terms of primary energy, with a reduction of up to 40.22% with package 06, only considering the application of passive measures. The improvement increased in line with the increase in insulation thickness and replacement of the windows with a more efficient one, also as expected, mainly due to the reduction of thermal losses through the envelope.

Table 15: Renovation packages and primary energy results

ID (cost-opt. file)	**Renovation packages**	**Primary energy**	**Δ from Ref.**
RI	Reference scenario	**104.21**	**-**
Pack 01	[Main.] + [corridor wall (EPS 60 mm]) + [ETICS (EPS 60 mm)] + [Pitched roof (MW 100 mm above horizontal slab] + [Ref. windows]	**70.44**	**32.41%**
Pack 02	[Main.] + [corridor wall (EPS 60 mm]) + [ETICS (EPS 80 mm)] + [Pitched roof (MW 100 mm above horizontal slab] + [Ref. windows]	**69.06**	**33.74%**
Pack 03	[Main.] + [corridor wall (EPS 60 mm]) + [ETICS (EPS 100 mm)] + [Pitched roof (MW 100 mm above horizontal slab] + [Ref. windows]	**68.02**	**34.73%**
Pack 04	[Main.] + [corridor wall (EPS 60 mm]) + [ETICS (EPS 60 mm)] + [Pitched roof (MW 100 mm above horizontal slab] + [PVC frame + double glass (standard)]	**64.51**	**38.09%**
Pack 05	[Main.] + [corridor wall (EPS 60 mm]) + [ETICS (EPS 80 mm)] + [Pitched roof (MW 100 mm above horizontal slab] + [PVC frame + double glass (standard)]	**63.26**	**39.29%**
Pack 06	[Main.] + [corridor wall (EPS 60 mm]) + [ETICS (EPS 100 mm)] + [Pitched roof (MW 100 mm above horizontal slab] + [PVC frame + double glass (standard)]	**62.30**	**40.22%**

Note: The values presented for primary energy are in (kWh/ m^2.year).

Analysing the useful energy results for the renewal packages, which can be seen in detail in the cost-optimal file (Annex 3), it is possible to notice that although the renovation package reduces the need for heating, It also increases the need for cooling, even if at a residual value, compared with the reference scenario. Then, consulting the results of the individual renovation measures, it is noted that this increase is mainly caused by addition of insulation on the facade, for the reasons already described.

Also concerning the portions of useful energy need, as shown in Figure 57, it can be observed that with the improvement of the thermal behaviour of the dwelling and the decrease of absolute values for air conditioning, the demand for DHW starts to prevail among the other parcels. The need for cooling remains the least of the three types in this phase.

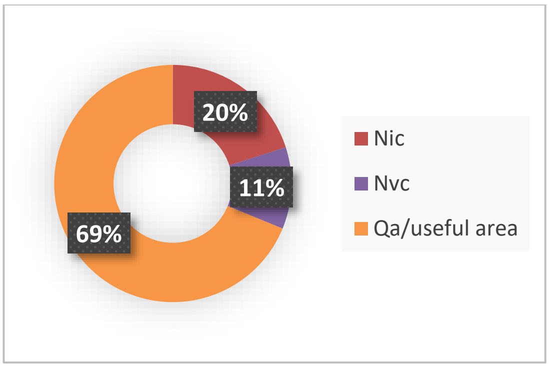


Figure 57: Proportion of each parcel of the energy useful need, for pack 06

II. Renovation of the technical systems

Some usual systems for this type of building in Portugal were chosen for the renovation proposals, following the established minimum requirements.

a) System 01

First, the use of solar collectors for DHW was chosen, following the recommendations of Decree-Law 118/2013. After filling in the data in the SCE tool, it presented a minimum Eren of 1414 kWh, as per Annex 4. Due to its ease and independence of operation, the thermosyphon system was chosen, respecting the minimum volume deposit required per apartment, i.e. 160l. It is worth mentioning that the collectors must be installed on the roof of the buildings on the south-facing side, due to the sun exposure, so this is the area available for the installation of the solar collectors, and should also be a factor to considering when choosing the model. Then, a model that met the above requirements and that had sufficient data on the tool in use for “Eren” contribution simulation and available price data on the Price Generator was chosen, which was a thermosyphon system by Junkers composed of two collectors and a common deposit: TSS300 FCC-2 (3.87m^2), as per Annex 4. After a new simulation, then an “Eren” of 1734 kWh was obtained, as per Annex 4, which corresponds to a value of 21.81 kWh/m^2.year.

However, as described in section 3.5.1, renewable energy systems must supply at least 50% of the total annual primary energy. Thus, the isolated measure is not sufficient to meet the minimum requirements.

It was then decided to replace the Multi-split and the gas water heater (auxiliary system in this case) with other more efficient equipment.

The WTD compact sensor from Vulcano, capacity 15l/min and efficiency of 0.92 (Annex 2) was chosen for the gas water heater, while a Multi-split air-air from Mitsubishi was chosen for heating and cooling, with the SCM50ZS-W used for the exterior unit (COP of 4.90 and EER of 5.17 – calculated by dividing nominal consumption by equipment capacity). For the interior, 3 units compatible with the exterior one and with configurations typically used for the type of space were chosen, the SKM20ZSP-W, as per Annex 2.

After these changes, a new calculation of primary energy was made, and it was verified that the contribution of the solar collectors met the required 50% of the contribution. All results are in the optimal-cost file in Annex 3 and summarized in the cost-optimal graph to be presented at the end of this section.

b) System 02

Since the contribution of heat pumps has been considered renewable, as long as the minimum criteria mentioned in section 3.4.2 are met, the solution has been considered and used more frequently in energy renovation. Despite presenting the use of interior space as inconvenient, it is understood that there is enough space for its installation using the storage room and kitchen, if necessary, as long as it presents better results in terms of global cost and primary energy than the other options under analysis.

So, for the second system option, an Ariston air-to-water aerothermal heat pump for air conditioning and DHW was chosen, with COP=5, EER=4.9, COP DHW=3.2, and capacity for 180 litres: NIBUM FLEX M NET, as per Annex 2.

For the fluid circulation regarding air conditioning, five units of the convector also from Ariston were chosen for the dwelling: Nimbus Aquaslim FS 20 – x5 (Annex 2).

The calculation of the heat pump "Eren" was done according to the procedure described in section 3.4.2, and the results found for each one of the packages, considering the technical data of the chosen model, are shown in Table 16. The minimum contribution of 50% was met by the system.

Table 16: Heat pump contribution to Eren

Pack	Nic	Eren/useful area (Heating)	Nvc	Eren/useful area (Cooling)	Qa/ useful area	Eren/useful area (DHW)
Pack 01	12.11	9.69	4.44	3.53	29.90	20.56
Pack 02	11.55	9.24	4.46	3.55	29.90	20.56
Pack 03	11.11	8.89	4.54	3.61	29.90	20.56
Pack 04	9.66	7.73	4.68	3.73	29.90	20.56
Pack 05	9.13	7.30	4.77	3.80	29.90	20.56
Pack 06	8.72	6.98	4.84	3.86	29.90	20.56

Note: The values presented for Nic, Nvc, Qa/useful area, and Eren/useful area are in (kWh/ m^2.year).

c) System 03

Although the result of the previous system showed a good reduction in terms of primary energy, it had an associated high global cost as a result, above the cost-effectiveness threshold. To obtain an intermediate solution, and considering that with the reduction of the energy need presented by the renovation packages, the demand for DHW turns out to be preponderant in this phase of the study, in system 3 it was adopted a heat pump only for DHW (with higher COP), and replaced the reference Multi-split by the more efficient option addressed in system 01.

Then, the heat pump for DHW from HTW was chosen, with a deposit of 200l and COP=3.77 (calculated by dividing nominal consumption by equipment capacity), as per Annex 2.

For the “Eren” contribution, still using Equation 12, the result obtained per useful area was 21.97 kWh/m^2.year, which was sufficient to meet the established minimum requirements. Although the renewable contribution to be deducted is practically equal to the value obtained by system 01 using the solar collector, the final results are very different between both solutions, mainly due to the COP of the equipment used, which generates much lower final energy, and compensates the highest “Fpu” relative to the source of electricity when compared to the gas-based equipment of system 01.

d) System 04

Finally, the last solution proposed includes system 03 with the addition of the photovoltaic system, to get even closer to a nearly zero energy building. It was chosen 1 PV panel of 180W since the contribution of “Eren” simulated by the PVGIS is already sufficient to supply the final energy for the

Multi-split to meet the heating and cooling needs (in this case, the "Eren" was deducted after converting the useful to final energy using, by considering the Multi-split coefficients). It is considered here a grid-connected system with "Eren" related only for self-consumption. The results presented by the simulation tool can be seen in Annex 4.

As expected, the solution meets the minimum 50% required for the contribution of renewable energy, as it has additional contributions concerning system 03, which was already sufficient to meet the established requirements.

For the budget, an "INNOVA" brand model available in the Price Generator for 180W power was considered, which has dimensions of 1326x808x35 mm, suitable for use in the available roof area. To obtain the investment and maintenance costs of the solution, a micro-inverter of 250W per apartment was also considered. A summary of the analysed systems is presented in Table 17.

Table 17: Technical and renewable energy systems

Scenario	Heating	Cooling	DHW	Renewable energy systems
Ref. System	Electric heater (COP=1.00)	Multi-split (EER=3.00)	Gas water heater (η=0.82)	-
System 01 (S1)	Multi-split (COP=4.90)	Multi-split (EER=5.17)	Gas water heater (η=0.92)	Thermal solar system (DHW)
System 02 (S2)	Heat pump (COP=5.00)	Heat pump (COP=4.90)	Heat pump (COP=3.20)	Heat pump (air conditioning and DHW)
System 03 (S3)	Multi-split (COP=4.90)	Multi-split (EER=5.17)	Heat pump (COP=3.77)	Heat pump (DHW)
System 04 (S4)	Multi-split (COP=4.90)	Multi-split (EER=5.17)	Heat pump (COP=3.77)	Heat pump (DHW) + PV system (air conditioning)

Cost-optimal graph

The packages involving passive renovation measures were then combined with proposals to replace technical systems and the use of renewable energy systems to obtain the new primary energy values, as per Annex 3. It is noteworthy, that the reduction in primary energy compared to the reference scenario achieved through the combination of passive measures packages with technical systems and renewable energies was 95 %.

Finally, after calculating the global costs for all renewable packages, the cost-optimal graph with the 30 final scenarios was generated, and it is shown in Figure 58.

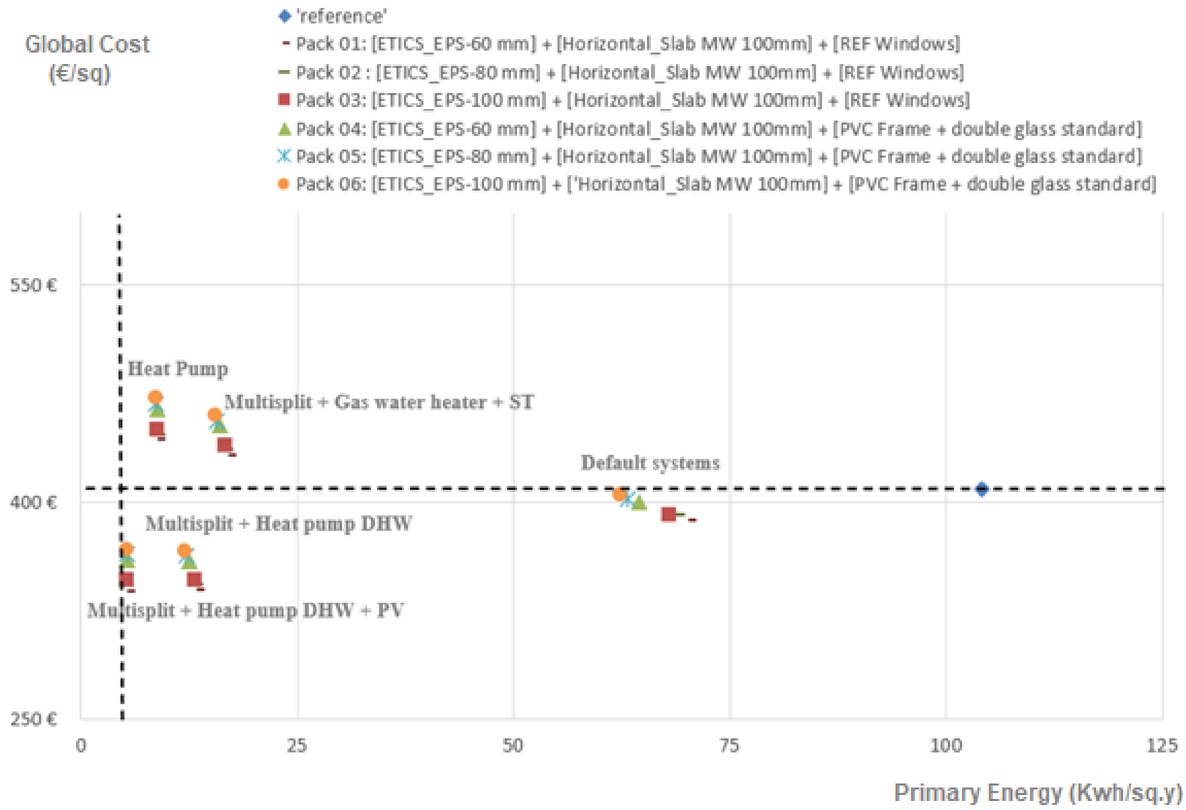


Figure 58: Cost-optimal graph

Analysing the cost-optimal graph, it can be seen that the cost-optimal solution is the combination of package 01 with system 04. However, due to the limitation of the U-value of the reference window, i.e. greater than the regulatory maximum, considering that the difference in the global cost was residual between the cost-optimal solution and the renovation proposal that considers replacement by a double-glass window, and considering that the primary energy results are equal for both options, it is recommended that the last is adopted in the social neighbourhood, which is the combination of Package 04 + System 04.

Maintenance + corridor wall (EPS 60mm) + ETICS (EPS 60mm) + Pitched roof (MW 100 mm above the horizontal slab) + PVC frame + double glass (standard)

+

Multi-split (COP=4.90 / EER= 5.17) + Heat pump DHW (COP=3.2) + PV (180W)

It is worth mentioning that the different values for the global cost between the solutions that involved the use of systems 03 and 04 were minimal, practically unnoticeable in the graph. However, the use of photovoltaic panels allowed for an even greater reduction in the primary energy, for what can be considered as the nZEB level, not only for this specific package but for the others also combined with S4. The renewable energy system proved to be a positive resource in energy renovation, while it allowed for improved thermal performance without increasing global cost, as it offset the increase in investment and maintenance costs with a reduction in energy costs.

With the choice of the renovation proposal, the primary energy of the housing unit went from 104.21 kWh/ m^2.year to 5.26 kWh/ m^2.year, presenting a reduction of 95 %, concerning the reference scenario. Regarding the global costs, the reduction represented 12 %, decreasing from 408.89 $€/m^2$ to 359.86 $€/m^2$. This result can be considered satisfactory, and it demonstrates the advantage associated with the synergistic effect of associating passive individual measures among them also with the technical systems. More than that, the result points to the importance of using renewable energy systems and their contribution to the nZEB goal. The final renovation proposal has 93 % of its primary energy corresponding to renewable energy, in this case, used for both air conditioning and DHW.

5.2 Resilience analysis

5.2.1 Primary energy

The first step to analyse the robustness of the results, as foreseen according to the steps described in section 3.5.3, was the conversion of the weather files obtained from the EnergyPlus website for the years 2020 and 2050. The CCWorldWeatherGen presents the estimated variations for some of the climatic parameters, as can be seen in Annex 5. For the daily mean temperature, for example, it estimates an annual increase in the order of 0.66 °C for 2020, and 1.93 °C for 2050, which varies during the year, with the highest temperature rise during summer, as expected, i.e., up to 2.94 °C increase in June for 2050. It is noteworthy that the increase in indoor temperature is not only a result of external temperature rise but also due to the more solar gains projected.

The new files were then generated considering these new climatic conditions, to analyse the change in thermal behaviour caused by projected climate changes.

The second step was to run the energy simulations in DesignBuilder for the reference model again. The results of “Nic” and “Nvc” for the two future scenarios were then weighted among the individual results of the six typologies under consideration in this study, following the same procedure already performed previously, to obtain new useful energy values for heating and cooling that are representative of the social neighbourhood (one for 2020 and another for 2050). Finally, the values obtained were then linearly interpolated in Excel, according to the procedure suggested in section 3.5.3, as shown in Figures 59 and 60.

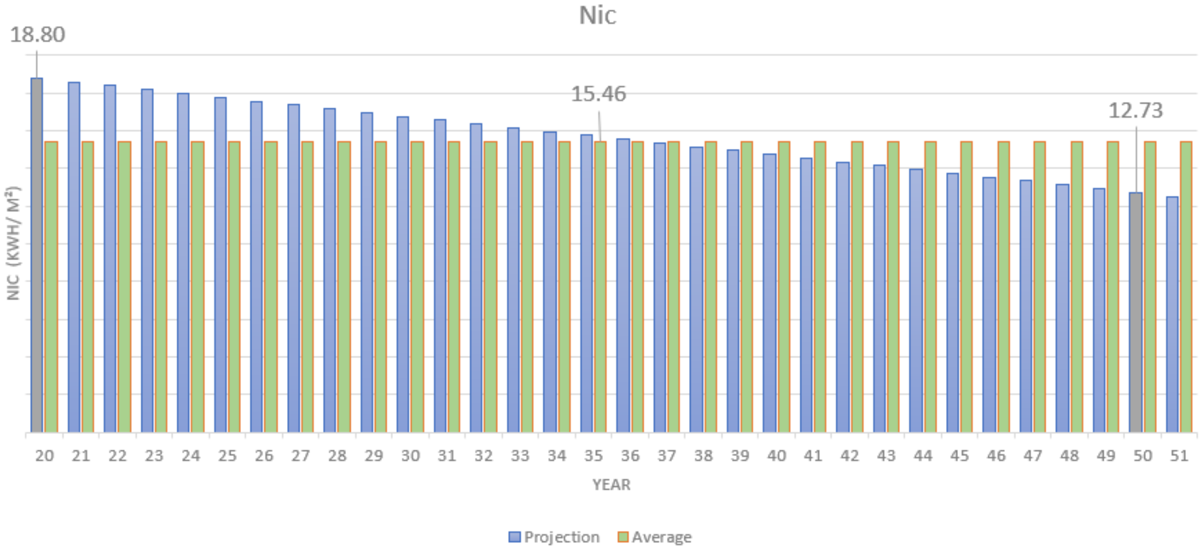


Figure 59: Linear interpolation between projected Nic values for 2020 and 2050

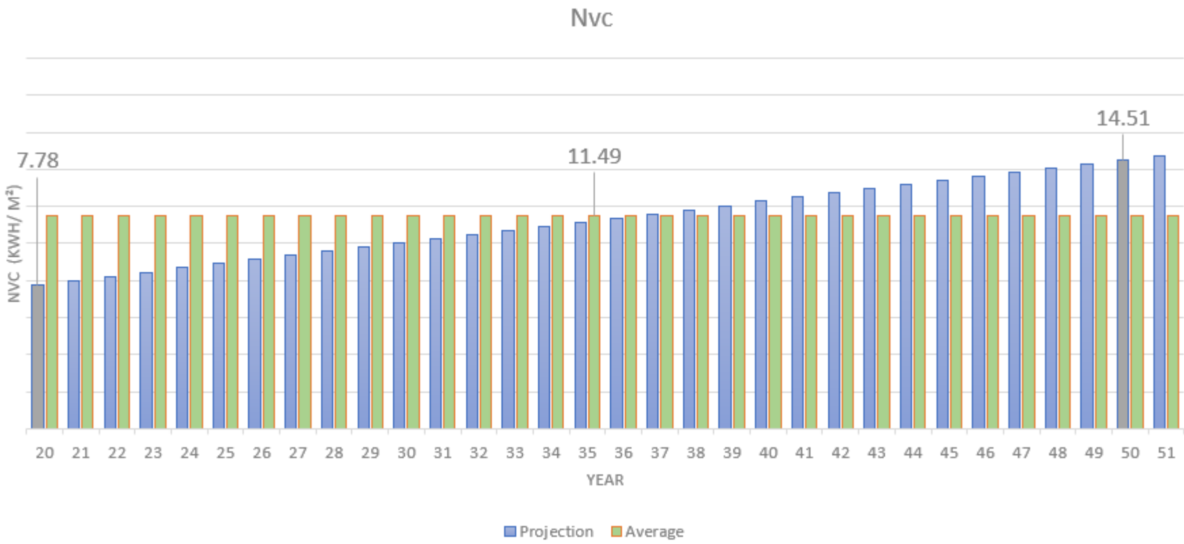


Figure 60: Linear interpolation between projected Nvc values for 2020 and 2050

Before proceeding to the calculation of primary energy and global cost, some analysis can already be done. The results obtained somehow met the expected behaviour described in section 2.5, i.e., a drastic rise in cooling energy use and a moderate decrease in heating energy use, as presented in Figure 61.

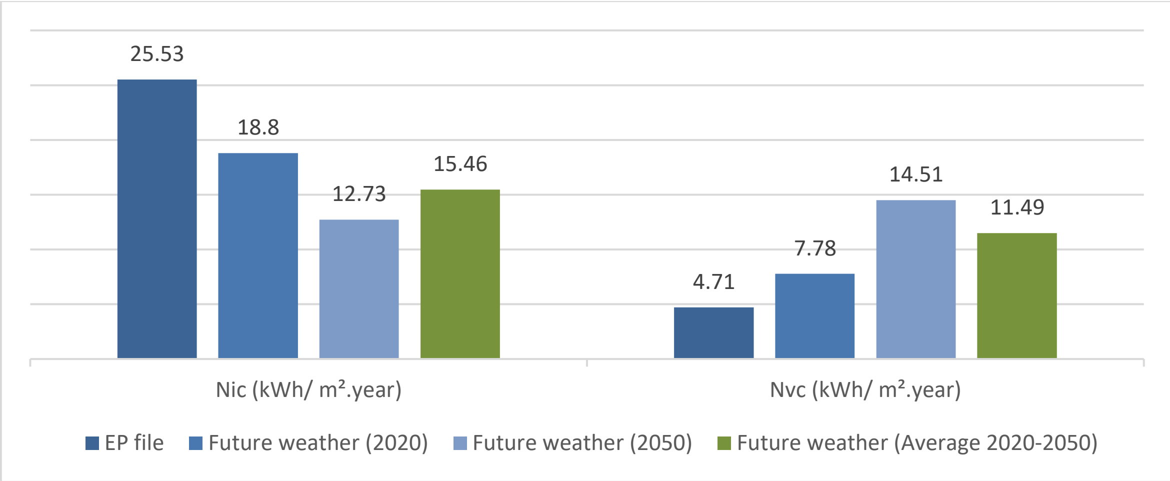


Figure 61: Comparison of standard and adapted methodologies for useful energy for the reference dwelling

The corresponding values of useful energy for heating decreased by around 32% in 2050, compared to the projected current values (weather file 2020) results, while for the corresponding values of useful energy for cooling, the increase corresponded to 87%.

It is also possible to see that the estimated values for 2020, using the climate file converted into CCWorldWeatherGen, generated useful heating needs 26% lesser than the weather file obtained through the EP website and created from measurements of years and decades ago. Regarding the need for cooling, the difference was 65% more for the 2020 estimate. It is also noted that these differences are more accentuated when compared to 2050, considering the increase in climate change, i.e., the future scenario considers the useful energy for heating 50% lesser than expected using the conventional weather file from EP, and an absurd increase for the cooling demand, in the range of 208%.

Finally, analysing the three parcels of the useful energy need, a change in the proportions can also be perceived in Figure 62, compared with the conventional methodology, showing the increased representation of the cooling requirement, as expected.

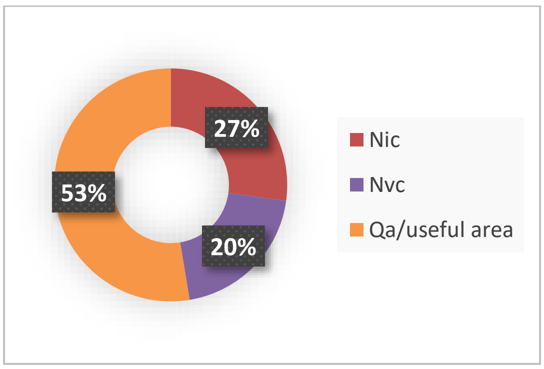


Figure 62: Proportion of each parcel of the energy useful need, for the reference model (adapted methodology)

Continuing with the proposal to adopt the methodology in analysis, considering the same systems by default used in the conventional scenario, the primary energy for the reference model was calculated, based on the average values of “Nic” and “Nvc” after the linear interpolation procedure. The results can be seen in Table 18.

Table 18: Annual primary energy for the reference scenario (adapted methodology)

ID	**Nic**	**η**	**Nvc**	**η**	**Qa/ m²**	**η**	**Final energy**	**Fpu**	**Fpu**	**Fpu**	**Primary energy**
RI	15.46	1	11.49	3	29.90	0.82	**55.76**	2.5	2.5	1	**84.69**

Note: The values presented for Nic, Nvc, Qa/m², final energy, and primary energy are in (kWh/ m².year).

Analysing the table above, it can be noted that the need for useful energy considering future projections is lower than that obtained through the traditional method, i.e., for heating and cooling the total value is 26.95 kWh/m². year as opposed to the total of 30.24 kWh/ m².year obtained before. This behaviour can be associated with the specific climatic zone in which the social neighbourhood is inserted. Considering that the north of Portugal is characterized by having a greater need for heating than for cooling, a scenario that projects an increase in temperature tends to minimize this parcel of need, which is the largest among the two, thus justifying the reduction in energy demand. It is possible, for example, that for buildings located in warmer areas where the need for cooling prevails, the useful and primary energy values increase according to the projection of the temperature increase.

Furthermore, analysing the reduction in the total value of primary energy, it is also worth noting that in addition to the reduction in useful energy, the default systems considered present a 3 times greater efficiency for the cooling equipment. In this way, the increased energy demand, i.e. cooling, has a correspondingly more efficient technical system than the heating system, which now has less demand to be supplied than before. This factor also has a direct impact on final energy, and consequently on primary energy.

5.2.2 Passive renovation measures

The next analysis involves the renovation scenarios. The same renovation measures proposed earlier were simulated again in the DB with the future climate files, and the results can be seen in Table 19.

Table 19: Renovation measures and primary energy results (adapted methodology)

ID (cost-opt. file)	Constructive element	Renovation measures	Primary energy (kWh/m².year)	Δ from Ref.
RI	-	Reference scenario	**84.69**	**-**
Var 01	Wall	Maintenance + Exterior wall: ETICS EPS 60 mm	**78.01**	**7.89%**
Var 02		Maintenance + Exterior wall: ETICS EPS 80 mm	**77.21**	**8.83%**
Var 03		Maintenance + Exterior wall: ETICS EPS 100 mm	**76.58**	**9.57%**
Var 20		Maintenance + Exterior wall: EPS 60 mm from the inside	**78.65**	**7.13%**
Var 29	Roof	Maintenance + MW 100 mm in the horizontal slab of the pitched roof	**69.61**	**17.80%**
Var 30		Maintenance + MW 120 mm in the horizontal slab of the pitched roof	**69.29**	**18.18%**
Var 31		Maintenance + MW 150 mm in the horizontal slab of the pitched roof	**68.91**	**18.64%**
Var 38	Windows	Maintenance + PVC frame and double glass (low-e)	**80.71**	**4.69%**
Var 39		Maintenance + Wood frame and double glass (low-e)	**81.51**	**3.76%**
Var 40		Maintenance + PVC frame and double glass (standard)	**82.19**	**2.95%**

The percentages of primary energy reduction for the future scenario in terms of the intervened constructive elements remain like those of the conventional scenario, with values a little lower than the last ones.

The only most significant change detected concerns window renovation measures. Initially, the greatest reduction had been achieved by PVC frames with low-e double glass, followed by the PVC solution with standard double glass and only then by wooden frames with low-e double glass. However, as can be seen above, for the future scenario, the “Var 39” solution showed better results than the “Var 40”, this being the measure with the smallest reduction in terms of primary energy among the three.

Analysing the results of each package of the useful energy for these solutions, as per Annex 3, it is possible to see that the change in the behaviour of the PVC window with standard double glass is due to the increased need for cooling in a greater proportion than the other measures of windows. This change is probably because the standard glass allows greater solar radiation to pass through than low-e glass, which for the future scenario characterized by the increase of solar radiation, results in an even greater amount of thermal gain through the windows, consequently greater cooling needs. It is understood, then, that low emissivity glasses tend to have greater importance in the coming decades, considering the climate zone under study.

Cost-optimal graph

To complete the cost-optimal adaptation, the global costs of all measures (both the reference model and the renovation measures) were calculated, this time using the projected and interpolated values shown in blue in Figures 59 and 60, instead of the fixed values obtained through the climatic file of the EP website.

For example, considering the reference model, for the calculation of energy consumption due to cooling in the year 2050, the projected value for 2050 “Nvc” was used, i.e. 14,51 kWh/m^2, divided by the efficiency of the technical system in use, i.e. EER=3 for the Multi-split considered, obtaining for that year a final energy value for cooling equal to 4.84 kWh/m^2, which was multiplied by the price of electricity by kWh estimated for this year. Meanwhile, the calculation for the conventional methodology would consider the fixed value of “Nvc” for the entire life cycle of the building, i.e. 4.71 kWh/m^2, divided by the same efficiency of 3, obtaining as a result for the energy consumption due to cooling in 2050 the value of 1.57 kWh/m^2, which was also be multiplied by the corresponding energy price estimated for this year.

After calculating all the global cost values, the new cost-optimal graph is then generated, and it is shown in Figure 63.

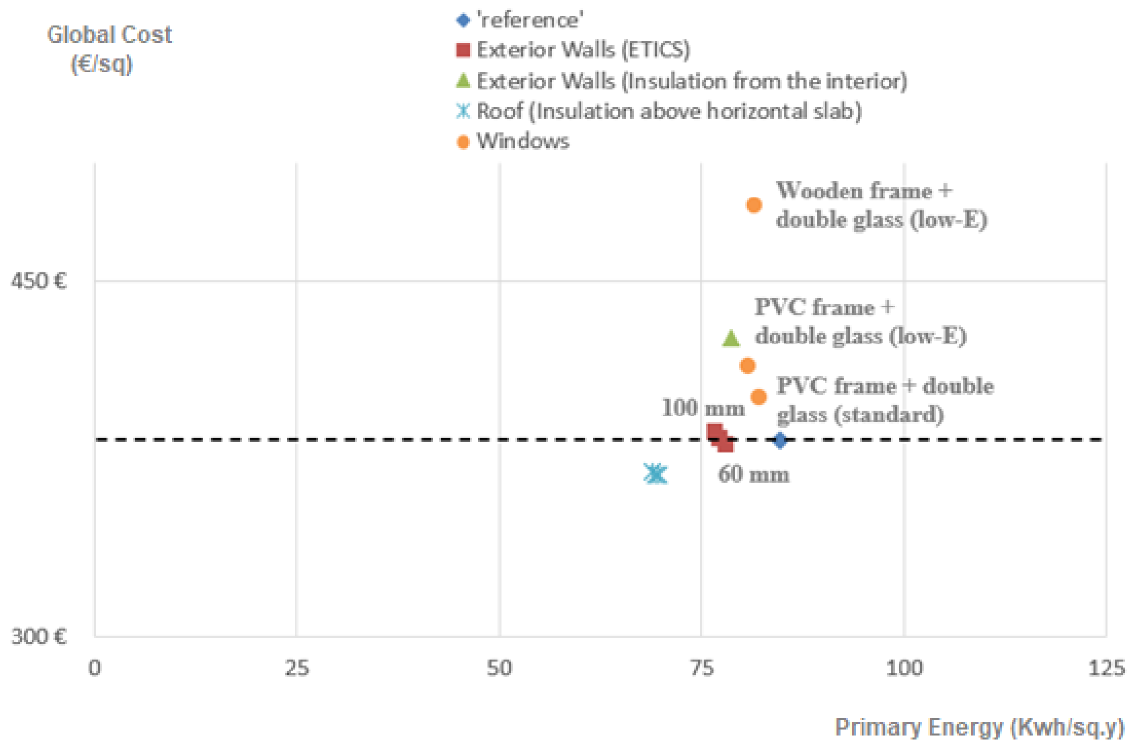


Figure 63: Cost-optimal graph of renovation measures (adapted methodology)

Analysing the results above, it can be noted that the interventions proposed for the pitched roof presented a behaviour similar to that obtained through the conventional methodology, demonstrating that they are not only cost-effective but also the cost-optimal solution among the proposed renovation measures, for both methodologies.

For exterior walls (ETICS), however, the global cost associated with the solutions rose concerning the reference model. As the renovation measures for the ETICS previously had a global cost close to that of the reference scenario, the proposal involving the addition of EPS with a thickness of 100 mm was slightly above the profitability level, presenting a global cost of 0.91% above the reference scenario.

In general, this increase in the global cost of renovation proposals may be associated with the improvement in the thermal performance of the reference scenario. When the building under study has high energy consumption, renovation proposals tend to be more cost-effective, after all, the reduction in the energy cost parcel can more easily offset the increase in investment and maintenance costs normally associated with these solutions.

Going back to the graph analysis, the proposal to insulatlfacade from inside the building showed that it is still not cost-effective, demonstrating that the possible improvement in thermal behaviour due to the reduction of the surface mass capable of absorbing heat (expected behaviour for the summer) was not significant. Despite having shown an extreme increase in the need for cooling, the need for heating continued to represent the largest share among both, considering the average interpolated needs for the interval of the life cycle of the social neighbourhood, as present in Figure 62. Furthermore, thermal losses due to thermal bridges probably continued to present unfavourable thermal behaviour, also responsible for presenting a worse thermal behaviour than the application of the insulation from the exterior. Finally, the solution continued to present a higher overall cost than the reference scenario, being above the cost-effective threshold, proving to be an unfeasible solution according to both methodologies.

Finally, considering the interventions on the windows, although the wooden frame solution with low emissivity double glazing has shown a greater reduction concerning primary energy than the PVC frame with standard double glazing, it continued to present a higher global cost associate. Since all three renovation solutions for the glazed openings are above the reference, it was decided to still use the option of the lowest global cost associated, same as in the conventional methodology, for the same reason previously described (non-compliance with the minimum U-value).

Given the above points, it is understood that there was not enough significant change in the renovation measures to change the proposed energy renovation packages. The only possible change would be the exclusion of packages involving the ETICS 100 mm. However, three points were considered to keep them: the first is that package 6 was the one that presented the greatest reduction in terms of primary energy for the conventional methodology, presenting a greater chance of obtaining the nZEB level, which is also one of the objectives of the study in question; the second is that the percentage difference for the global cost compared to the baseline scenario was very small, less than 1%; finally, as this is a comparative analysis, maintaining the same renovation proposals ends up being the recommended procedure for analysing the results, whenever possible. Thus, it was decided to keep the same renovation packages initially proposed.

5.2.3 Renovation packages

I. Package of passive renovation measures

After repetition of the energy simulation for the renovation packages, using DesignBuilder, and calculating the corresponding primary energy values, following the adapted methodology in use, the results are shown in Table 20. It is worth remembering that, as with the conventional methodology previously applied, the renovation packages also include renovation of the wall in contact with the stairwell/corridor, due to the need to reduce its U-value, so that it meets the established legal limits.

Table 20: Renovation packages and primary energy results

ID (cost-opt. file)	Renovation packages	Primary energy	Δ from Ref.
RI	Reference scenario	**84.69**	**-**
Pack 01	[Main.] + [corridor wall (EPS 60 mm]) + [Ext. wall (EPS 60 mm)] + [Pitched roof (MW 100 mm above horizontal slab] + [Ref. windows]	**61.60**	**27.27%**
Pack 02	[Main.] + [corridor wall (EPS 60 mm]) + [Ext. wall (EPS 80 mm)] + [Pitched roof (MW 100 mm above horizontal slab] + [Ref. windows]	**60.81**	**28.20%**
Pack 03	[Main.] + [corridor wall (EPS 60 mm]) + [Ext. wall (EPS 100 mm)] + [Pitched roof (MW 100 mm above horizontal slab] + [Ref. windows]	**60.17**	**28.95%**
Pack 04	[Main.] + [corridor wall (EPS 60 mm]) + [Ext. wall (EPS 60 mm)] + [Pitched roof (MW 100 mm above horizontal slab] + [PVC frame + double glass (standard)]	**58.41**	**31.04%**
Pack 05	[Main.] + [corridor wall (EPS 60 mm]) + [Ext. wall (EPS 80 mm)] + [Pitched roof (MW 100 mm above horizontal slab] + [PVC frame + double glass (standard)]	**57.68**	**31.89%**
Pack 06	[Main.] + [corridor wall (EPS 60 mm]) + [Ext. wall (EPS 100 mm)] + [Pitched roof (MW 100 mm above horizontal slab] + [PVC frame + double glass (standard)]	**57.16**	**32.50%**

Note: The values presented for primary energy are in (kWh/ m^2.year).

Although the renovation packages presented better thermal performance compared to the isolated measures, as expected, once again the reduction of primary energy considering the future scenario was less significant than considering the traditional scenario, reaching a reduction of 32.50% with package 06, in contrast to the 40.22% previously obtained. The behaviour in terms of improvement with increasing insulation thickness and replacing the windows with more efficient ones occurred as expected.

Analysing the three parcels of the useful energy needs, as per Annex 3, it is also noticed a significant change in their proportions concerning the reference scenario, so that now the cooling parcel has a greater representation than the heating parcel (Figure 64). Besides, since the demand for DHW is considered constant and the useful energy for air conditioning has reduced in absolute terms, this portion represents for the packages an even greater percentage of the total useful energy.

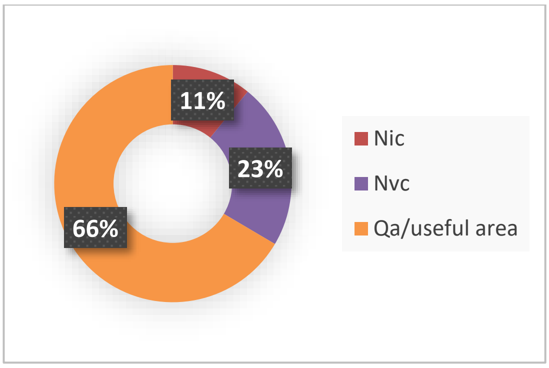


Figure 64: Proportion of each parcel of the energy useful need, for pack 06 (adapted methodology)

I. Renovation of the technical systems

The same technical systems were used for this phase of the analysis, considering here that their behaviour will remain the same during the next decades, as described in section 3.5.3. The renewable energy systems were also the same, however, some changes may be considered.

The contribution of solar systems in the future is estimated to remain the same, still referencing the section mentioned above, so the "Eren" for the thermal solar system and photovoltaic panels continues equally. Regarding the contribution of the heat pump to DHW, as the useful energy for this purpose remains the same, the value of "Eren" in this case is also equal to the previous one. Only the heat pump for air conditioning had a new "Eren" calculation, as the useful energy needs for heating and cooling were changed, consequently changing the "Qusable" presented in Equation 12. The new results are shown in Table 21.

The contribution of renewable energy systems to all the above proposals meets the minimum 50% in terms of primary energy, following the legal requirement, previously explained. The respective percentages can be seen in Annex 3.

Table 21: Heat pump contribution to Eren

Pack	Nic	Eren/useful area (Heating)	Nvc	Eren/useful area (Cooling)	Qa/ useful area	Eren/useful area (DHW)
Pack 01	6.80	5.44	9.76	7.76	29.90	20.56
Pack 02	6.46	5.16	9.83	7.82	29.90	20.56
Pack 03	6.19	4.96	9.88	7.87	29.90	20.56
Pack 04	5.44	4.35	10.01	7.97	29.90	20.56
Pack 05	5.12	4.10	10.10	8.04	29.90	20.56
Pack 06	4.89	3.91	10.17	8.09	29.90	20.56

Note: The values presented for Nic, Nvc, Qa/useful area, and Eren/useful area are in (kWh/ m^2.year).

Cost-optimal graph

Combining the proposed packages with the defined solutions for the technical systems and renewable energy systems, the new primary energy values were obtained, as demonstrated in Annex 3. The greatest reduction obtained in terms of primary energy, considering the reference scenario, was 94 %, similar to the percentage obtained through the conventional methodology.

Finally, after a new calculation of the global costs considering the adaptation of the energy costs, the cost-optimal graph was updated, and it is shown in Figure 65.

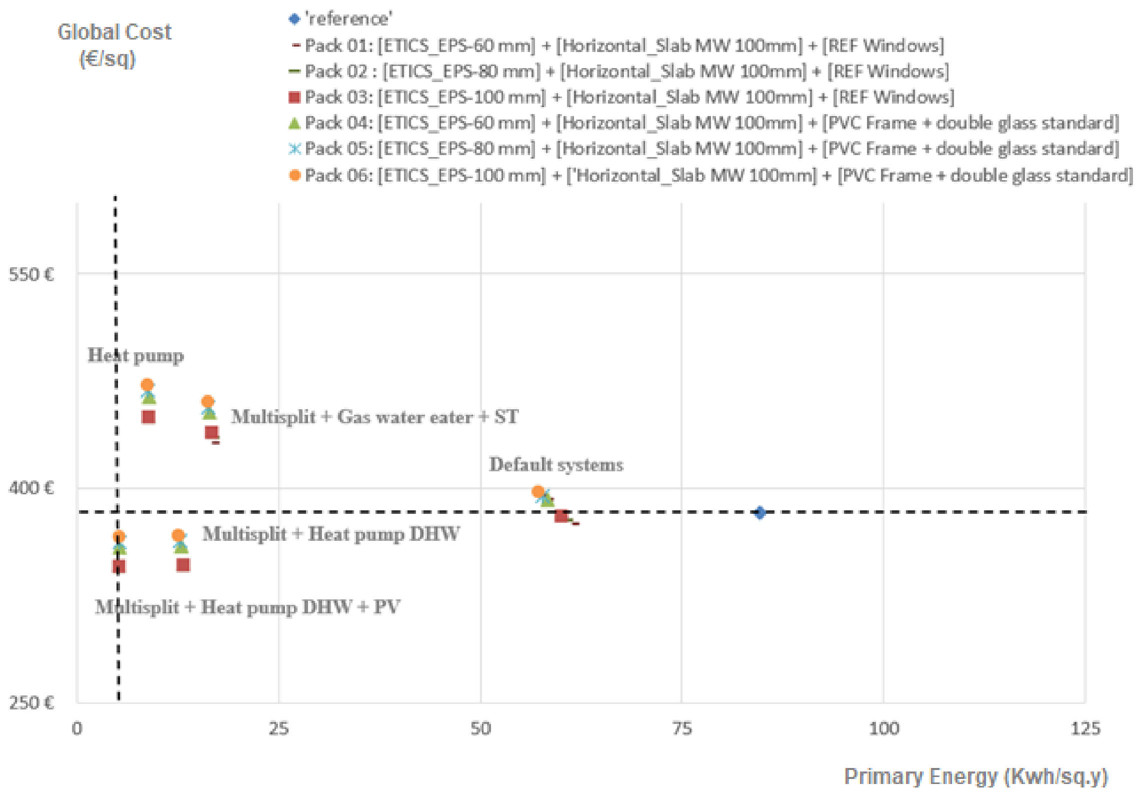


Figure 65: Cost-optimal graph (adapted methodology)

Maintenance + corridor wall (EPS 60mm) + ETICS (EPS 60mm) + Pitched roof (MW 100 mm above the horizontal slab) + PVC frame + double glass (standard)

\+

Multi-split (COP=4.90 / EER= 5.17) + Heat pump DHW (COP=3.2) + PV (180W)

The equal value obtained for the primary energy of cost-optimal solutions and framed in the nZEB level is because the photovoltaic panel can supply the air conditioning needs, which are already well reduced in this phase of the study. So, the residual value for the primary energy is due to the use of the heat pump for DHW. As the "Eren" calculation for this system is based on a proportion of the useful energy referring to the parcel that is served by the equipment, considering that in S4 it is used for DHW and that its value was considered equal among the methodologies, the value then remains constant in both analyses.

The nZEB level is achieved by the solutions combined with System 04, also due to the improvement in thermal performance through the contribution of photovoltaic panels, compared to System 03.

With the choice of the renovation proposal, the primary energy of the housing unit went from 84.69 kWh/ m².year to 5.26 kWh/ m².year, presenting a reduction of 94 %, concerning the reference scenario. Regarding the global cost, the reduction represented 6 %, decreasing from 383.14 $€/m^2$ to 358.82 $€/m^2$. The final renovation proposal has 92 % of its primary energy corresponding to renewable energy, in this case, both for air conditioning and for DHW.

It is worth highlighting here the greatest difficulty of renovation solutions in being profitable. The global cost reduction, as described, was smaller than that obtained through the conventional method. Furthermore, analysing the graph, it can be seen that part of the renewal packages went above the cost-effectiveness threshold, while in the conventional scenario, all of them were cost-effective. This behaviour demonstrates, as already discussed, that the methodology that involves a worse thermal performance, in this case, allows the renovation solutions to reach lower global cost proportionally concerning the reference, by compensating the reduction of the energy cost to the detriment of the increase in investment and maintenance cost.

CHAPTER 6: CONCLUSION AND FUTURE WORK

The main conclusions made with the completion of this dissertation are described in this section, as well as suggestions and possible future works related to the studied subjects.

6.1 Conclusion

The application of the cost-optimal methodology to analyse the cost-effectiveness of energy renovation proposals allowed that the established goals for this study were fulfilled, through the definition of a proposal capable of optimizing the thermal behaviour of the Santa Tecla neighbourhood up to a level considered as nZEB.

The synergy caused by the renovation packages proved to be important for improving the thermal performance of the neighbourhood, achieving a reduction in primary energy in the order of 32.5 % and 40.22 % (adapted and conventional methodology, respectively) while the individual renovation measures had achieved improvements in the order of 18.64% and 20.25%. However, it was only through the combination of the renovation packages encompassing passive measures with more efficient technical systems and the use of renewable energy that it was possible to reach the final results with very low energy values, i.e. reduction of 94% and 95% concerning the primary energy of the reference scenario.

The solution chosen at the end of this study encompasses a combination of the maintenance measures; the renovation of the walls of the apartments in contact with the stairwell through the addition of 60 mm of EPS; intervention on the facade through the use of ETICS with 60mm of EPS; addition of 100 mm of mineral wool above the horizontal concrete slab of the pitched roof; replacement of the existing window frames with others of PVC with standard double glazing, so that the solution presents values within the established regulatory limit. In addition, the renovation of the social neighbourhood includes the replacement of technical systems by a multi-split for air conditioning (COP=4.90 and EER=5.17) supplied by a 180W photovoltaic panel and the use of a heat pump for DHW (COP=3.77).

The robustness and resilience of the proposed solutions were evaluated through the application of the adapted cost-optimal methodology, to also encompass the future scenarios projected for the climate zone in which the neighbourhood is located, which was done using future weather files. The tool used in this study, i.e. CCWorldWeatherGen, considers an increase in temperature on the order of 1.93 °C to 2050, with peaks of 2.94 °C during the summer. This change in the weather parameters used in the dynamic simulation tool, despite being responsible for the reduction in useful heating needs for the case study, was also responsible for the increase of useful energy for cooling. Because the climatic zone in which the social neighbourhood is located is characterized by much greater heating needs, the combination of this variation resulted in lower values of primary energy. It is thought that in climatic zones that present the inverse behaviour (greater cooling than heating needs) this fluctuation in primary energy values may increase.

The cost-optimal graphs obtained through the adapted methodology presented a behaviour similar to those of the conventional method, regarding the renovation proposals, but with some differences in terms of values. For example, the renovation measures presented higher proportional global costs when compared to the reference solution, than what was observed in the graph obtained through the conventional method. It is believed that the main reason is related to the lower energy need presented by the adaptation proposal, which makes that the improved thermal performance of the measures decreases the energy cost during the life cycle of the building less significantly, compensating for less the addition of investment and maintenance costs due to the renovation proposals.

It is also worth noting the alteration of the results presented for the windows interventions. The energy simulation considering the future climate data showed better results for the solutions that involve the use of glass with low emissivity than for the standard one, i.e. lower energy requirements. Considering the predicted climate changes and the increase in solar radiation, it is concluded that low-emissivity glass presents itself as a promising solution for the future in terms of thermal performance. However, for this specific case study, they were not able to offset the investment cost with the reduction in energy cost.

However, the simplification made in the modelling phase may have been a limitation and influenced this result, after all, the windows were considered as a unique solution both in terms of modelling and obtaining energy performance as well as to obtaining the global cost. That is, the same renovation solution was considered for all openings of the social housing, regardless of the facade's solar orientation, for example. It is possible, then, that the use of different windows for each facade would have generated better results for the relationship between global cost and thermal performance, such as the use of low-emissivity glass in the south-facing facade and standard glass in the north-facing facade.

During the process of modelling and imputing the variables in the program, it was noticed that the dynamic simulation involves a huge number of variables and information that need to be added about the building. Unlike static simulation, for example, to complete the model it is necessary to add very specific information, such as usage profiles, which can vary greatly depending on the people who live in the apartment and their habits, such as the time that the dwelling is occupied and the opening hours of the windows. During the process of defining these variables, many intermediate simulations were performed, and it was noted that changing only one of these parameters can reasonably change the simulated energy needs.

This change can have a direct impact on the choice of renovation proposals, after all, as previously discussed, the definition of the global cost of the solutions often permeates the relationship between their investment cost and the energy cost, which depends precisely on the useful energy needs. Thus, despite not considering this to have been a limitation of the study, after all, typical profiles were used and kept the same constant for all proposals, it is recommended to use a hybrid method of modelling running calibrations to the model, whenever possible, to help in the process of defining these variables and make the process even more assertive to the reality of each building under analysis.

6.2 Future work

The analysis of future climate projections and their interaction with the thermal performance of buildings is presented as a very broad theme and leaves room for new questions and future works.

First, as described during the dissertation, there are several possible future scenarios projected by scientists and scholars, and the prediction of data collection for distant decades is an extremely difficult task. These climate changes are directly influenced by man, varying according to resource use, economic development, demographic growth, etc., and predicting how each of these variables will unfold in the coming decades and the interaction of the effects of each one of them opens margin for an uncountable number of variations. How to predict, for example, a pandemic and the impact on population growth caused by it, before it happens? Then, to minimize the differences in results between such different scenarios for future projections, the recommendation is then to carry out a sensitivity analysis considering different emission scenarios, using, for example, a more “optimistic” and a more “pessimistic” scenario, to identify the impact on the thermal performance of the building,

A question that arises when analysing the estimated global temperature rise is what effect this change can have on the functioning and efficiency of technical systems. In this dissertation, it was considered that their behaviour would remain the same, however, it is possible that in practice this is not the case. For example, to calculate the DHW demand, it is considered that the temperature increase necessary for the preparation of DHW has a reference value of 35°C, which can be changed in the future with the temperature variation, giving rise to different values of the need of useful energy. Finally, it is also worth emphasizing the questioning regarding the change in the behaviour of solar systems in this context, although some scholars predict that the efficiency of these systems will remain the same. As described earlier in the dissertation because although solar radiation is expected to increase, the increase in external temperature tends to cause less efficiency of the panels.

Another question that arises is related to the fact that the increase in temperature predicted for the future directly influences the thermal comfort inside the buildings. Thus, is it possible to predict, for example, that the establishment of comfort temperatures in the future will be adjusted to counterbalance this increase? If this is done, how could this variation influence the results of energy requirements made in this study, considering the comfort temperatures currently established?

Finally, also concerning thermal comfort, although the default systems for air conditioning were considered in this study, as per the guideline of the thermal regulation, in reality, it is known that a large part of the apartments in social neighbourhoods do not have any air conditioning system. So that the low-income families will be exposed to even higher temperatures than today, which is a major concern, especially in terms of the health of users. Although the study presents results of proposals for energy renovation with lower global costs, this consideration is made encompassing the entire life cycle of the building, that is, these interventions are beneficial in the long term, but continue to be associated with an initial investment cost that often cannot be supported by the humblest population. Thus, alert to the need to intensify government programs that allow this portion of the population to implement these energy renovations solutions, to be minimally prepared for the climate changes foreseen for the future.

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ANNEX 1 – COMPACT SCHEDULES

```
Schedule:Compact,
Occ_Residential,
Fraction,
Through: 31 Dec,
For: Weekdays,
Until: 05:00,     1.00,
Until: 06:00,     0.80,
Until: 08:00,     0.75,
Until: 09:00,     0.50,
Until: 15:00,     0.43,
Until: 18:00,     0.50,
Until: 21:00,     0.75,
Until: 24:00,     0.80,
For: Saturday,
Until: 07:00,     1.00,
Until: 08:00,     0.80,
Until: 09:00,     0.75,
Until: 10:00,     0.50,
Until: 15:00,     0.43,
Until: 18:00,     0.50,
Until: 21:00,     0.75,
Until: 24:00,     0.80,
For: Sunday Holidays,
Until: 07:00,     1.00,
Until: 08:00,     0.80,
Until: 09:00,     0.75,
Until: 10:00,     0.50,
Until: 15:00,     0.43,
Until: 18:00,     0.50,
Until: 21:00,     0.75,
Until: 24:00,     0.80,
For: SummerDesignDay,
Until: 24:00,     1,
```

Figure 66: Occupancy 136chedule

```
Schedule:Compact,
Occ_Residential,
Fraction,
Through: 31 Dec,
For: Weekdays,
Until: 06:00,     0.00,
Until: 22:00,     1.00,
Until: 23:00,     0.80,
Until: 24:00,     0.20,
For: Saturday,
Until: 07:00,     0.00,
Until: 22:00,     1.00,
Until: 23:00,     0.80,
Until: 24:00,     0.20,
For: Sunday Holidays,
Until: 07:00,     0.00,
Until: 22:00,     1.00,
Until: 23:00,     0.80,
Until: 24:00,     0.20,
For: SummerDesignDay,
Until: 24:00,     1,
For: AllOtherDays,
Until: 24:00,     0    ;
```

Figure 67: Lighting 136chedule

```
Schedule:Compact,
On,
Any Number,
Through: 12/31,
For: WinterDesignDay,
Until: 24:00,   0,
For: AllOtherDays,
Until: 24:00,   1;
```

Figure 68: Equipment 137chedule

```
Schedule:Compact,
On,
Any Number,
Through: 12/31,
For: AllDays,
Until: 24:00,   1 ;
```

Figure 69: Infiltration Schedule

```
Schedule:Compact,
Dwell_DomCommonAreas_Heat,
Temperature,
Through: 31 Dec,
For: Weekdays SummerDesignDay,
Until: 05:00, 0.5,
Until: 10:00, 1,
Until: 15:00, 0.5,
Until: 24:00, 1,
For: WinterDesignDay,
Until: 24:00, 1,
For: Weekends,
Until: 07:00, 0.5,
Until: 21:00, 1,
Until: 24:00, 0.5,
For: Holidays,
Until: 07:00, 0.5,
Until: 21:00, 1,
Until: 24:00, 0.5,
For: AllOtherDays,
Until: 24:00, 0;
```

Figure 70: Compact 137chedule: heating equipment

```
Schedule:Compact,
Dwell_DomCommonAreas_Cool,
Temperature,
Through: 31 Dec,
For: Weekdays SummerDesignDay,
Until: 05:00, 0,
Until: 10:00, 1,
Until: 15:00, 0,
Until: 24:00, 1,
For: Weekends,
Until: 07:00, 0,
Until: 21:00, 1,
Until: 24:00, 0,
For: Holidays,
Until: 07:00, 0,
Until: 21:00, 1,
Until: 24:00, 0,
For: WinterDesignDay AllOtherDays,
Until: 24:00, 0;
```

Figure 71: Compact 138chedule: cooling equipment

Annex 2 – Technical information: renovation solutions

Largura (em cm)	15	Indicado para	Casa de banho
Altura (em cm)	15	Marca do produto	EQUATION
Profundidade (em cm)	10,9	Tipo	Extratores
Peso net (em kg)	0,556	Tipo de embalagem	Caixa
Tipo de comando	Interruptor	Material principal	ABS
Indicador de funcionamento	Não	Tipo de produto	Ventoinha exaustor axial
Rolamentos de esferas	Não	Tensão (em V)	230
Caudal de ar (em m³/h)	86	Velocidade (em rpm)	2300
Nível sonoro em funcionamento (em dB(A))	Mais de 30	Internet of Things (IoT): Objeto conectado	Não
Diâmetro da conduta - arejadores (em mm)	100	Família de cor	Branco
Válvula de retenção	Não	Destino	Parede
Nível sonoro (em dB(A))	35	Percentagem sem encastramento	100
Passagem a alta velocidade	Mediante interruptor	Sistema de fecho	Automático
No duche ou acima da banheira	Não	Tipo de extração	Direto
Para WC	Sim	Índice de proteção (ip + ik)	IPx4
Para casa de banho	Sim	Modo de fixação	De encastrar
Para cozinhas	Sim	Forma	Helicoidal
Para várias divisões	Não	Garantia do produto (em anos, para publicação)	2
Para outra divisão (lavandaria, cave…)	Não	EAN	3276000607052
Superfície a ventilar (modelo intermitente) (em m²)	De 2 a 7		

Figure 72: Datasheet – Bathroom extractor fan (EQUATION Q1 100MM) [126]

Largura (em cm)	26	Indicado para	Cozinha
Altura (em cm)	37	Medidas	33X28X17.3 cm
Profundidade (em cm)	17,3	Marca do produto	CATA
Peso net (em kg)	3,02	Tipo	Extratores
Tipo de comando	Nenhum	Tipo de embalagem	Caixa
Indicador de funcionamento	Não	Tipo de produto	Ventoinha do exaustor de cozinha
Rolamentos de esferas	Não	Tensão (em V)	230
Caudal de ar (em m³/h)	450	Velocidade (em rpm)	1200
Nível sonoro em funcionamento (em dB(A))	Inferior a 30	Internet of Things (IoT): Objeto conectado	Não
Diâmetro da conduta - arejadores (em mm)	100	Família de cor	Bege
Válvula de retenção	Não	Destino	Parede
Nível sonoro (em dB(A))	57	Família de cor	Bege
Passagem a alta velocidade	Mediante interruptor	Controlo à distância	Não
No duche ou acima da banheira	Não	Sistema de fecho	Automático
Para WC	Não	Tipo de extração	Direto
Para casa de banho	Não	Modo de fixação	De encastrar
Para cozinhas	Sim	Forma	Helicoidal
Para várias divisões	Não	Garantia do produto (em anos, para publicação)	2
Para outra divisão (lavandaria, cave…)	Não	EAN	8422248010832
Superfície a ventilar (modelo intermitente) (em m²)	De 5 a 12		

Figure 73: Datasheet – kitchen extractor fan (PROFISSIONAL 500 140W) [127]

	ID	dim 1	dim 2	Area	P	Glazed fraction	Af	Ag	Uf	Ug	lg	Linear transm. Coef	Uw	Un	Uwdn
S	J1	1.5	2	3.00	7	0.65	1.05	1.95	1.50	1.40	7.00	0.08	**1.62**	**1.20**	**1.37**
S	J2	0.95	1	0.95	3.9	0.65	0.33	0.62	1.50	1.40	3.90	0.08	**1.76**	**1.27**	**1.47**
N	J3	0.95	1	0.95	3.9	0.65	0.33	0.62	1.50	1.40	3.90	0.08	**1.76**	**1.27**	**1.47**
E	J4	0.75	0.95	0.71	3.4	0.65	0.25	0.46	1.50	1.40	3.40	0.08	**1.82**	**1.30**	**1.51**
N	J5	0.95	1.1	1.05	4.1	0.65	0.37	0.68	1.50	1.40	4.10	0.08	**1.75**	**1.26**	**1.46**
N	J6	0.95	1.6	1.52	5.1	0.65	0.53	0.99	1.50	1.40	5.10	0.08	**1.70**	**1.24**	**1.42**
N	J7	0.75	2.19	1.64	5.88	0.65	0.57	1.07	1.50	1.40	5.88	0.08	**1.72**	**1.25**	**1.44**

Figure 74: Uwdn calculation for PVC frame and double glass (low-e)

	ID	dim 1	dim 2	Area	P	Glazed fraction	Af	Ag	Uf	Ug	lg	Linear transm. Coef	Uw	Un	Uwdn
S	J1	1.5	2	3	7	0.65	1.05	1.95	2.50	1.40	7.00	0.08	**1.97**	**1.38**	**1.61**
S	J2	0.95	1	0.95	3.9	0.65	0.33	0.62	2.50	1.40	3.90	0.08	**2.11**	**1.44**	**1.71**
N	J3	0.95	1	0.95	3.9	0.65	0.33	0.62	2.50	1.40	3.90	0.08	**2.11**	**1.44**	**1.71**
E	J4	0.75	0.95	0.7125	3.4	0.65	0.25	0.46	2.50	1.40	3.40	0.08	**2.17**	**1.47**	**1.75**
N	J5	0.95	1.1	1.045	4.1	0.65	0.37	0.68	2.50	1.40	4.10	0.08	**2.10**	**1.44**	**1.70**
N	J6	0.95	1.6	1.52	5.1	0.65	0.53	0.99	2.50	1.40	5.10	0.08	**2.05**	**1.41**	**1.67**
N	J7	0.75	2.19	1.6425	5.88	0.65	0.57	1.07	2.50	1.40	5.88	0.08	**2.07**	**1.42**	**1.68**

Figure 75: Uwdn calculation for the wooden frame and double glass (low-e)

	ID	dim 1	dim 2	Area	P	Glazed fraction	Af	Ag	Uf	Ug	lg	Linear transm. Coef	Uw	Un	Uwdn
S	J1	1.5	2	3	7	0.65	1.05	1.95	1.50	2.70	7.00	0.08	**2.47**	**1.60**	**1.95**
S	J2	0.95	1	0.95	3.9	0.65	0.33	0.62	1.50	2.70	3.90	0.08	**2.61**	**1.66**	**2.04**
N	J3	0.95	1	0.95	3.9	0.65	0.33	0.62	1.50	2.70	3.90	0.08	**2.61**	**1.66**	**2.04**
E	J4	0.75	0.95	0.7125	3.4	0.65	0.25	0.46	1.50	2.70	3.40	0.08	**2.66**	**1.68**	**2.07**
N	J5	0.95	1.1	1.045	4.1	0.65	0.37	0.68	1.50	2.70	4.10	0.08	**2.59**	**1.65**	**2.03**
N	J6	0.95	1.6	1.52	5.1	0.65	0.53	0.99	1.50	2.70	5.10	0.08	**2.55**	**1.63**	**2.00**
N	J7	0.75	2.19	1.6425	5.88	0.65	0.57	1.07	1.50	2.70	5.88	0.08	**2.57**	**1.64**	**2.01**

Figure 76: Uwdn calculation for PVC frame and double glass (standard)

Vidro isolante composto com vidros básicos para comparação	**TRANSMISSÃO DE LUZ NATURAL** Percentagem de luz transmitida ao interior	**FATOR SOLAR** Percentagem de radiação solar que entra em casa	**ISOLAMENTO TÉRMICO** Menor o valor menor perda energética	
			Câmara preenchida com ar	Câmara preenchida com árgon a 90%
VIDRO FLOAT Float 4 mm/Câmara 16mm/Float 4mm	82.8	79.3	2.7	2.6
VIDRO BAIXA EMISSIVIDADE Float 4 mm/Câmara 16mm/ /ClimaGuard Premium2 4mm - Capa na face #3	81.9	63.8	1.4	1.1

Figure 77: Datasheet – window glasses (GuardianSun)

[138]

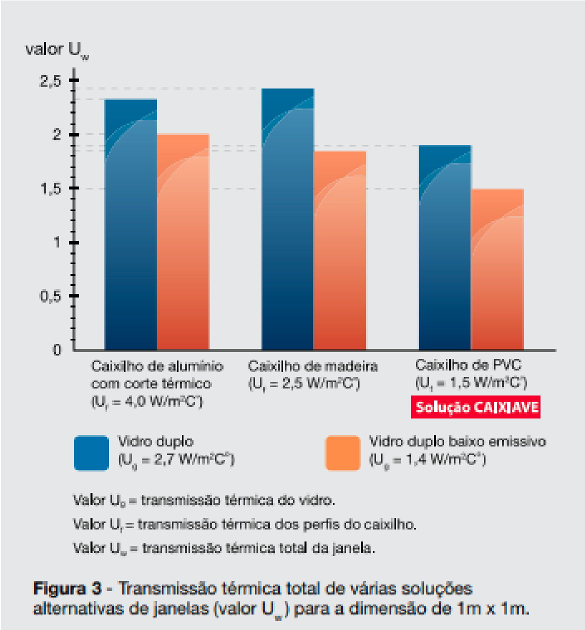

Figure 78: Technical information – window frames (Caixiave)

[60]

SCM40, 45ZS-W

SCM50, 60ZS-W

Ud. Exterior			SCM40ZS-W	SCM45ZS-W	SCM50ZS-W	SCM60ZS-W
Combinación			2x1	2x1	3x1	3x1
Número de unidades a conectar			2	2	Mín. 2 - Máx. 3	Mín. 2 - Máx. 3
Potencia conectable			Mín. 4,0 - Máx. 6,0	Mín. 4,5 - Máx. 7.0	Mín. 4,0 - Máx. 8,5	Mín. 4,0 - Máx. 11,0
Alimentación eléctrica			I-220 V. 50Hz.	I-220 V. 50Hz.	I-220 V. 50Hz.	I-220 V. 50Hz.
Intensidad nominal	Frío/Calor	A	3,7 / 3,8	4,5 / 4,9	4,7 / 5,4	6,8 / 7,1
Capacidad	Frío (mín-nom-máx.)	kW	1,5 - 4 - 5,9	1,5 - 4,5 - 6,4	1,7 - 5,0 - 7,1	1,7 - 6,0 - 7,5
		kcal/h	1.290 - 3.440 - 5.074	1.290 - 3.870 - 5.504	1.462 - 4.300 - 6.106	1.462 - 5.160 - 6.450
	Calor (mín-nom-máx.)	kW	1,0 - 4,5 - 6,3	1,0 - 5,3 - 6,5	1,0 - 6 - 7,5	1,0 - 6,8 - 7,8
		kcal/h	860 - 3.870 - 5.418	860 - 4.558 - 5.590	860 - 5.160 - 6.450	860 - 5.848 - 6.710
Consumo nominal	Frío/ Calor	kW	0,80 / 0,83	0,96 / 1,06	1,02 / 1,16	1,32 / 1,40
Nivel sonoro	Frío/ Calor	dB (A)	49 / 51	50 / 52	49 / 52	50 / 52
Dimensiones (alto x ancho x fondo)		mm	595 x 780 x 290	595 x 780 x 290	640 x 850 x 290	640 x 850 x 290
Peso		kg	40	40	48,5	48,5
Caudal de aire	Frío	m³/h	1.950	1.950	2.460	2.460
Tubería de refrigerante	Línea de líquido / gas[1]	pulgadas	(1/4" - 3/8") x 2	(1/4" - 3/8") x 2	(1/4" - 3/8") x 3	(1/4" - 3/8") x 3
Precarga de refrigerante R32	kg / Longitud de línea que cubre la carga (m)		1,4 / 20	1,4 / 20	1,8 / 40	1,8 / 40
Carga adicional de refrigerante R32	grs/m de línea frigorífica		20	20	No requerido	No requerido
Unidades interiores compatibles	SRK-ZSX-W (-WB, -WT)		20, 25, 35	20, 25, 35	20, 25, 35, 50	20, 25, 35, 50, 60
	SRK-ZS-W (-WB, -WT)		20, 25, 35	20, 25, 35	20, 25, 35, 50	20, 25, 35, 50
	SKM-ZSP-W		20, 25, 35	20, 25, 35	20, 25, 35	20, 25, 35
	SRK-ZR-W		-	-	-	-
	FDTC-VH		25, 35	25, 35	25, 35, 50	25, 35, 50, 60
	SRR-ZS-W		25, 35	25, 35	25, 35, 50	25, 35, 50, 60
	FDUM-VH		-	-	50	50
	FDE-VH		-	-	50	50
	SRF-ZS-W		25, 35	25, 35	25, 35, 50	25, 35, 50

Figure 79: Datasheet – Multi-split system (MITSUBISHI: SCM50ZS-W)

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GAMA Multi-Split R32

			Unidades Exteriores						NUEVO
			2x1	2x1	3x1	3x1	4x1	4x1	5x1
Unidades Interiores			SCM40ZS-W	SCM45ZS-W	SCM50ZS-W	SCM60ZS-W	SCM71ZS-W	SCM80ZS-W	SCM100ZS-W
Diamond	Serie DIAMOND	SRK20ZSX-W	●	●	●	●	●	●	●
		SRK25ZSX-W	●	●	●	●	●	●	●
		SRK35ZSX-W	●	●	●	●	●	●	●
		SRK50ZSX-W			●	●	●	●	●
		SRK60ZSX-W				●	●	●	●
Premium	Serie PREMIUM	SRK20ZS-W	●	●	●	●	●	●	●
		SRK25ZS-W	●	●	●	●	●	●	●
		SRK35ZS-W	●	●	●	●	●	●	●
		SRK50ZS-W			●	●	●	●	●
Smart	Serie SMART	SKM20ZSP-W	●	●	●	●	●	●	●
		SKM25ZSP-W	●	●	●	●	●	●	●
		SKM35ZSP-W	●	●	●	●	●	●	●
	NUEVO Serie SMART	SRK71ZR-W					●	●	●
		SRK80ZR-W							●

Figure 80: Datasheet – Multi-split system (MITSUBISHI: SKM20ZSP-W)

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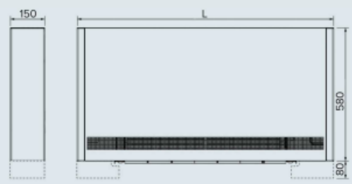
DADOS TÉCNICOS		40 M NET	50 M NET	70 M NET	90 M NET	110 M NET
RENDIMENTO DA BOMBA DE CALOR EM AQUECIMENTO						
Potência térmica máximo aquecimento com pavimento radiante (Tar 7ºC, Tágua 35/30ºC)	kW	5,7	7,1	11	14	16,7
Potência térmica máxima aquecimento (Tar 7ºC, Tágua 45/40ºC)	kW	5,5	6,8	10,5	13,3	16
SCOP climas quentes segundo EN14825 para pavimento radiante (baixa temperatura)		5,69	5,88	5,64	6,07	6,21
SCOP climas quentes segundo EN14825 (temperatura média)		3,53	3,84	3,84	3,91	4,10
COP Nominal (Tar 7ºC, Tágua 35/30ºC) segundo EN14511		5,1	5	5	5,1	5
Potência térmica nominal (Tar 7ºC, Tágua 35/30ºC segundo EN14511	kW	3,5	4,4	6,4	8,5	10,4
Potência nominal absorvida (Tar 7ºC, Tágua 35/30 ºC) segundo EN14511	kW	0,7	0,9	1,3	1,7	2,1
Potência máxima absorvida com bomba de calor (resistências apoio opcionais)	kW	2,1(4)	2,75(4)	3,85(4)	5(6)	6,3(6)
T envio aquecimento min/máx	ºC			20/60		
T ar exterior min/máx	ºC			-20/35		
Volume mínimo de água na instalação	l	20	25	35	45	55
RENDIMENTO DA BOMBA DE CALOR EM ARREFECIMENTO						
Potência térmica máxima em arrefecimento (Tar 35ºC. Tágua 18/23ºC)	kW	6,9	8,5	12	13,6	16,6
Potência térmica nominal em arrefecimento (Tar 35ºC, Tágua 18/23ºC) segundo EN14511	kW	4,8	5,9	7,5	10,6	12,5
Potência nominal absorvida (Tar 35ºC, Tágua 18/23 ºC) segundo EN14511	kW	0,9	1,2	1,5	2,2	2,7
EER (Tar 35ºC, Tágua 18/23ºC) segundo EN14511		5,4	4,9	5	4,9	4,6
Tida arrefecimento min/máx	ºC			5/22		
T aire exterior min./máx.	ºC			10/43		
RENDIMENTO BOMBA DE CALOR EM AQS						
COP segundo EN16147 (Clima médio 7ºC / Clima mais quente 14ºC)		2,6/3,2	2,6/3,2	2,6/2,8	3,1/3,3	3,1/3,3
Tempo de aquecimento (Tacum 52ºC)	h:m	1:48	1:48	1:30	1:52	1:50
capacidade do acumulador	l	180	180	180	300	300
Quantidade de água quente a 0ºC numa única extracção	l	241	241	247	434	434

Figure 81: Datasheet – aerothermal heat pump for air conditioning and DHW (ARISTON: NIMBUS FLEX M NET) [141]



Modelo	20	40
L mm	923	1323

DADOS TÉCNICOS		20			40		
Velocidade		Baixa	Média	Alta	Baixa	Média	Alta
EM REFRIGERAÇÃO (A)							
Capacidade total	kW	0,75	1,36	2,12	1,32	2,39	3,30
Capacidade sensível	kW	0,59	1,07	1,72	1,02	1,84	2,71
Perdas de carga água	kPa	1,9	4,3	8,2	2,5	8,8	18,0
Caudal de água	m3/h	0,13	0,23	0,35	0,23	0,41	0,61
Classe energética			B			A	
EM AQUECIMENTO (B)							
Capacidade total	kW	0,82	1,53	2,211	1,47	2,59	3,81
Perdas de carga agua	kPa	1,5	4,3	9,2	3,0	8,9	2,12
Caudal de agua	m3/h	0,14	0,27	0,41	0,26	0,45	0,69
Classe energética			B			B	
Potência sonora (c)	dB(A)	35	45	53	36	47	55
Potência elétrica absorbida	W	4	8	19	5	11	29
Conteúdo de água	Litros		0,8			1,46	
Ligações hidráulicas (lado direito)	Pulgadas	3/4 (2 tubos)					
Diâmetro descarga condensados	mm	14					
Peso	Kg		20			26	

ENERGIA AEROTÉRMICA

Figure 82: Datasheet - convector (ARISTON: NIMBUS AQUASLIM FS) [142]

Características | Dimensões e Peso | Avaliações | Documentos

Largura (em cm)	58	EcoLogica	Energia renovável
Altura (em cm)	186	Tipo de embalagem	Caixa
Profundidade (em cm)	58	Tipo de produto	Bomba de calor ar/água
Peso net (em kg)	115	Bateria incluída	Não
Tensão (em V)	230	Tipo de comando	Não é necessário controle remoto
Potência calorífica (em kW)	2,3	Internet of Things (IoT): Objeto conectado	Não
Garantia do compressor (em anos)	2	Família de cor	Preto
Garantia das partes elétricas (em anos)	2	Tipo AEE	Sim
Nível sonoro (em dB(A))	60	Potência (em W)	2000
Potência consumida (em kW)	0,61	Garantia do produto (em anos, para publicação)	3
Marca	HTW	EAN	8435483800120

Figure 83: Datasheet – heat pump for DHW (HTW 200L)

[143]

RENDIMENTO DOS ESQUENTADORES COMPACTOS	CAPACIDADE	RENDIMENTO 100%	RENDIMENTO 30%
GAMA ESQUENTADORES COMPACTOS DE EXAUSTÃO NATURAL			
WTDKG Sensor HDG e WTDKB Sensor Atmosférico	11 l/min	88,10%	81%
WTDKG Sensor HDG e WTDKB Sensor Atmosférico	14 l/min	87,40%	79%
WTDKG Sensor HDG e WTDKB Sensor Atmosférico	18 l/min	88,40%	78%
WRDG Click! HDG, WRDB Click! e WRB Click!	11 l/min	88,10%	80%
WRDG Click! HDG e WRDB Click!	14 l/min	87,40%	78%
WRDB Click!	18 l/min	88,40%	78%
WE tic-tic	11 l/min	88,00%	-
GAMA ESQUENTADORES COMPACTOS DE EXAUSTÃO VENTILADA			
WTD Sensor Ventilado e WRD Click! Ventilado	11 l/min	86,70%	75%
WTD Sensor Ventilado e WRD Click! Ventilado	14 l/min	86,80%	75%
WTD Sensor Ventilado e WRD Click! Ventilado	17 l/min	88,20%	75%
ESQUENTADORES COMPACTOS VENTILADOS E ESTANQUES			
WTD Sensor Compacto	12 l/min	92%	94%
WTD Sensor Compacto	15 l/min	92%	94%
WTD Sensor Compacto	18 l/min	92%	94%
WTD AME Sensor Connect Edição Comemorativa	12 l/min	92%	94%
WTD AME Sensor Connect	12 l/min	92%	94%
WTD AME Sensor Connect	15 l/min	92%	94%

Figure 84: Datasheet – gas water heater (WTD COMPACT SENSOR FROM VULCANO)

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ANNEX 3 – COST-OPTIMAL DATA

Table 22: Cost-optimal (conventional methodology)

			Initial Global Cost	Exploration Cost (30	Total Cost (30 years)	Nic (kWh/m².year)		Nvc (kWh/m².year)		Nac (kWh/m².year)		Conversion Rates			Ntc (kWh/m²	Reduction due to	
			Private	Private	Private	Total	η	Total	η	Total	η	Nic	Nvc	Nac	Total	Total	ER
	REF	Maintenance	14,898 €	17,609 €	408.89 €	25.53	1	4.71	3	29.90	0.82	2.5	2.5	1	104.21	0	0%
Exterior Walls (ETICS)	var 1	Maintenance + ETICS EPS 60mm	16,917 €	14,976 €	401.17 €	20.86	1	5.33	3	29.90	0.82	2.5	2.5	1	93.06	10.71%	0%
	var 2	Maintenance + ETICS EPS 80mm	17,194 €	14,854 €	403.13 €	20.30	1	5.39	3	29.90	0.82	2.5	2.5	1	91.71	12.00%	0%
	var 3	Maintenance + ETICS EPS 100mm	17,457 €	14,769 €	405.35 €	19.88	1	5.43	3	29.90	0.82	2.5	2.5	1	90.69	12.98%	0%
Exterior Walls (Insulation from the interior)	var 20	Maintenance + EW_Inso.Int. EPS 60mm	17,587 €	17,927 €	446.71 €	21.18	1	5.40	3	29.90	0.82	2.5	2.5	1	93.91	9.88%	0%
Roof (Insulation above horizontal slab)	var 29	Maintenance + Horizontal_Slab EPS 100mm	15,407 €	15,381 €	387.27 €	17.84	1	3.61	3	29.90	0.82	2.5	2.5	1	84.07	19.33%	0%
	var 30	Maintenance + Horizontal_Slab EPS 120mm	15,469 €	15,334 €	387.45 €	17.66	1	3.59	3	29.90	0.82	2.5	2.5	1	83.61	19.78%	0%
	var 31	Maintenance + Horizontal_Slab EPS 150mm	15,563 €	15,288 €	388.06 €	17.47	1	3.57	3	29.90	0.82	2.5	2.5	1	83.11	20.25%	0%
Windows	var 38	PVC_Frames_Windows. 2x low e	17,707 €	17,059 €	437.31 €	23.21	1	4.40	3	29.90	0.82	2.5	2.5	1	98.16	5.81%	0%
	var 39	Wooden_Windows. 2x low e	21,319 €	18,888 €	505.75 €	23.76	1	4.32	3	29.90	0.82	2.5	2.5	1	99.46	4.56%	0%
	var 40	PVC_Frames_Windows. 2x Standard	16,782 €	16,805 €	422.48 €	23.11	1	4.84	3	29.90	0.82	2.5	2.5	1	98.27	5.70%	0%
Packs	[ETICS_EPS-60 mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [Standard Systems REF]	Package 1 - var 42	17,994 €	12,764 €	386.89 €	12.11	1	4.44	3	29.90	0.82	2.5	2.5	1	70.44	32.41%	0%
	[ETICS_EPS-80 mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [Standard Systems REF]	Package 2 - var 43	18,238 €	12,639 €	388.39 €	11.55	1	4.46	3	29.90	0.82	2.5	2.5	1	69.06	33.74%	0%
	[ETICS_EPS-100 mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [Standard Systems REF]	Package 3 - var 44	18,501 €	12,551 €	390.59 €	11.11	1	4.54	3	29.90	0.82	2.5	2.5	1	68.02	34.73%	0%
	[ETICS_EPS-60 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [Standard Systems REF]	Package 4- var 45	19,845 €	11,962 €	400.09 €	9.66	1	4.68	3	29.90	0.82	2.5	2.5	1	64.51	38.09%	0%
	[ETICS_EPS-80 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [Standard Systems REF]	Package 5 - var 46	20,122 €	11,852 €	402.19 €	9.13	1	4.77	3	29.90	0.82	2.5	2.5	1	63.26	39.29%	0%
	[ETICS_EPS-100 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [Standard Systems REF]	Package 6 - var 47	20,384 €	11,772 €	404.48 €	8.72	1	4.84	3	29.90	0.82	2.5	2.5	1	62.30	40.22%	0%
Pack 01: [ETICS_EPS-60 mm] + [Horizontal_Slab MW 100mm] + [REF Windows]	[ETICS_EPS-60 mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [Solar Collector + multi-split + water heater]	PAC 1 + S1 - var 48	22,536 €	11,827 €	432.24 €	12.11	4.9	4.44	5.17	29.90	0.92	2.5	2.5	1	17.12	83.57%	53%
	[ETICS_EPS-60 mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [heat pump]	PAC 1 + S2 - var 49	25,369 €	9,810 €	442.51 €	12.11	5.00	4.44	4.9	29.90	3.2	2.5	2.5	2.5	8.97	91.39%	72%
	[ETICS_EPS-60 mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [multi-split + DHW heat pump	PAC 1 + S3 - var 50	19,543 €	7,402 €	338.93 €	12.11	4.9	4.44	5.17	29.90	3.77	2.5	2.5	2.5	13.58	86.97%	78%
	[ETICS_EPS-60 mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [multi-split + DHW heat pump + PV]	PAC 1 + S4 - var 51	20,026 €	6,859 €	338.17 €	12.11	4.9	4.44	5.17	29.90	3.77	2.5	2.5	2.5	5.46	94.76%	90%
Pack 02 : [ETICS_EPS-80 mm] + [Horizontal_Slab MW 100mm] + [REF Windows]	[ETICS_EPS-80 mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [Solar Collector + multi-split + water heater]	PAC 2 + S1 - var 56	22,813 €	11,826 €	435.72 €	11.55	4.9	4.46	5.17	29.90	0.92	2.5	2.5	1	16.84	83.84%	54%
	[ETICS_EPS-80 mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [heat pump]	PAC 2 + S2 - var 57	25,646 €	9,835 €	446.30 €	11.55	5.00	4.46	4.9	29.90	3.2	2.5	2.5	2.5	8.92	91.44%	72%
	[ETICS_EPS-80 mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [multi-split + DHW heat pump	PAC 2 + S3 - var 58	19,820 €	7,401 €	342.40 €	11.55	4.9	4.46	5.17	29.90	3.77	2.5	2.5	2.5	13.31	87.23%	79%
	[ETICS_EPS-80 mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [multi-split + DHW heat pump + PV]	PAC 2 + S4 - var 59	20,303 €	6,866 €	341.75 €	11.55	4.9	4.46	5.17	29.90	3.77	2.5	2.5	2.5	5.26	95%	90%

			Initial Global Cost	Exploration Cost (30	Total Cost (30 years)	Nic (kWh/m².year)		Nvc (kWh/m².year)		Nac (kWh/m².year)		Conversion Rates			Ntc (kWh/m²	Reduction due to	
			Private	Private	Private	Total	η	Total	η	Total	η	Nic	Nvc	Nac	Total	Total	ER
Pack 03: [ETICS_EPS-100 mm] + [Horizontal_Slab MW 100mm] + [REF Windows]	[ETICS_EPS-100 mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] +[Solar Collector + multi-split + water heater]	PAC 3 + S1 - var 64	23,076 €	11,834 €	439.11 €	11.11	4.9	4.54	5.17	29.90	0.92	2.5	2.5	1	16.66	84%	54%
	[ETICS_EPS-100 mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [heat pump]	PAC 3 + S2 - var 65	25,909 €	9,859 €	449.91 €	11.11	5.00	4.54	4.9	29.90	3.2	2.5	2.5	2.5	8.88	91%	72%
	[ETICS_EPS-100 mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [multi-split + DHW heat pump]	PAC 3 + S3 - var 66	20,082 €	7,409 €	345.80 €	11.11	4.9	4.54	5.17	29.90	3.77	2.5	2.5	2.5	13.12	87%	79%
	[ETICS_EPS-100 mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [multi-split + DHW heat pump + PV]	PAC 3 + S4 - var 67	20,566 €	6,894 €	345.41 €	11.11	4.9	4.54	5.17	29.90	3.77	2.50	2.50	2.50	5.26	95%	91%
Pack 04: [ETICS_EPS-60 mm] + [Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard]	[ETICS_EPS-60 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [Solar Collector + multi-split + water heater]	PAC 4 + S1 - var 72	24,419 €	11,564 €	452.62 €	9.66	4.9	4.68	5.17	29.90	0.92	2.5	2.5	1	15.98	85%	55%
	[ETICS_EPS-60 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [heat pump]	PAC 4 + S2 - var 73	27,253 €	9,649 €	464.17 €	9.66	5.00	4.68	4.9	29.90	3.2	2.5	2.5	2.5	8.75	92%	105%
	[ETICS_EPS-60 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [multi-split + DHW heat pump	PAC 4 + S3 - var 74	21,426 €	7,138 €	359.30 €	9.66	4.9	4.68	5.17	29.90	3.77	2.5	2.5	2.5	12.45	88%	81%
	[ETICS_EPS-60 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [multi-split+DHW heat pump + PV]	PAC 4 + S4 - var 75	21,910 €	6,700 €	359.86 €	9.66	4.9	4.68	5.17	29.90	3.77	2.50	2.50	2.50	5.26	95%	93%
Pack 05: [ETICS_EPS-80 mm] + [Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard]	[ETICS_EPS-80 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [Solar Collector + multi-split + water heater]	PAC 5 + S1 - var 80	24,696 €	11,568 €	456.16 €	9.13	4.9	4.77	5.17	29.90	0.92	2.5	2.5	1	15.76	85%	55%
	[ETICS_EPS-80 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [heat pump]	PAC 5 + S2 - var 81	27,530 €	9,675 €	467.98 €	9.13	5.00	4.77	4.9	29.90	3.2	2.5	2.5	2.5	8.71	92%	72%
	[ETICS_EPS-80 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [multi-split + DHW heat pump	PAC 5 + S3 - var 82	21,703 €	7,143 €	362.85 €	9.13	4.9	4.77	5.17	29.90	3.77	2.5	2.5	2.5	12.22	88%	82%
	[ETICS_EPS-80 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard]+ [multi-split+DHW heat pump + PV]	PAC 5 + S4 - var 83	22,187 €	6,730 €	363.73 €	9.13	4.9	4.77	5.17	29.90	3.77	2.50	2.50	2.50	5.26	95%	94%
Pack 06: [ETICS_EPS-100 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard]	[ETICS_EPS-100 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [Solar Collector + multi-split + water heater]	PAC 6 + S1 - var 88	24,959 €	11,577 €	459.57 €	8.72	4.9	4.84	5.17	29.90	0.92	2.5	2.5	1	15.58	85%	56%
	[ETICS_EPS-100 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [heat pump]	PAC 6 + S2 - var 89	27,792 €	9,692 €	471.50 €	8.72	5.00	4.84	4.9	29.90	3.2	2.5	2.5	2.5	8.67	92%	72%
	[ETICS_EPS-100 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [multi-split + DHW heat pump	PAC 6 + S3 - var 90	21,966 €	7,152 €	366.26 €	8.72	4.9	4.84	5.17	29.90	3.77	2.5	2.5	2.5	12.05	88%	83%
	[ETICS_EPS-100 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [multi-split+DHW heat pump + PV]	PAC 6 + S4 - var 91	22,449 €	6,758 €	367.39 €	8.72	4.9	4.84	5.17	29.90	3.77	2.5	2.5	2.5	5.26	95%	95%

Table 23: Budget: investment and maintenance costs

Heating area (m2)

Table 1 - Santa Tecla

INDICATIVE TABLE FOR THE ENUMERATION OF THE VARIATIONS / SELECTED MEASURES

DESCRIPTION	**Unit of Measure**	**A (m2)**	**Price/m2**	**Main/m2**	**BASE**	Main	**VAR 01** Main+ETICS EPS 60mm	Main
Rehabilitation costs of one apartment		79.50						
Opaque Envelope					4,469.42 €	109.18 €	6,929.63 €	27.71 €
Glazed Openings					797.29 €	37.56 €	797.29 €	37.56 €
Heating / Cooling					2,758.78 €	81.14 €	2,758.78 €	81.14 €
Other					1,622.96 €	12.01 €	1,622.96 €	12.01 €
Domestic Hot Water					403.28 €	53.30 €	403.28 €	53.30 €
Renewables					0.00 €	0.00 €	0.00 €	0.00 €
TOTAL						**293.19 €**		**211.72 €**
Other								
Replacement of water piping - toilet, bathroom, and kitchen	vg	1.00	1622.96	12.008	1,622.96 €	12.01 €	1,622.96 €	12.01 €
Exterior Walls								
Repair of cracks and others on the facade (€/m2 facade area)	m²	59.60	16.18	0.05 €	964.30 €	2.92 €		
Mechanical cleaning of the facade with compressed air (€/m2 facade area)	m²	59.60	10.44	0.00 €	622.20 €	0.00 €		
Painting of the exterior walls with plastic based paint (€/m2 facade area)	m²	59.60	10.19	1.78 €	607.30 €	106.26 €		
Scaffolding Rent Cost	days	8.00	149.00	0.00 €	1,191.96 €	0.00 €	1,191.96 €	0.00 €
Scaffolding transport, assembly and dismantle	un	1.00	827.67	0.00 €	827.67 €	0.00 €	827.67 €	0.00 €
ETICS EPS 60mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls	m²	59.60	78.09	0.47 €			4,654.01 €	27.71 €
ETICS EPS 80mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls	m²	59.60	81.87	0.50 €				
ETICS EPS 100mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls	m²	59.60	85.45	0.52 €				
Insulation by the interior (λ=0.038), EPS 60mm; Lifetime of 30 years (€/m2 area of the exterior walls)	m²	59.60	36.67	1.46 €				
Walls in contact with unconditioned space (corridors)								
Insulation by the interior (λ=0.038), EPS 60mm; Lifetime of 30 years (€/m2 area of the walls)	m²	11.88	36.67	1.46 €				
Roof								
Cleaning of the roof tiles (€ / m2 area of the roof)	m²	25.71	8.11	0.00 €	208.49 €	0.00 €	208.49 €	0.00 €
Cleaning of the gutters	m	9.37	5.07	0.00 €	47.50 €	0.00 €	47.50 €	0.00 €
Horizontal slab insulation (MW - λ=0.035) 100mm; Lifetime of 30 years (€ / m2 area of the slab)	m²	17.90	23.10	0.12 €				
Horizontal slab insulation (MW - λ=0.035) 120mm; Lifetime of 30 years (€ / m2 area of the slab)	m²	17.90	25.89	0.13 €				
Horizontal slab insulation (MW - λ=0.035) 150mm; Lifetime of 30 years (€ / m2 area of the slab)	m2	17.90	30.20	0.16 €				
Windows	**m2**							
Reparation and paiting of the window frames	m2	9.82	81.19	3.83 €	797.29 €	37.56 €	797.29 €	37.56 €
PVC frames	Vg	1.00	1908.19	20.69 €				
Wooden Frames	Vg	1.00	4844.73	120.05 €				
Double glass standard 4:16:4; Lifetime 30 years;	m²	9.82	42.80	0.90 €				
Double glass with low E 4:16:4; Lifetime 30 years;	m²	9.82	119.36	2.51 €				
Ventilation								
Bath extractor Equation Q1 100 mm	un	1.00	28.53	1.00 €				
Kitchen extractor 500 140w	un	1.00	68.31	11.27 €				
Systems								
Gas water heater, Life time 20 years;	un	1.00	403.28	53.30 €	403.28 €	53.30 €	403.28 €	53.30 €
Collector units;	un	5.00	411.50	3.81 €				
Air-Air Multi split External *"Mitsubishi" SCM50ZS-W*; COP 4.9; EER 5.17 / 3 interior units SKM20ZSP-W ; Life time 15 years;	vg	1.00	2757.70	88.80 €				
Air-Air Multi split External; EER 3; Life time 15 years;	un	1.00	1409.98	49.35 €	1,409.98 €	49.35 €	1,409.98 €	49.35 €
Air-Air Multi split Internal; 3 un; Life time 15 years;	vg	1.00	959.10	26.33 €	959.10 €	26.33 €	959.10 €	26.33 €
Gas water heater Vulcano WTD Sensor compact; ᥰ=92%; Life time 20 years;	un	1.00	521.60	68.93 €				
Electrical heating unit 100% (1 per room); Life time 15 years	un	3.00	129.90	1.82 €	389.70 €	5.46 €	389.70 €	5.46 €
Renewables								
Heat Pump (DHW and climatization); COP 5; EER 4.9; COP AQS 3.2; Life time 20 years;	un	1.00	6376.69	391.88 €				
Heat Pump (DHW); COP 3.77; Life time 20 years;	un	1.00	1375.20	149.29 €				
1 Kit PVs Junkers with 2 collector plates and a deposit: FCC-2 S CTE TSS 300L ;rend 0,761; Life time 20 years;	vg	1.00	2840.64	291.54 €				
PV - 1 kit: 1 PV module of 180 W + inverter (described in the text-based file)	kit	1.00	321.04	21.79 €				

Heating area (m2)

Table 1 - Santa Tecla

INDICATIVE TABLE FOR THE ENUMERATION OF THE VARIATIONS / SELECTED MEASURES

	Exterior Wall With Insulation by the Interior					
DESCRIPTION	**VAR 02** Main+ETICS EPS 80mm	Main	**VAR 03** Main+ETICS EPS 100mm	Main	**VAR 20** Main+ETICS_Inso.Int. EPS 60mm	Main
Rehabilitation costs of one apartment						
Opaque Envelope	7,154.91 €	29.50 €	7,368.27 €	31.17 €	6,654.88 €	196.32 €
Glazed Openings	797.29 €	37.56 €	797.29 €	37.56 €	797.29 €	37.56 €
Heating / Cooling	2,758.78 €	81.14 €	2,758.78 €	81.14 €	2,758.78 €	81.14 €
Other	1,622.96 €	12.01 €	1,622.96 €	12.01 €	1,622.96 €	12.01 €
Domestic Hot Water	403.28 €	53.30 €	403.28 €	53.30 €	403.28 €	53.30 €
Renewables	0.00 €	0.00 €	0.00 €	0.00 €	0.00 €	0.00 €
TOTAL		**213.51 €**		**215.18 €**		**380.32 €**
Other						
Replacement of water piping - toilet, bathroom, and kitchen	1,622.96 €	12.01 €	1,622.96 €	12.01 €	1,622.96 €	12.01 €
Exterior Walls						
Repair of cracks and others on the facade (€/m2 facade area)					964.30 €	2.92 €
Mechanical cleaning of the facade with compressed air (€/m2 facade area)					622.20 €	0.00 €
Painting of the exterior walls with plastic based paint (€/m2 facade area)					607.30 €	106.26 €
Scaffolding Rent Cost	1,191.96 €	0.00 €	1,191.96 €	0.00 €	1,191.96 €	0.00 €
Scaffolding transport, assembly and dismantle	827.67 €	0.00 €	827.67 €	0.00 €	827.67 €	0.00 €
ETICS EPS 60mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls						
ETICS EPS 80mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls	4,879.29 €	29.50 €				
ETICS EPS 100mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls			5,092.65 €	31.17 €		
Insulation by the interior (λ=0.038), EPS 60mm; Lifetime of 30 years (€/m2 area of the exterior walls)					2,185.46 €	87.13 €
Walls in contact with unconditioned space (corridors)						
Insulation by the interior (λ=0.038), EPS 60mm; Lifetime of 30 years (€/m2 area of the walls)						
Roof						
Cleaning of the roof tiles (€ / m2 area of the roof)	208.49 €	0.00 €	208.49 €	0.00 €	208.49 €	0.00 €
Cleaning of the gutters	47.50 €	0.00 €	47.50 €	0.00 €	47.50 €	0.00 €
Horizontal slab insulation (MW - λ=0.035) 100mm; Lifetime of 30 years (€ / m2 area of the slab)						
Horizontal slab insulation (MW - λ=0.035) 120mm; Lifetime of 30 years (€ / m2 area of the slab)						
Horizontal slab insulation (MW - λ=0.035) 150mm; Lifetime of 30 years (€ / m2 area of the slab)						
Windows						
Reparation and paiting of the window frames	797.29 €	37.56 €	797.29 €	37.56 €	797.29 €	37.56 €
PVC frames						
Wooden Frames						
Double glass standard 4:16:4; Lifetime 30 years;						
Double glass with low E 4:16:4; Lifetime 30 years;						
Ventilation						
Bath extractor Equation Q1 100 mm						
Kitchen extractor 500 140w						
Systems						
Gas water heater, Life time 20 years;	403.28 €	53.30 €	403.28 €	53.30 €	403.28 €	53.30 €
Collector units;						
Air-Air Multi split External *"Mitsubishi" SCM50ZS-W*; COP 4.9; EER 5.17 / 3 interior units SKM20ZSP-W ; Life time 15 years;						
Air-Air Multi split External; EER 3; Life time 15 years;	1,409.98 €	49.35 €	1,409.98 €	49.35 €	1,409.98 €	49.35 €
Air-Air Multi split Internal; 3 un; Life time 15 years;	959.10 €	26.33 €	959.10 €	26.33 €	959.10 €	26.33 €
Gas water heater Vulcano WTD Sensor compact; ∏=92%; Life time 20 years;						
Electrical heating unit 100% (1 per room); Life time 15 years	389.70 €	5.46 €	389.70 €	5.46 €	389.70 €	5.46 €
Renewables						
Heat Pump (DHW and climatization); COP 5; EER 4.9; COP AQS 3.2; Life time 20 years;						
Heat Pump (DHW); COP 3.77; Life time 20 years;						
1 Kit PVs Junkers with 2 collector plates and a deposit: FCC-2 S CTE TSS 300L ;rend 0,761; Life time 20 years;						
PV - 1 kit: 1 PV module of 180 W + inverter (described in the text-based file)						

Heating area (m2)

Table 1 - Santa Tecla

INDICATIVE TABLE FOR THE ENUMERATION OF THE VARIATIONS / SELECTED MEASURES

DESCRIPTION	VAR 29 Main+Horizontal_Slab MW 100mm	Main	VAR 30 Main+Horizontal_Slab MW 120mm	Main	VAR 31 Main+Horizontal_Slab EPS 150mm	Main
Rehabilitation costs of one apartment						
Opaque Envelope	4,882.91 €	111.24 €	4,932.85 €	111.56 €	5,010.00 €	112.08 €
Glazed Openings	797.29 €	37.56 €	797.29 €	37.56 €	797.29 €	37.56 €
Heating / Cooling	2,758.78 €	81.14 €	2,758.78 €	81.14 €	2,758.78 €	81.14 €
Other	1,622.96 €	12.01 €	1,622.96 €	12.01 €	1,622.96 €	12.01 €
Domestic Hot Water	403.28 €	53.30 €	403.28 €	53.30 €	403.28 €	53.30 €
Renewables	0.00 €	0.00 €	0.00 €	0.00 €	0.00 €	0.00 €
TOTAL		**295.25 €**		**295.57 €**		**296.09 €**
Other						
Replacement of water piping - toilet, bathroom, and kitchen	1,622.96 €	12.01 €	1,622.96 €	12.01 €	1,622.96 €	12.01 €
Exterior Walls						
Repair of cracks and others on the facade (€/m2 facade area)	964.30 €	2.92 €	964.30 €	2.92 €	964.30 €	2.92 €
Mechanical cleaning of the facade with compressed air (€/m2 facade area)	622.20 €	0.00 €	622.20 €	0.00 €	622.20 €	0.00 €
Painting of the exterior walls with plastic based paint (€/m2 facade area)	607.30 €	106.26 €	607.30 €	106.26 €	607.30 €	106.26 €
Scaffolding Rent Cost	1,191.96 €	0.00 €	1,191.96 €	0.00 €	1,191.96 €	0.00 €
Scaffolding transport, assembly and dismantle	827.67 €	0.00 €	827.67 €	0.00 €	827.67 €	0.00 €
ETICS EPS 60mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls						
ETICS EPS 80mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls						
ETICS EPS 100mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls						
Insulation by the interior (λ=0.038), EPS 60mm; Lifetime of 30 years (€/m2 area of the exterior walls)						
Walls in contact with unconditioned space (corridors)						
Insulation by the interior (λ=0.038), EPS 60mm; Lifetime of 30 years (€/m2 area of the walls)						
Roof						
Cleaning of the roof tiles (€ / m2 area of the roof)	208.49 €	0.00 €	208.49 €	0.00 €	208.49 €	0.00 €
Cleaning of the gutters	47.50 €	0.00 €	47.50 €	0.00 €	47.50 €	0.00 €
Horizontal slab insulation (MW - λ=0.035) 100mm; Lifetime of 30 years (€ / m2 area of the slab)	413.49 €	2.06 €				
Horizontal slab insulation (MW - λ=0.035) 120mm; Lifetime of 30 years (€ / m2 area of the slab)			463.43 €	2.38 €		
Horizontal slab insulation (MW - λ=0.035) 150mm; Lifetime of 30 years (€ / m2 area of the slab)					540.58 €	2.90 €
Windows						
Reparation and paiting of the window frames	797.29 €	37.56 €	797.29 €	37.56 €	797.29 €	37.56 €
PVC frames						
Wooden Frames						
Double glass standard 4:16:4; Lifetime 30 years;						
Double glass with low E 4:16:4; Lifetime 30 years;						
Ventilation						
Bath extractor Equation Q1 100 mm						
Kitchen extractor 500 140w						
Systems						
Gas water heater, Life time 20 years;	403.28 €	53.30 €	403.28 €	53.30 €	403.28 €	53.30 €
Collector units;						
Air-Air Multi split External *"Mitsubishi" SCM50ZS-W*; COP 4.9; EER 5.17 / 3 interior units SKM20ZSP-W ; Life time 15 years;						
Air-Air Multi split External; EER 3; Life time 15 years;	1,409.98 €	49.35 €	1,409.98 €	49.35 €	1,409.98 €	49.35 €
Air-Air Multi split Internal; 3 un; Life time 15 years;	959.10 €	26.33 €	959.10 €	26.33 €	959.10 €	26.33 €
Gas water heater Vulcano WTD Sensor compact; Ƞ=92%; Life time 20 years;						
Electrical heating unit 100% (1 per room); Life time 15 years	389.70 €	5.46 €	389.70 €	5.46 €	389.70 €	5.46 €
Renewables						
Heat Pump (DHW and climatization); COP 5; EER 4.9; COP AQS 3.2; Life time 20 years;						
Heat Pump (DHW); COP 3.77; Life time 20 years;						
1 Kit PVs Junkers with 2 collector plates and a deposit: FCC-2 S CTE TSS 300L ;rend 0,761; Life time 20 years;						
PV - 1 kit: 1 PV module of 180 W + inverter (described in the text-based file)						

Heating area (m2)

Table 1 - Santa Tecla

INDICATIVE TABLE FOR THE ENUMERATION OF THE VARIATIONS / SELECTED MEASURES

DESCRIPTION	**VAR 38** Main+PVC Frame + double glass (low-E)	Main	**VAR 39** Main+Wooden Frame +double glass (low-E)	Main	**VAR 40** Main+PVC Frame + double glass (standard)	Main
Rehabilitation costs of one apartment						
Opaque Envelope	4,469.42 €	109.18 €	4,469.42 €	109.18 €	4,469.42 €	109.18 €
Glazed Openings	3,080.29 €	45.31 €	6,016.82 €	144.66 €	2,328.49 €	29.52 €
Heating / Cooling	2,758.78 €	81.14 €	2,758.78 €	81.14 €	2,758.78 €	81.14 €
Other	1,622.96 €	12.01 €	1,622.96 €	12.01 €	1,622.96 €	12.01 €
Domestic Hot Water	403.28 €	53.30 €	403.28 €	53.30 €	403.28 €	53.30 €
Renewables	0.00 €	0.00 €	0.00 €	0.00 €	0.00 €	0.00 €
TOTAL		**300.94 €**		**400.29 €**		**285.15 €**
Other						
Replacement of water piping - toilet, bathroom, and kitchen	1,622.96 €	12.01 €	1,622.96 €	12.01 €	1,622.96 €	12.01 €
Exterior Walls						
Repair of cracks and others on the facade (€/m2 facade area)	964.30 €	2.92 €	964.30 €	2.92 €	964.30 €	2.92 €
Mechanical cleaning of the facade with compressed air (€/m2 facade area)	622.20 €	0.00 €	622.20 €	0.00 €	622.20 €	0.00 €
Painting of the exterior walls with plastic based paint (€/m2 facade area)	607.30 €	106.26 €	607.30 €	106.26 €	607.30 €	106.26 €
Scaffolding Rent Cost	1,191.96 €	0.00 €	1,191.96 €	0.00 €	1,191.96 €	0.00 €
Scaffolding transport, assembly and dismantle	827.67 €	0.00 €	827.67 €	0.00 €	827.67 €	0.00 €
ETICS EPS 60mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls						
ETICS EPS 80mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls						
ETICS EPS 100mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls						
Insulation by the interior (λ=0.038), EPS 60mm; Lifetime of 30 years (€/m2 area of the exterior walls)						
Walls in contact with unconditioned space (corridors)						
Insulation by the interior (λ=0.038), EPS 60mm; Lifetime of 30 years (€/m2 area of the walls)						
Roof						
Cleaning of the roof tiles (€ / m2 area of the roof)	208.49 €	0.00 €	208.49 €	0.00 €	208.49 €	0.00 €
Cleaning of the gutters	47.50 €	0.00 €	47.50 €	0.00 €	47.50 €	0.00 €
Horizontal slab insulation (MW - λ=0.035) 100mm; Lifetime of 30 years (€ / m2 area of the slab)						
Horizontal slab insulation (MW - λ=0.035) 120mm; Lifetime of 30 years (€ / m2 area of the slab)						
Horizontal slab insulation (MW - λ=0.035) 150mm; Lifetime of 30 years (€ / m2 area of the slab)						
Windows						
Reparation and paiting of the window frames						
PVC frames	1,908.19 €	20.69 €			1,908.19 €	20.69 €
Wooden Frames			4,844.73 €	120.05 €		
Double glass standard 4:16:4; Lifetime 30 years;					420.30 €	8.83 €
Double glass with low E 4:16:4; Lifetime 30 years;	1,172.10 €	24.61 €	1,172.10 €	24.61 €		
Ventilation						
Bath extractor Equation Q1 100 mm						
Kitchen extractor 500 140w						
Systems						
Gas water heater, Life time 20 years;	403.28 €	53.30 €	403.28 €	53.30 €	403.28 €	53.30 €
Collector units;						
Air-Air Multi split External *"Mitsubishi" SCM50ZS-W*; COP 4.9; EER 5.17 / 3 interior units SKM20ZSP-W ; Life time 15 years;						
Air-Air Multi split External; EER 3; Life time 15 years;	1,409.98 €	49.35 €	1,409.98 €	49.35 €	1,409.98 €	49.35 €
Air-Air Multi split Internal; 3 un; Life time 15 years;	959.10 €	26.33 €	959.10 €	26.33 €	959.10 €	26.33 €
Gas water heater Vulcano WTD Sensor compact; η=92%; Life time 20 years;						
Electrical heating unit 100% (1 per room); Life time 15 years	389.70 €	5.46 €	389.70 €	5.46 €	389.70 €	5.46 €
Renewables						
Heat Pump (DHW and climatization); COP 5; EER 4.9; COP AQS 3.2; Life time 20 years;						
Heat Pump (DHW); COP 3.77; Life time 20 years;						
1 Kit PVs Junkers with 2 collector plates and a deposit: FCC-2 S CTE TSS 300L ;rend 0,761; Life time 20 years;						
PV - 1 kit: 1 PV module of 180 W + inverter (described in the text-based file)						

Heating area (m2)

Table 1 - Santa Tecla

INDICATIVE TABLE FOR THE ENUMERATION OF THE VARIATIONS / SELECTED MEASURES

DESCRIPTION	VAR 42 [ETICS_EPS-60 mm] + ['Horizontal_Slab MW 100mm] + [REF Window] + [Default Systems REF]	Main	VAR 43 [ETICS_EPS-80 mm] + ['Horizontal_Slab MW 100mm] + [REF Window] + [Default Systems REF]	Main	VAR 44 [ETICS_EPS-100 mm] + ['Horizontal_Slab MW 100mm] + [REF Window] + [Default Systems REF]	Main
Rehabilitation costs of one apartment						
Opaque Envelope	7,343.12 €	29.77 €	7,568.40 €	31.56 €	7,781.76 €	33.23 €
Glazed Openings	797.29 €	37.56 €	797.29 €	37.56 €	797.29 €	37.56 €
Heating / Cooling	2,758.78 €	81.14 €	2,758.78 €	81.14 €	2,758.78 €	81.14 €
Other	2,058.42 €	29.37 €	2,058.42 €	29.37 €	2,058.42 €	29.37 €
Domestic Hot Water	403.28 €	53.30 €	403.28 €	53.30 €	403.28 €	53.30 €
Renewables	0.00 €	0.00 €	0.00 €	0.00 €	0.00 €	0.00 €
TOTAL		**231.14 €**		**232.93 €**		**234.60 €**
Other						
Replacement of water piping - toilet, bathroom, and kitchen	1,622.96 €	12.01 €	1,622.96 €	12.01 €	1,622.96 €	12.01 €
Exterior Walls						
Repair of cracks and others on the facade (€/m2 facade area)						
Mechanical cleaning of the facade with compressed air (€/m2 facade area)						
Painting of the exterior walls with plastic based paint (€/m2 facade area)						
Scaffolding Rent Cost	1,191.96 €	0.00 €	1,191.96 €	0.00 €	1,191.96 €	0.00 €
Scaffolding transport, assembly and dismantle	827.67 €	0.00 €	827.67 €	0.00 €	827.67 €	0.00 €
ETICS EPS 60mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls	4,654.01 €	27.71 €				
ETICS EPS 80mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls			4,879.29 €	29.50 €		
ETICS EPS 100mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls					5,092.65 €	31.17 €
Insulation by the interior (λ=0.038), EPS 60mm; Lifetime of 30 years (€/m2 area of the exterior walls)						
Walls in contact with unconditioned space (corridors)						
Insulation by the interior (λ=0.038), EPS 60mm; Lifetime of 30 years (€/m2 area of the walls)	435.46 €	17.36 €	435.46 €	17.36 €	435.46 €	17.36 €
Roof						
Cleaning of the roof tiles (€ / m2 area of the roof)	208.49 €	0.00 €	208.49 €	0.00 €	208.49 €	0.00 €
Cleaning of the gutters	47.50 €	0.00 €	47.50 €	0.00 €	47.50 €	0.00 €
Horizontal slab insulation (MW - λ=0.035) 100mm; Lifetime of 30 years (€ / m2 area of the slab)	413.49 €	2.06 €	413.49 €	2.06 €	413.49 €	2.06 €
Horizontal slab insulation (MW - λ=0.035) 120mm; Lifetime of 30 years (€ / m2 area of the slab)						
Horizontal slab insulation (MW - λ=0.035) 150mm; Lifetime of 30 years (€ / m2 area of the slab)						
Windows						
Reparation and paiting of the window frames	797.29 €	37.56 €	797.29 €	37.56 €	797.29 €	37.56 €
PVC frames						
Wooden Frames						
Double glass standard 4:16:4; Lifetime 30 years;						
Double glass with low E 4:16:4; Lifetime 30 years;						
Ventilation						
Bath extractor Equation Q1 100 mm						
Kitchen extractor 500 140w						
Systems						
Gas water heater, Life time 20 years;	403.28 €	53.30 €	403.28 €	53.30 €	403.28 €	53.30 €
Collector units;						
Air-Air Multi split External *"Mitsubishi" SCM50ZS-W*; COP 4.9; EER 5.17 / 3 interior units SKM20ZSP-W ; Life time 15 years;						
Air-Air Multi split External; EER 3; Life time 15 years;	1,409.98 €	49.35 €	1,409.98 €	49.35 €	1,409.98 €	49.35 €
Air-Air Multi split Internal; 3 un; Life time 15 years;	959.10 €	26.33 €	959.10 €	26.33 €	959.10 €	26.33 €
Gas water heater Vulcano WTD Sensor compact; Ƞ=92%; Life time 20 years;						
Electrical heating unit 100% (1 per room); Life time 15 years	389.70 €	5.46 €	389.70 €	5.46 €	389.70 €	5.46 €
Renewables						
Heat Pump (DHW and climatization); COP 5; EER 4.9; COP AQS 3.2; Life time 20 years;						
Heat Pump (DHW); COP 3.77; Life time 20 years;						
1 Kit PVs Junkers with 2 collector plates and a deposit: FCC-2 S CTE TSS 300L ;rend 0,761; Life time 20 years;						
PV - 1 kit: 1 PV module of 180 W + inverter (described in the text-based file)						

Heating area (m2)

Table 1 - Santa Tecla

INDICATIVE TABLE FOR THE ENUMERATION OF THE VARIATIONS / SELECTED MEASURES

DESCRIPTION	VAR 45 [ETICS_EPS-60 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [Default Systems REF]	Main	VAR 46 [ETICS_EPS-80 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [Default Systems REF]	Main	VAR 47 [ETICS_EPS-100 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [Default Systems REF]	Main
Rehabilitation costs of one apartment						
Opaque Envelope	7,343.12 €	29.77 €	7,568.40 €	31.56 €	7,781.76 €	33.23 €
Glazed Openings	2,328.49 €	29.52 €	2,328.49 €	29.52 €	2,328.49 €	29.52 €
Heating / Cooling	2,758.78 €	81.14 €	2,758.78 €	81.14 €	2,758.78 €	81.14 €
Other	2,058.42 €	29.37 €	2,058.42 €	29.37 €	2,058.42 €	29.37 €
Domestic Hot Water	403.28 €	53.30 €	403.28 €	53.30 €	403.28 €	53.30 €
Renewables	0.00 €	0.00 €	0.00 €	0.00 €	0.00 €	0.00 €
TOTAL		**223.10 €**		**224.89 €**		**226.56 €**
Other						
Replacement of water piping - toilet, bathroom, and kitchen	1,622.96 €	12.01 €	1,622.96 €	12.01 €	1,622.96 €	12.01 €
Exterior Walls						
Repair of cracks and others on the facade (€/m2 facade area)						
Mechanical cleaning of the facade with compressed air (€/m2 facade area)						
Painting of the exterior walls with plastic based paint (€/m2 facade area)						
Scaffolding Rent Cost	1,191.96 €	0.00 €	1,191.96 €	0.00 €	1,191.96 €	0.00 €
Scaffolding transport, assembly and dismantle	827.67 €	0.00 €	827.67 €	0.00 €	827.67 €	0.00 €
ETICS EPS 60mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls	4,654.01 €	27.71 €				
ETICS EPS 80mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls			4,879.29 €	29.50 €		
ETICS EPS 100mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls					5,092.65 €	31.17 €
Insulation by the interior (λ=0.038), EPS 60mm; Lifetime of 30 years (€/m2 area of the exterior walls)						
Walls in contact with unconditioned space (corridors)						
Insulation by the interior (λ=0.038), EPS 60mm; Lifetime of 30 years (€/m2 area of the walls)	435.46 €	17.36 €	435.46 €	17.36 €	435.46 €	17.36 €
Roof						
Cleaning of the roof tiles (€ / m2 area of the roof)	208.49 €	0.00 €	208.49 €	0.00 €	208.49 €	0.00 €
Cleaning of the gutters	47.50 €	0.00 €	47.50 €	0.00 €	47.50 €	0.00 €
Horizontal slab insulation (MW - λ=0.035) 100mm; Lifetime of 30 years (€ / m2 area of the slab)	413.49 €	2.06 €	413.49 €	2.06 €	413.49 €	2.06 €
Horizontal slab insulation (MW - λ=0.035) 120mm; Lifetime of 30 years (€ / m2 area of the slab)						
Horizontal slab insulation (MW - λ=0.035) 150mm; Lifetime of 30 years (€ / m2 area of the slab)						
Windows						
Reparation and paiting of the window frames						
PVC frames	1,908.19 €	20.69 €	1,908.19 €	20.69 €	1,908.19 €	20.69 €
Wooden Frames						
Double glass standard 4:16:4; Lifetime 30 years;	420.30 €	8.83 €	420.30 €	8.83 €	420.30 €	8.83 €
Double glass with low E 4:16:4; Lifetime 30 years;						
Ventilation						
Bath extractor Equation Q1 100 mm						
Kitchen extractor 500 140w						
Systems						
Gas water heater, Life time 20 years;	403.28 €	53.30 €	403.28 €	53.30 €	403.28 €	53.30 €
Collector units;						
Air-Air Multi split External "*Mitsubishi*" *SCM50ZS-W*; COP 4.9; EER 5.17 / 3 interior units SKM20ZSP-W ; Life time 15 years;						
Air-Air Multi split External; EER 3; Life time 15 years;	1,409.98 €	49.35 €	1,409.98 €	49.35 €	1,409.98 €	49.35 €
Air-Air Multi split Internal; 3 un; Life time 15 years;	959.10 €	26.33 €	959.10 €	26.33 €	959.10 €	26.33 €
Gas water heater Vulcano WTD Sensor compact; ῃ=92%; Life time 20 years;						
Electrical heating unit 100% (1 per room); Life time 15 years	389.70 €	5.46 €	389.70 €	5.46 €	389.70 €	5.46 €
Renewables						
Heat Pump (DHW and climatization); COP 5; EER 4.9; COP AQS 3.2; Life time 20 years;						
Heat Pump (DHW); COP 3.77; Life time 20 years;						
1 Kit PVs Junkers with 2 collector plates and a deposit: FCC-2 S CTE TSS 300L ;rend 0,761; Life time 20 years;						
PV - 1 kit: 1 PV module of 180 W + inverter (described in the text-based file)						

Heating area (m2)

Table 1 - Santa Tecla

INDICATIVE TABLE FOR THE ENUMERATION OF THE VARIATIONS / SELECTED MEASURES

	PACKAGE 1 + SYSTEMS						
	S1		S2		S3		
DESCRIPTION	VAR 48 [ETICS_EPS-60 mm] + ['Horizontal_Slab MW 100mm] + [REF Window] + [Solar Collector + multi-split + gas water heater]	Main	VAR 49 [ETICS_EPS-60 mm] + ['Horizontal_Slab MW 100mm] + [REF Window] + [heat pump]	Main	VAR 50 [ETICS_EPS-60 mm] + ['Horizontal_Slab MW 100mm] + [REF Window] + [multi-split + DHW heat pump]	Main	
Rehabilitation costs of one apartment							
Opaque Envelope	7,343.12 €	29.77 €	7,343.12 €	29.77 €	7,343.12 €	29.77 €	
Glazed Openings	797.29 €	37.56 €	797.29 €	37.56 €	797.29 €	37.56 €	
Heating / Cooling	2,757.70 €	88.80 €	0.00 €	0.00 €	2,757.70 €	88.80 €	
Other	2,155.26 €	41.64 €	2,155.26 €	41.64 €	2,155.26 €	41.64 €	0
Domestic Hot Water	521.60 €	68.93 €	0.00 €	0.00 €	0.00 €	0.00 €	
Renewables	2,840.64 €	291.54 €	8,434.19 €	410.93 €	1,375.20 €	149.29 €	
TOTAL		**558.24 €**		**519.90 €**		**347.06 €**	
Other							
Replacement of water piping - toilet, bathroom, and kitchen	1,622.96 €	12.01 €	1,622.96 €	12.01 €	1,622.96 €	12.01 €	
Exterior Walls							
Repair of cracks and others on the facade (€/m2 facade area)							
Mechanical cleaning of the facade with compressed air (€/m2 facade area)							
Painting of the exterior walls with plastic based paint (€/m2 facade area)							
Scaffolding Rent Cost	1,191.96 €	0.00 €	1,191.96 €	0.00 €	1,191.96 €	0.00 €	
Scaffolding transport, assembly and dismantle	827.67 €	0.00 €	827.67 €	0.00 €	827.67 €	0.00 €	
ETICS EPS 60mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls	4,654.01 €	27.71 €	4,654.01 €	27.71 €	4,654.01 €	27.71 €	
ETICS EPS 80mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls							
ETICS EPS 100mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls							
Insulation by the interior (λ=0.038), EPS 60mm; Lifetime of 30 years (€/m2 area of the exterior walls)							
Walls in contact with unconditioned space (corridors)							
Insulation by the interior (λ=0.038), EPS 60mm; Lifetime of 30 years (€/m2 area of the walls)	435.46 €	17.36 €	435.46 €	17.36 €	435.46 €	17.36 €	
Roof							
Cleaning of the roof tiles (€ / m2 area of the roof)	208.49 €	0.00 €	208.49 €	0.00 €	208.49 €	0.00 €	
Cleaning of the gutters	47.50 €	0.00 €	47.50 €	0.00 €	47.50 €	0.00 €	
Horizontal slab insulation (MW - λ=0.035) 100mm; Lifetime of 30 years (€ / m2 area of the slab)	413.49 €	2.06 €	413.49 €	2.06 €	413.49 €	2.06 €	
Horizontal slab insulation (MW - λ=0.035) 120mm; Lifetime of 30 years (€ / m2 area of the slab)							
Horizontal slab insulation (MW - λ=0.035) 150mm; Lifetime of 30 years (€ / m2 area of the slab)							
Windows							
Reparation and paiting of the window frames	797.29 €	37.56 €	797.29 €	37.56 €	797.29 €	37.56 €	
PVC frames							
Wooden Frames							
Double glass standard 4:16:4; Lifetime 30 years;							
Double glass with low E 4:16:4; Lifetime 30 years;							
Ventilation							
Bath extractor Equation Q1 100 mm	28.53 €	1.00 €	28.53 €	1.00 €	28.53 €	1.00 €	
Kitchen extractor 500 140w	68.31 €	11.27 €	68.31 €	11.27 €	68.31 €	11.27 €	
Systems							
Gas water heater, Life time 20 years;							
Collector units;			2,057.50 €	19.05 €			
Air-Air Multi split External *"Mitsubishi" SCM50ZS-W*; COP 4.9; EER 5.17 / 3 interior units SKM20ZSP-W ; Life time 15 years;	2,757.70 €	88.80 €			2,757.70 €	88.80 €	
Air-Air Multi split External; EER 3; Life time 15 years;							
Air-Air Multi split Internal; 3 un; Life time 15 years;							
Gas water heater Vulcano WTD Sensor compact; Ƞ=92%; Life time 20 years;	521.60 €	68.93 €					
Electrical heating unit 100% (1 per room); Life time 15 years							
Renewables							
Heat Pump (DHW and climatization); COP 5; EER 4.9; COP AQS 3.2; Life time 20 years;			6,376.69 €	391.88 €			
Heat Pump (DHW); COP 3.77; Life time 20 years;					1,375.20 €	149.29 €	
1 Kit PVs Junkers with 2 collector plates and a deposit: FCC-2 S CTE TSS 300L ;rend 0,761; Life time 20 years;	2,840.64 €	291.54 €					
PV - 1 kit: 1 PV module of 180 W + inverter (described in the text-based file)							

Heating area (m2)

Table 1 - Santa Tecla

INDICATIVE TABLE FOR THE ENUMERATION OF THE VARIATIONS / SELECTED MEASURES

					PACKAGE 2	
	S4		S1		S2	
DESCRIPTION	VAR 51 [ETICS_EPS-60 mm] + ['Horizontal_Slab MW 100mm] + [REF Window] + [multi-split + DHW Heat pump + PV]	Main	VAR 56 [ETICS_EPS-60 mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [Solar Collector + multi-split + water heater]	Main	VAR 57 [ETICS_EPS-60 mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [heat pump]	Main
Rehabilitation costs of one apartment						
Opaque Envelope	7,343.12 €	29.77 €	7,568.40 €	31.56 €	7,568.40 €	31.56 €
Glazed Openings	797.29 €	37.56 €	797.29 €	37.56 €	797.29 €	37.56 €
Heating / Cooling	2,757.70 €	88.80 €	2,757.70 €	88.80 €	0.00 €	0.00 €
Other	2,155.26 €	41.64 €	2,155.26 €	41.64 €	2,155.26 €	41.64 €
Domestic Hot Water	0.00 €	0.00 €	521.60 €	68.93 €	0.00 €	0.00 €
Renewables	1,696.24 €	171.08 €	2,840.64 €	291.54 €	8,434.19 €	410.93 €
TOTAL		**368.85 €**		**560.03 €**		**521.69 €**
Other						
Replacement of water piping - toilet, bathroom, and kitchen	1,622.96 €	12.01 €	1,622.96 €	12.01 €	1,622.96 €	12.01 €
Exterior Walls						
Repair of cracks and others on the facade (€/m2 facade area)						
Mechanical cleaning of the facade with compressed air (€/m2 facade area)						
Painting of the exterior walls with plastic based paint (€/m2 facade area)						
Scaffolding Rent Cost	1,191.96 €	0.00 €	1,191.96 €	0.00 €	1,191.96 €	0.00 €
Scaffolding transport, assembly and dismantle	827.67 €	0.00 €	827.67 €	0.00 €	827.67 €	0.00 €
ETICS EPS 60mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls	4,654.01 €	27.71 €				
ETICS EPS 80mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls			4,879.29 €	29.50 €	4,879.29 €	29.50 €
ETICS EPS 100mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls						
Insulation by the interior (λ=0.038), EPS 60mm; Lifetime of 30 years (€/m2 area of the exterior walls)						
Walls in contact with unconditioned space (corridors)						
Insulation by the interior (λ=0.038), EPS 60mm; Lifetime of 30 years (€/m2 area of the walls)	435.46 €	17.36 €	435.46 €	17.36 €	435.46 €	17.36 €
Roof						
Cleaning of the roof tiles (€ / m2 area of the roof)	208.49 €	0.00 €	208.49 €	0.00 €	208.49 €	0.00 €
Cleaning of the gutters	47.50 €	0.00 €	47.50 €	0.00 €	47.50 €	0.00 €
Horizontal slab insulation (MW - λ=0.035) 100mm; Lifetime of 30 years (€ / m2 area of the slab)	413.49 €	2.06 €	413.49 €	2.06 €	413.49 €	2.06 €
Horizontal slab insulation (MW - λ=0.035) 120mm; Lifetime of 30 years (€ / m2 area of the slab)						
Horizontal slab insulation (MW - λ=0.035) 150mm; Lifetime of 30 years (€ / m2 area of the slab)						
Windows						
Reparation and paiting of the window frames	797.29 €	37.56 €	797.29 €	37.56 €	797.29 €	37.56 €
PVC frames						
Wooden Frames						
Double glass standard 4:16:4; Lifetime 30 years;						
Double glass with low E 4:16:4; Lifetime 30 years;						
Ventilation						
Bath extractor Equation Q1 100 mm	28.53 €	1.00 €	28.53 €	1.00 €	28.53 €	1.00 €
Kitchen extractor 500 140w	68.31 €	11.27 €	68.31 €	11.27 €	68.31 €	11.27 €
Systems						
Gas water heater, Life time 20 years;						
Collector units;					2,057.50 €	19.05 €
Air-Air Multi split External *"Mitsubishi" SCM50ZS-W*; COP 4.9; EER 5.17 / 3 interior units SKM20ZSP-W ; Life time 15 years;	2,757.70 €	88.80 €	2,757.70 €	88.80 €		
Air-Air Multi split External; EER 3; Life time 15 years;						
Air-Air Multi split Internal; 3 un; Life time 15 years;						
Gas water heater Vulcano WTD Sensor compact; Ƞ=92%; Life time 20 years;			521.60 €	68.93 €		
Electrical heating unit 100% (1 per room); Life time 15 years						
Renewables						
Heat Pump (DHW and climatization); COP 5; EER 4.9; COP AQS 3.2; Life time 20 years;					6,376.69 €	391.88 €
Heat Pump (DHW); COP 3.77; Life time 20 years;	1,375.20 €	149.29 €				
1 Kit PVs Junkers with 2 collector plates and a deposit: FCC-2 S CTE TSS 300L ;rend 0,761; Life time 20 years;			2,840.64 €	291.54 €		
PV - 1 kit: 1 PV module of 180 W + inverter (described in the text-based file)	321.04 €	21.79 €				

Heating area (m2)

Table 1 - Santa Tecla

INDICATIVE TABLE FOR THE ENUMERATION OF THE VARIATIONS / SELECTED MEASURES

	+ SYSTEMS					
	S3		S4		S1	
DESCRIPTION	VAR 58 [ETICS_EPS-60 mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [multi-split + DHW heat pump]	Main	VAR 59 [ETICS_EPS-60 mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [multi-split + PV + DHW heat pump]	Main	VAR 64 [ETICS EPS 120mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [Solar Collector + multi-split + water heater]	Main
Rehabilitation costs of one apartment						
Opaque Envelope	7,568.40 €	31.56 €	7,568.40 €	31.56 €	7,781.76 €	33.23 €
Glazed Openings	797.29 €	37.56 €	797.29 €	37.56 €	797.29 €	37.56 €
Heating / Cooling	2,757.70 €	88.80 €	2,757.70 €	88.80 €	2,757.70 €	88.80 €
Other	2,155.26 €	41.64 €	2,155.26 €	41.64 €	2,155.26 €	41.64 €
Domestic Hot Water	0.00 €	0.00 €	0.00 €	0.00 €	521.60 €	68.93 €
Renewables	1,375.20 €	149.29 €	1,696.24 €	171.08 €	2,840.64 €	291.54 €
TOTAL		**348.85 €**		**370.64 €**		**561.70 €**
Other						
Replacement of water piping - toilet, bathroom, and kitchen	1,622.96 €	12.01 €	1,622.96 €	12.01 €	1,622.96 €	12.01 €
Exterior Walls						
Repair of cracks and others on the facade (€/m2 facade area)						
Mechanical cleaning of the facade with compressed air (€/m2 facade area)						
Painting of the exterior walls with plastic based paint (€/m2 facade area)						
Scaffolding Rent Cost	1,191.96 €	0.00 €	1,191.96 €	0.00 €	1,191.96 €	0.00 €
Scaffolding transport, assembly and dismantle	827.67 €	0.00 €	827.67 €	0.00 €	827.67 €	0.00 €
ETICS EPS 60mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls						
ETICS EPS 80mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls	4,879.29 €	29.50 €	4,879.29 €	29.50 €		
ETICS EPS 100mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls					5,092.65 €	31.17 €
Insulation by the interior (λ=0.038), EPS 60mm; Lifetime of 30 years (€/m2 area of the exterior walls)						
Walls in contact with unconditioned space (corridors)						
Insulation by the interior (λ=0.038), EPS 60mm; Lifetime of 30 years (€/m2 area of the walls)	435.46 €	17.36 €	435.46 €	17.36 €	435.46 €	17.36 €
Roof						
Cleaning of the roof tiles (€ / m2 area of the roof)	208.49 €	0.00 €	208.49 €	0.00 €	208.49 €	0.00 €
Cleaning of the gutters	47.50 €	0.00 €	47.50 €	0.00 €	47.50 €	0.00 €
Horizontal slab insulation (MW - λ=0.035) 100mm; Lifetime of 30 years (€ / m2 area of the slab)	413.49 €	2.06 €	413.49 €	2.06 €	413.49 €	2.06 €
Horizontal slab insulation (MW - λ=0.035) 120mm; Lifetime of 30 years (€ / m2 area of the slab)						
Horizontal slab insulation (MW - λ=0.035) 150mm; Lifetime of 30 years (€ / m2 area of the slab)						
Windows						
Reparation and paiting of the window frames	797.29 €	37.56 €	797.29 €	37.56 €	797.29 €	37.56 €
PVC frames						
Wooden Frames						
Double glass standard 4:16:4; Lifetime 30 years;						
Double glass with low E 4:16:4; Lifetime 30 years;						
Ventilation						
Bath extractor Equation Q1 100 mm	28.53 €	1.00 €	28.53 €	1.00 €	28.53 €	1.00 €
Kitchen extractor 500 140w	68.31 €	11.27 €	68.31 €	11.27 €	68.31 €	11.27 €
Systems						
Gas water heater, Life time 20 years;						
Collector units;						
Air-Air Multi split External *"Mitsubishi" SCM50ZS-W*; COP 4.9; EER 5.17 / 3 interior units SKM20ZSP-W ; Life time 15 years;	2,757.70 €	88.80 €	2,757.70 €	88.80 €	2,757.70 €	88.80 €
Air-Air Multi split External; EER 3; Life time 15 years;						
Air-Air Multi split Internal; 3 un; Life time 15 years;						
Gas water heater Vulcano WTD Sensor compact; Ƞ=92%; Life time 20 years;					521.60 €	68.93 €
Electrical heating unit 100% (1 per room); Life time 15 years						
Renewables						
Heat Pump (DHW and climatization); COP 5; EER 4.9; COP AQS 3.2; Life time 20 years;						
Heat Pump (DHW); COP 3.77; Life time 20 years;	1,375.20 €	149.29 €	1,375.20 €	149.29 €		
1 Kit PVs Junkers with 2 collector plates and a deposit: FCC-2 S CTE TSS 300L ;rend 0,761; Life time 20 years;					2,840.64 €	291.54 €
PV - 1 kit: 1 PV module of 180 W + inverter (described in the text-based file)			321.04 €	21.79 €		

Heating area (m2)

Table 1 - Santa Tecla

INDICATIVE TABLE FOR THE ENUMERATION OF THE VARIATIONS / SELECTED MEASURES

	PACKAGE 3 + SYSTEMS					
	S2		S3		S4	
DESCRIPTION	VAR 65 [ETICS EPS 120mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [Heat Pump]	Main	VAR 66 [ETICS EPS 120mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [multi-split + DHW heat pump]	Main	VAR 67 [ETICS EPS 120mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [multisplit + PV + DHW heat pump]	Main
Rehabilitation costs of one apartment						
Opaque Envelope	7,781.76 €	33.23 €	7,781.76 €	33.23 €	7,781.76 €	33.23 €
Glazed Openings	797.29 €	37.56 €	797.29 €	37.56 €	797.29 €	37.56 €
Heating / Cooling	0.00 €	0.00 €	2,757.70 €	88.80 €	2,757.70 €	88.80 €
Other	2,155.26 €	41.64 €	2,155.26 €	41.64 €	2,155.26 €	41.64 €
Domestic Hot Water	0.00 €	0.00 €	0.00 €	0.00 €	0.00 €	0.00 €
Renewables	8,434.19 €	410.93 €	1,375.20 €	149.29 €	1,696.24 €	171.08 €
TOTAL		**523.36 €**		**350.52 €**		**372.31 €**
Other						
Replacement of water piping - toilet, bathroom, and kitchen	1,622.96 €	12.01 €	1,622.96 €	12.01 €	1,622.96 €	12.01 €
Exterior Walls						
Repair of cracks and others on the facade (€/m2 facade area)						
Mechanical cleaning of the facade with compressed air (€/m2 facade area)						
Painting of the exterior walls with plastic based paint (€/m2 facade area)						
Scaffolding Rent Cost	1,191.96 €	0.00 €	1,191.96 €	0.00 €	1,191.96 €	0.00 €
Scaffolding transport, assembly and dismantle	827.67 €	0.00 €	827.67 €	0.00 €	827.67 €	0.00 €
ETICS EPS 60mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls						
ETICS EPS 80mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls						
ETICS EPS 100mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls	5,092.65 €	31.17 €	5,092.65 €	31.17 €	5,092.65 €	31.17 €
Insulation by the interior (λ=0.038), EPS 60mm; Lifetime of 30 years (€/m2 area of the exterior walls)						
Walls in contact with unconditioned space (corridors)						
Insulation by the interior (λ=0.038), EPS 60mm; Lifetime of 30 years (€/m2 area of the walls)	435.46 €	17.36 €	435.46 €	17.36 €	435.46 €	17.36 €
Roof						
Cleaning of the roof tiles (€ / m2 area of the roof)	208.49 €	0.00 €	208.49 €	0.00 €	208.49 €	0.00 €
Cleaning of the gutters	47.50 €	0.00 €	47.50 €	0.00 €	47.50 €	0.00 €
Horizontal slab insulation (MW - λ=0.035) 100mm; Lifetime of 30 years (€ / m2 area of the slab)	413.49 €	2.06 €	413.49 €	2.06 €	413.49 €	2.06 €
Horizontal slab insulation (MW - λ=0.035) 120mm; Lifetime of 30 years (€ / m2 area of the slab)						
Horizontal slab insulation (MW - λ=0.035) 150mm; Lifetime of 30 years (€ / m2 area of the slab)						
Windows						
Reparation and paiting of the window frames	797.29 €	37.56 €	797.29 €	37.56 €	797.29 €	37.56 €
PVC frames						
Wooden Frames						
Double glass standard 4:16:4; Lifetime 30 years;						
Double glass with low E 4:16:4; Lifetime 30 years;						
Ventilation						
Bath extractor Equation Q1 100 mm	28.53 €	1.00 €	28.53 €	1.00 €	28.53 €	1.00 €
Kitchen extractor 500 140w	68.31 €	11.27 €	68.31 €	11.27 €	68.31 €	11.27 €
Systems						
Gas water heater, Life time 20 years;						
Collector units;	2,057.50 €	19.05 €				
Air-Air Multi split External *"Mitsubishi" SCM50ZS-W*; COP 4.9; EER 5.17 / 3 interior units SKM20ZSP-W ; Life time 15 years;			2,757.70 €	88.80 €	2,757.70 €	88.80 €
Air-Air Multi split External; EER 3; Life time 15 years;						
Air-Air Multi split Internal; 3 un; Life time 15 years;						
Gas water heater Vulcano WTD Sensor compact; Ŋ=92%; Life time 20 years;						
Electrical heating unit 100% (1 per room); Life time 15 years						
Renewables						
Heat Pump (DHW and climatization); COP 5; EER 4.9; COP AQS 3.2; Life time 20 years;	6,376.69 €	391.88 €				
Heat Pump (DHW); COP 3.77; Life time 20 years;			1,375.20 €	149.29 €	1,375.20 €	149.29 €
1 Kit PVs Junkers with 2 collector plates and a deposit: FCC-2 S CTE TSS 300L ;rend 0,761; Life time 20 years;						
PV - 1 kit: 1 PV module of 180 W + inverter (described in the text-based file)					321.04 €	21.79 €

Heating area (m2)

Table 1 - Santa Tecla

INDICATIVE TABLE FOR THE ENUMERATION OF THE VARIATIONS / SELECTED MEASURES

	S1		S2		S3	
DESCRIPTION	VAR 72 [ETICS_EPS-60 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [Solar Collector + multi-split + water heater]	Main	VAR73 [ETICS_EPS-60 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [heat pump]	Main	VAR 74 [ETICS_EPS-60 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [multi-split + DHW heat pump	Main
Rehabilitation costs of one apartment						
Opaque Envelope	7,343.12 €	29.77 €	7,343.12 €	29.77 €	7,343.12 €	29.77 €
Glazed Openings	2,328.49 €	29.52 €	2,328.49 €	29.52 €	2,328.49 €	29.52 €
Heating / Cooling	2,757.70 €	88.80 €	0.00 €	0.00 €	2,757.70 €	88.80 €
Other	2,155.26 €	41.64 €	2,155.26 €	41.64 €	2,155.26 €	41.64 €
Domestic Hot Water	521.60 €	68.93 €	0.00 €	0.00 €	0.00 €	0.00 €
Renewables	2,840.64 €	291.54 €	8,434.19 €	410.93 €	1,375.20 €	149.29 €
TOTAL		**550.20 €**		**511.86 €**		**339.02 €**
Other						
Replacement of water piping - toilet, bathroom, and kitchen	1,622.96 €	12.01 €	1,622.96 €	12.01 €	1,622.96 €	12.01 €
Exterior Walls						
Repair of cracks and others on the facade (€/m2 facade area)						
Mechanical cleaning of the facade with compressed air (€/m2 facade area)						
Painting of the exterior walls with plastic based paint (€/m2 facade area)						
Scaffolding Rent Cost	1,191.96 €	0.00 €	1,191.96 €	0.00 €	1,191.96 €	0.00 €
Scaffolding transport, assembly and dismantle	827.67 €	0.00 €	827.67 €	0.00 €	827.67 €	0.00 €
ETICS EPS 60mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls	4,654.01 €	27.71 €	4,654.01 €	27.71 €	4,654.01 €	27.71 €
ETICS EPS 80mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls						
ETICS EPS 100mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls						
Insulation by the interior (λ=0.038), EPS 60mm; Lifetime of 30 years (€/m2 area of the exterior walls)						
Walls in contact with unconditioned space (corridors)						
Insulation by the interior (λ=0.038), EPS 60mm; Lifetime of 30 years (€/m2 area of the walls)	435.46 €	17.36 €	435.46 €	17.36 €	435.46 €	17.36 €
Roof						
Cleaning of the roof tiles (€ / m2 area of the roof)	208.49 €	0.00 €	208.49 €	0.00 €	208.49 €	0.00 €
Cleaning of the gutters	47.50 €	0.00 €	47.50 €	0.00 €	47.50 €	0.00 €
Horizontal slab insulation (MW - λ=0.035) 100mm; Lifetime of 30 years (€ / m2 area of the slab)	413.49 €	2.06 €	413.49 €	2.06 €	413.49 €	2.06 €
Horizontal slab insulation (MW - λ=0.035) 120mm; Lifetime of 30 years (€ / m2 area of the slab)						
Horizontal slab insulation (MW - λ=0.035) 150mm; Lifetime of 30 years (€ / m2 area of the slab)						
Windows						
Reparation and paiting of the window frames						
PVC frames	1,908.19 €	20.69 €	1,908.19 €	20.69 €	1,908.19 €	20.69 €
Wooden Frames						
Double glass standard 4:16:4; Lifetime 30 years;	420.30 €	8.83 €	420.30 €	8.83 €	420.30 €	8.83 €
Double glass with low E 4:16:4; Lifetime 30 years;						
Ventilation						
Bath extractor Equation Q1 100 mm	28.53 €	1.00 €	28.53 €	1.00 €	28.53 €	1.00 €
Kitchen extractor 500 140w	68.31 €	11.27 €	68.31 €	11.27 €	68.31 €	11.27 €
Systems						
Gas water heater, Life time 20 years;						
Collector units;			2,057.50 €	19.05 €		
Air-Air Multi split External *"Mitsubishi" SCM50ZS-W*; COP 4.9; EER 5.17 / 3 interior units SKM20ZSP-W ; Life time 15 years;	2,757.70 €	88.80 €			2,757.70 €	88.80 €
Air-Air Multi split External; EER 3; Life time 15 years;						
Air-Air Multi split Internal; 3 un; Life time 15 years;						
Gas water heater Vulcano WTD Sensor compact; ɳ=92%; Life time 20 years;	521.60 €	68.93 €				
Electrical heating unit 100% (1 per room); Life time 15 years						
Renewables						
Heat Pump (DHW and climatization); COP 5; EER 4.9; COP AQS 3.2; Life time 20 years;			6,376.69 €	391.88 €		
Heat Pump (DHW); COP 3.77; Life time 20 years;					1,375.20 €	149.29 €
1 Kit PVs Junkers with 2 collector plates and a deposit: FCC-2 S CTE TSS 300L ;rend 0,761; Life time 20 years;	2,840.64 €	291.54 €				
PV - 1 kit: 1 PV module of 180 W + inverter (described in the text-based file)						

Heating area (m2)

Table 1 - Santa Tecla

INDICATIVE TABLE FOR THE ENUMERATION OF THE VARIATIONS / SELECTED MEASURES

	PACKAGE 4 + SYSTEMS					
	S4		S5		S6	
DESCRIPTION	**VAR 75 [ETICS_EPS-60 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [multi-split+DHW heat pump + PV]**	Main	76 [PE_MORE-CONECT 220mm] + ['Horizontal_Slab MW mm] + [PVC Frame + double glass low E] + [Sistemas: Caldeira + AVAC + ST (AQS)]	Main	77 [PE_MORE-CONECT 220mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass low E] + [Sistemas: heat pump + PV]	Main
Rehabilitation costs of one apartment						
Opaque Envelope	7,343.12 €	29.77 €	2,275.62 €	0.00 €	2,275.62 €	0.00 €
Glazed Openings	2,328.49 €	29.52 €	3,080.29 €	45.31 €	3,080.29 €	45.31 €
Heating / Cooling	2,757.70 €	88.80 €			6,376.69 €	391.88 €
Other	2,155.26 €	41.64 €	2,057.50 €	19.05 €	2,057.50 €	19.05 €
Domestic Hot Water	0.00 €	0.00 €				
Renewables	1,696.24 €	171.08 €	2,840.64 €	291.54 €		
TOTAL		**360.81 €**		**355.90 €**		**456.24 €**
Other						
Replacement of water piping - toilet, bathroom, and kitchen	1,622.96 €	12.01 €				
Exterior Walls						
Repair of cracks and others on the facade (€/m2 facade area)						
Mechanical cleaning of the facade with compressed air (€/m2 facade area)						
Painting of the exterior walls with plastic based paint (€/m2 facade area)						
Scaffolding Rent Cost	1,191.96 €	0.00 €	1,191.96 €	0.00 €	1,191.96 €	0.00 €
Scaffolding transport, assembly and dismantle	827.67 €	0.00 €	827.67 €	0.00 €	827.67 €	0.00 €
ETICS EPS 60mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls	4,654.01 €	27.71 €				
ETICS EPS 80mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls						
ETICS EPS 100mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls						
Insulation by the interior (λ=0.038), EPS 60mm; Lifetime of 30 years (€/m2 area of the exterior walls)						
Walls in contact with unconditioned space (corridors)						
Insulation by the interior (λ=0.038), EPS 60mm; Lifetime of 30 years (€/m2 area of the walls)	435.46 €	17.36 €				
Roof						
Cleaning of the roof tiles (€ / m2 area of the roof)	208.49 €	0.00 €	208.49 €	0.00 €	208.49 €	0.00 €
Cleaning of the gutters	47.50 €	0.00 €	47.50 €	0.00 €	47.50 €	0.00 €
Horizontal slab insulation (MW - λ=0.035) 100mm; Lifetime of 30 years (€ / m2 area of the slab)	413.49 €	2.06 €				
Horizontal slab insulation (MW - λ=0.035) 120mm; Lifetime of 30 years (€ / m2 area of the slab)						
Horizontal slab insulation (MW - λ=0.035) 150mm; Lifetime of 30 years (€ / m2 area of the slab)						
Windows						
Reparation and paiting of the window frames						
PVC frames	1,908.19 €	20.69 €	1,908.19 €	20.69 €	1,908.19 €	20.69 €
Wooden Frames						
Double glass standard 4:16:4; Lifetime 30 years;	420.30 €	8.83 €				
Double glass with low E 4:16:4; Lifetime 30 years;			1,172.10 €	24.61 €	1,172.10 €	24.61 €
Ventilation						
Bath extractor Equation Q1 100 mm	28.53 €	1.00 €				
Kitchen extractor 500 140w	68.31 €	11.27 €				
Systems						
Gas water heater, Life time 20 years;						
Collector units;			2,057.50 €	19.05 €	2,057.50 €	19.05 €
Air-Air Multi split External *"Mitsubishi" SCM50ZS-W*; COP 4.9; EER 5.17 / 3 interior units SKM20ZSP-W ; Life time 15 years;	2,757.70 €	88.80 €	2,757.70 €	88.80 €		
Air-Air Multi split External; EER 3; Life time 15 years;						
Air-Air Multi split Internal; 3 un; Life time 15 years;						
Gas water heater Vulcano WTD Sensor compact; Ƞ=92%; Life time 20 years;						
Electrical heating unit 100% (1 per room); Life time 15 years						
Renewables						
Heat Pump (DHW and climatization); COP 5; EER 4.9; COP AQS 3.2; Life time 20 years;					6,376.69 €	391.88 €
Heat Pump (DHW); COP 3.77; Life time 20 years;	1,375.20 €	149.29 €				
1 Kit PVs Junkers with 2 collector plates and a deposit: FCC-2 S CTE TSS 300L ;rend 0,761; Life time 20 years;			2,840.64 €	291.54 €		
PV - 1 kit: 1 PV module of 180 W + inverter (described in the text-based file)	321.04 €	21.79 €				

Heating area (m2)

Table 1 - Santa Tecla

INDICATIVE TABLE FOR THE ENUMERATION OF THE VARIATIONS / SELECTED MEASURES

DESCRIPTION	S7 78 [PE_MORE-CONECT 220mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass low E] + [Sistemas: water heater + AVAC + PV]	Main	S8 79 [PE_MORE-CONECT 220mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass low E] + [Sistemas: Caldeira + ST]	Main	S1 VAR 80 [ETICS EPS 80mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass low E] + [Solar Collector + multi-split + water heater]	Main
Rehabilitation costs of one apartment						
Opaque Envelope	2,275.62 €	0.00 €	2,275.62 €	0.00 €	7,568.40 €	31.56 €
Glazed Openings	3,080.29 €	45.31 €	3,080.29 €	45.31 €	2,328.49 €	29.52 €
Heating / Cooling			2,078.00 €	190.00 €	2,757.70 €	88.80 €
Other			2,057.50 €	19.05 €	2,155.26 €	41.64 €
Domestic Hot Water	521.60 €	68.93 €			521.60 €	68.93 €
Renewables			2,840.64 €	291.54 €	2,840.64 €	291.54 €
TOTAL		**114.24 €**		**545.90 €**		**551.99 €**
Other						
Replacement of water piping - toilet, bathroom, and kitchen					1,622.96 €	12.01 €
Exterior Walls						
Repair of cracks and others on the facade (€/m2 facade area)						
Mechanical cleaning of the facade with compressed air (€/m2 facade area)						
Painting of the exterior walls with plastic based paint (€/m2 facade area)						
Scaffolding Rent Cost	1,191.96 €	0.00 €	1,191.96 €	0.00 €	1,191.96 €	0.00 €
Scaffolding transport, assembly and dismantle	827.67 €	0.00 €	827.67 €	0.00 €	827.67 €	0.00 €
ETICS EPS 60mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls						
ETICS EPS 80mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls					4,879.29 €	29.50 €
ETICS EPS 100mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls						
Insulation by the interior (λ=0.038), EPS 60mm; Lifetime of 30 years (€/m2 area of the exterior walls)						
Walls in contact with unconditioned space (corridors)						
Insulation by the interior (λ=0.038), EPS 60mm; Lifetime of 30 years (€/m2 area of the walls)					435.46 €	17.36 €
Roof						
Cleaning of the roof tiles (€ / m2 area of the roof)	208.49 €	0.00 €	208.49 €	0.00 €	208.49 €	0.00 €
Cleaning of the gutters	47.50 €	0.00 €	47.50 €	0.00 €	47.50 €	0.00 €
Horizontal slab insulation (MW - λ=0.035) 100mm; Lifetime of 30 years (€ / m2 area of the slab)					413.49 €	2.06 €
Horizontal slab insulation (MW - λ=0.035) 120mm; Lifetime of 30 years (€ / m2 area of the slab)						
Horizontal slab insulation (MW - λ=0.035) 150mm; Lifetime of 30 years (€ / m2 area of the slab)						
Windows						
Reparation and paiting of the window frames						
PVC frames	1,908.19 €	20.69 €	1,908.19 €	20.69 €	1,908.19 €	20.69 €
Wooden Frames						
Double glass standard 4:16:4; Lifetime 30 years;					420.30 €	8.83 €
Double glass with low E 4:16:4; Lifetime 30 years;	1,172.10 €	24.61 €	1,172.10 €	24.61 €		
Ventilation						
Bath extractor Equation Q1 100 mm					28.53 €	1.00 €
Kitchen extractor 500 140w					68.31 €	11.27 €
Systems						
Gas water heater, Life time 20 years;						
Collector units;			2,057.50 €	19.05 €		
Air-Air Multi split External *"Mitsubishi" SCM50ZS-W*; COP 4.9; EER 5.17 / 3 interior units SKM20ZSP-W ; Life time 15 years;	2,757.70 €	88.80 €			2,757.70 €	88.80 €
Air-Air Multi split External; EER 3; Life time 15 years;						
Air-Air Multi split Internal; 3 un; Life time 15 years;						
Gas water heater Vulcano WTD Sensor compact; Ɲ=92%; Life time 20 years;	521.60 €	68.93 €			521.60 €	68.93 €
Electrical heating unit 100% (1 per room); Life time 15 years						
Renewables						
Heat Pump (DHW and climatization); COP 5; EER 4.9; COP AQS 3.2; Life time 20 years;						
Heat Pump (DHW); COP 3.77; Life time 20 years;						
1 Kit PVs Junkers with 2 collector plates and a deposit: FCC-2 S CTE TSS 300L ;rend 0,761; Life time 20 years;			2,840.64 €	291.54 €	2,840.64 €	291.54 €
PV - 1 kit: 1 PV module of 180 W + inverter (described in the text-based file)	321.04 €	21.79 €				

Heating area (m2)

Table 1 - Santa Tecla

INDICATIVE TABLE FOR THE ENUMERATION OF THE VARIATIONS / SELECTED MEASURES

	PACKAGE 5 + SYSTEMS					
	S2		S3		S4	
DESCRIPTION	**VAR 81** [ETICS EPS 80mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass low E] + [heat pump]	Main	**VAR 82** [ETICS EPS 80mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass low E] + [multi-split + DHW heat pump]	Main	**VAR 83** [ETICS EPS 80mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass low E] + [multi-split + PV + DHW heat pump]	Main
Rehabilitation costs of one apartment						
Opaque Envelope	7,568.40 €	31.56 €	7,568.40 €	31.56 €	7,568.40 €	31.56 €
Glazed Openings	2,328.49 €	29.52 €	2,328.49 €	29.52 €	2,328.49 €	29.52 €
Heating / Cooling	0.00 €	0.00 €	2,757.70 €	88.80 €	2,757.70 €	88.80 €
Other	2,155.26 €	41.64 €	2,155.26 €	41.64 €	2,155.26 €	41.64 €
Domestic Hot Water	0.00 €	0.00 €	0.00 €	0.00 €	0.00 €	0.00 €
Renewables	8,434.19 €	410.93 €	1,375.20 €	149.29 €	1,696.24 €	171.08 €
TOTAL		**513.65 €**		**340.81 €**		**362.60 €**
Other						
Replacement of water piping - toilet, bathroom, and kitchen	1,622.96 €	12.01 €	1,622.96 €	12.01 €	1,622.96 €	12.01 €
Exterior Walls						
Repair of cracks and others on the facade (€/m2 facade area)						
Mechanical cleaning of the facade with compressed air (€/m2 facade area)						
Painting of the exterior walls with plastic based paint (€/m2 facade area)						
Scaffolding Rent Cost	1,191.96 €	0.00 €	1,191.96 €	0.00 €	1,191.96 €	0.00 €
Scaffolding transport, assembly and dismantle	827.67 €	0.00 €	827.67 €	0.00 €	827.67 €	0.00 €
ETICS EPS 60mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls						
ETICS EPS 80mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls	4,879.29 €	29.50 €	4,879.29 €	29.50 €	4,879.29 €	29.50 €
ETICS EPS 100mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls						
Insulation by the interior (λ=0.038), EPS 60mm; Lifetime of 30 years (€/m2 area of the exterior walls)						
Walls in contact with unconditioned space (corridors)						
Insulation by the interior (λ=0.038), EPS 60mm; Lifetime of 30 years (€/m2 area of the walls)	435.46 €	17.36 €	435.46 €	17.36 €	435.46 €	17.36 €
Roof						
Cleaning of the roof tiles (€ / m2 area of the roof)	208.49 €	0.00 €	208.49 €	0.00 €	208.49 €	0.00 €
Cleaning of the gutters	47.50 €	0.00 €	47.50 €	0.00 €	47.50 €	0.00 €
Horizontal slab insulation (MW - λ=0.035) 100mm; Lifetime of 30 years (€ / m2 area of the slab)	413.49 €	2.06 €	413.49 €	2.06 €	413.49 €	2.06 €
Horizontal slab insulation (MW - λ=0.035) 120mm; Lifetime of 30 years (€ / m2 area of the slab)						
Horizontal slab insulation (MW - λ=0.035) 150mm; Lifetime of 30 years (€ / m2 area of the slab)						
Windows						
Reparation and paiting of the window frames						
PVC frames	1,908.19 €	20.69 €	1,908.19 €	20.69 €	1,908.19 €	20.69 €
Wooden Frames						
Double glass standard 4:16:4; Lifetime 30 years;	420.30 €	8.83 €	420.30 €	8.83 €	420.30 €	8.83 €
Double glass with low E 4:16:4; Lifetime 30 years;						
Ventilation						
Bath extractor Equation Q1 100 mm	28.53 €	1.00 €	28.53 €	1.00 €	28.53 €	1.00 €
Kitchen extractor 500 140w	68.31 €	11.27 €	68.31 €	11.27 €	68.31 €	11.27 €
Systems						
Gas water heater, Life time 20 years;						
Collector units;	2,057.50 €	19.05 €				
Air-Air Multi split External *"Mitsubishi" SCM50ZS-W*; COP 4.9; EER 5.17 / 3 interior units SKM20ZSP-W ; Life time 15 years;			2,757.70 €	88.80 €	2,757.70 €	88.80 €
Air-Air Multi split External; EER 3; Life time 15 years;						
Air-Air Multi split Internal; 3 un; Life time 15 years;						
Gas water heater Vulcano WTD Sensor compact; Ƞ=92%; Life time 20 years;						
Electrical heating unit 100% (1 per room); Life time 15 years						
Renewables						
Heat Pump (DHW and climatization); COP 5; EER 4.9; COP AQS 3.2; Life time 20 years;	6,376.69 €	391.88 €				
Heat Pump (DHW); COP 3.77; Life time 20 years;			1,375.20 €	149.29 €	1,375.20 €	149.29 €
1 Kit PVs Junkers with 2 collector plates and a deposit: FCC-2 S CTE TSS 300L ;rend 0,761; Life time 20 years;						
PV - 1 kit: 1 PV module of 180 W + inverter (described in the text-based file)					321.04 €	21.79 €

Heating area (m2)

Table 1 - Santa Tecla

INDICATIVE TABLE FOR THE ENUMERATION OF THE VARIATIONS / SELECTED MEASURES

	PACKAGE 6 + SYSTEMS					
	S1		S2		S3	
DESCRIPTION	**VAR 88 [ETICS EPS 120mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass low E] + [Solar Collector + multi-split + water heater]**	Main	**VAR 89 [ETICS EPS 120mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass low E] + [heat pump]**	Main	**VAR 90 [ETICS EPS 120mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass low E] + [multi-split + DHW heat pump]**	Main
Rehabilitation costs of one apartment						
Opaque Envelope	7,781.76 €	33.23 €	7,781.76 €	33.23 €	7,781.76 €	33.23 €
Glazed Openings	2,328.49 €	29.52 €	2,328.49 €	29.52 €	2,328.49 €	29.52 €
Heating / Cooling	2,757.70 €	88.80 €	0.00 €	0.00 €	2,757.70 €	88.80 €
Other	2,155.26 €	41.64 €	2,155.26 €	41.64 €	2,155.26 €	41.64 €
Domestic Hot Water	521.60 €	68.93 €	0.00 €	0.00 €	0.00 €	0.00 €
Renewables	2,840.64 €	291.54 €	8,434.19 €	410.93 €	1,375.20 €	149.29 €
TOTAL		**553.66 €**		**515.32 €**		**342.48 €**
Other						
Replacement of water piping - toilet, bathroom, and kitchen	1,622.96 €	12.01 €	1,622.96 €	12.01 €	1,622.96 €	12.01 €
Exterior Walls						
Repair of cracks and others on the facade (€/m2 facade area)						
Mechanical cleaning of the facade with compressed air (€/m2 facade area)						
Painting of the exterior walls with plastic based paint (€/m2 facade area)						
Scaffolding Rent Cost	1,191.96 €	0.00 €	1,191.96 €	0.00 €	1,191.96 €	0.00 €
Scaffolding transport, assembly and dismantle	827.67 €	0.00 €	827.67 €	0.00 €	827.67 €	0.00 €
ETICS EPS 60mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls						
ETICS EPS 80mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls						
ETICS EPS 100mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls	5,092.65 €	31.17 €	5,092.65 €	31.17 €	5,092.65 €	31.17 €
Insulation by the interior (λ=0.038), EPS 60mm; Lifetime of 30 years (€/m2 area of the exterior walls)						
Walls in contact with unconditioned space (corridors)						
Insulation by the interior (λ=0.038), EPS 60mm; Lifetime of 30 years (€/m2 area of the walls)	435.46 €	17.36 €	435.46 €	17.36 €	435.46 €	17.36 €
Roof						
Cleaning of the roof tiles (€ / m2 area of the roof)	208.49 €	0.00 €	208.49 €	0.00 €	208.49 €	0.00 €
Cleaning of the gutters	47.50 €	0.00 €	47.50 €	0.00 €	47.50 €	0.00 €
Horizontal slab insulation (MW - λ=0.035) 100mm; Lifetime of 30 years (€ / m2 area of the slab)	413.49 €	2.06 €	413.49 €	2.06 €	413.49 €	2.06 €
Horizontal slab insulation (MW - λ=0.035) 120mm; Lifetime of 30 years (€ / m2 area of the slab)						
Horizontal slab insulation (MW - λ=0.035) 150mm; Lifetime of 30 years (€ / m2 area of the slab)						
Windows						
Reparation and paiting of the window frames						
PVC frames	1,908.19 €	20.69 €	1,908.19 €	20.69 €	1,908.19 €	20.69 €
Wooden Frames						
Double glass standard 4:16:4; Lifetime 30 years;	420.30 €	8.83 €	420.30 €	8.83 €	420.30 €	8.83 €
Double glass with low E 4:16:4; Lifetime 30 years;						
Ventilation						
Bath extractor Equation Q1 100 mm	28.53 €	1.00 €	28.53 €	1.00 €	28.53 €	1.00 €
Kitchen extractor 500 140w	68.31 €	11.27 €	68.31 €	11.27 €	68.31 €	11.27 €
Systems						
Gas water heater, Life time 20 years;						
Collector units;			2,057.50 €	19.05 €		
Air-Air Multi split External *"Mitsubishi" SCM50ZS-W*; COP 4.9; EER 5.17 / 3 interior units SKM20ZSP-W ; Life time 15 years;	2,757.70 €	88.80 €			2,757.70 €	88.80 €
Air-Air Multi split External; EER 3; Life time 15 years;						
Air-Air Multi split Internal; 3 un; Life time 15 years;						
Gas water heater Vulcano WTD Sensor compact; Π=92%; Life time 20 years;	521.60 €	68.93 €				
Electrical heating unit 100% (1 per room); Life time 15 years						
Renewables						
Heat Pump (DHW and climatization); COP 5; EER 4.9; COP AQS 3.2; Life time 20 years;			6,376.69 €	391.88 €		
Heat Pump (DHW); COP 3.77; Life time 20 years;					1,375.20 €	149.29 €
1 Kit PVs Junkers with 2 collector plates and a deposit: FCC-2 S CTE TSS 300L ;rend 0,761; Life time 20 years;	2,840.64 €	291.54 €				
PV - 1 kit: 1 PV module of 180 W + inverter (described in the text-based file)						

Heating area (m2)

Table 1 - Santa Tecla

INDICATIVE TABLE FOR THE ENUMERATION OF THE VARIATIONS / SELECTED MEASURES

	S4	
DESCRIPTION	**VAR 91 [ETICS EPS 120mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass low E] + [multi-split + PV + DHW heat pump]**	Main
Rehabilitation costs of one apartment		
Opaque Envelope	7,781.76 €	33.23 €
Glazed Openings	2,328.49 €	29.52 €
Heating / Cooling	2,757.70 €	88.80 €
Other	2,155.26 €	41.64 €
Domestic Hot Water	0.00 €	0.00 €
Renewables	1,696.24 €	171.08 €
TOTAL		**364.27 €**
Other		
Replacement of water piping - toilet, bathroom, and kitchen	1,622.96 €	12.01 €
Exterior Walls		
Repair of cracks and others on the facade (€/m2 facade area)		
Mechanical cleaning of the facade with compressed air (€/m2 facade area)		
Painting of the exterior walls with plastic based paint (€/m2 facade area)		
Scaffolding Rent Cost	1,191.96 €	0.00 €
Scaffolding transport, assembly and dismantle	827.67 €	0.00 €
ETICS EPS 60mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls		
ETICS EPS 80mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls		
ETICS EPS 100mm (λ=0.038); Lifetime of 30 years (€/m2 area of the exterior walls) - Includes preparation of the exterior side of the walls	5,092.65 €	31.17 €
Insulation by the interior (λ=0.038), EPS 60mm; Lifetime of 30 years (€/m2 area of the exterior walls)		
Walls in contact with unconditioned space (corridors)		
Insulation by the interior (λ=0.038), EPS 60mm; Lifetime of 30 years (€/m2 area of the walls)	435.46 €	17.36 €
Roof		
Cleaning of the roof tiles (€ / m2 area of the roof)	208.49 €	0.00 €
Cleaning of the gutters	47.50 €	0.00 €
Horizontal slab insulation (MW - λ=0.035) 100mm; Lifetime of 30 years (€ / m2 area of the slab)	413.49 €	2.06 €
Horizontal slab insulation (MW - λ=0.035) 120mm; Lifetime of 30 years (€ / m2 area of the slab)		
Horizontal slab insulation (MW - λ=0.035) 150mm; Lifetime of 30 years (€ / m2 area of the slab)		
Windows		
Reparation and paiting of the window frames		
PVC frames	1,908.19 €	20.69 €
Wooden Frames		
Double glass standard 4:16:4; Lifetime 30 years;	420.30 €	8.83 €
Double glass with low E 4:16:4; Lifetime 30 years;		
Ventilation		
Bath extractor Equation Q1 100 mm	28.53 €	1.00 €
Kitchen extractor 500 140w	68.31 €	11.27 €
Systems		
Gas water heater, Life time 20 years;		
Collector units;		
Air-Air Multi split External *"Mitsubishi" SCM50ZS-W*; COP 4.9; EER 5.17 / 3 interior units SKM20ZSP-W ; Life time 15 years;	2,757.70 €	88.80 €
Air-Air Multi split External; EER 3; Life time 15 years;		
Air-Air Multi split Internal; 3 un; Life time 15 years;		
Gas water heater Vulcano WTD Sensor compact; Π=92%; Life time 20 years;		
Electrical heating unit 100% (1 per room); Life time 15 years		
Renewables		
Heat Pump (DHW and climatization); COP 5; EER 4.9; COP AQS 3.2; Life time 20 years;		
Heat Pump (DHW); COP 3.77; Life time 20 years;	1,375.20 €	149.29 €
1 Kit PVs Junkers with 2 collector plates and a deposit: FCC-2 S CTE TSS 300L ;rend 0,761; Life time 20 years;		
PV - 1 kit: 1 PV module of 180 W + inverter (described in the text-based file)	321.04 €	21.79 €

Table 24: Cost-optimal (adapted methodology)

			Initial Global Cost	Exploration Cost (30	Total Cost (30 years)	Nic (kWh/m².year)		Nvc (kWh/m².year)		Nac (kWh/m².year)		Conversion Rates			(kWh/m².year)	n due to base	
			Private	Private	Private	Total	η	Total	η	Total	η	Nic	Nvc	Nac	Total	Total	
	REF	Maintenance	14,898 €	15,561 €	383.14 €	15.46	1	11.49	3	29.90	0.82	2.5	2.5	1	84.69	0	0%
Exterior Walls (ETICS)	var 1	Maintenance + ETICS EPS 60mm	16,917 €	13,387 €	381.18 €	12.47	1	12.44	3	29.90	0.82	2.5	2.5	1	78.01	7.89%	0%
	var 2	Maintenance + ETICS EPS 80mm	17,194 €	13,324 €	383.87 €	12.13	1	12.51	3	29.90	0.82	2.5	2.5	1	77.21	8.83%	0%
	var 3	Maintenance + ETICS EPS 100mm	17,457 €	13,279 €	386.61 €	11.86	1	12.56	3	29.90	0.82	2.5	2.5	1	76.58	9.57%	0%
Exterior Walls (Insulation from the interior)	var 20	Maintenance + EW_Inso.Int. EPS 60mm	17,587 €	16,318 €	426.47 €	12.73	1	12.43	3	29.90	0.82	2.5	2.5	1	78.65	7.13%	0%
Roof (Insulation above horizontal slab)	var 29	Maintenance + Horizontal_Slab EPS 100mm	15,407 €	13,874 €	368.32 €	10.39	1	8.61	3	29.90	0.82	2.5	2.5	1	69.61	17.80%	0%
	var 30	Maintenance + Horizontal_Slab EPS 120mm	15,469 €	13,840 €	368.66 €	10.28	1	8.55	3	29.90	0.82	2.5	2.5	1	69.29	18.18%	0%
	var 31	Maintenance + Horizontal_Slab EPS 150mm	15,563 €	13,807 €	369.43 €	10.15	1	8.48	3	29.90	0.82	2.5	2.5	1	68.91	18.64%	0%
Windows	var 38	PVC_Frames_Windows. 2x low e	17,707 €	15,237 €	414.38 €	14.16	1	10.62	3	29.90	0.82	2.5	2.5	1	80.71	4.69%	0%
	var 39	Wooden_Windows. 2x low e	21,319 €	17,013 €	482.15 €	14.52	1	10.49	3	29.90	0.82	2.5	2.5	1	81.51	3.76%	0%
	var 40	PVC_Frames_Windows. 2x Standard	16,782 €	15,098 €	401.00 €	14.43	1	11.58	3	29.90	0.82	2.5	2.5	1	82.19	2.95%	0%
Packs + ref systems	[ETICS_EPS-60 mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [Standard Systems REF]	Package 1 - var 42	17,994 €	11,831 €	375.16 €	6.80	1	9.76	3	29.90	0.82	2.5	2.5	1	61.60	27.27%	0%
	[ETICS_EPS-80 mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [Standard Systems REF]	Package 2 - var 43	18,238 €	11,767 €	377.42 €	6.46	1	9.83	3	29.90	0.82	2.5	2.5	1	60.81	28.20%	0%
	[ETICS_EPS-100 mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [Standard Systems REF]	Package 3 - var 44	18,501 €	11,723 €	380.17 €	6.19	1	9.88	3	29.90	0.82	2.5	2.5	1	60.17	28.95%	0%
	[ETICS_EPS-60 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [Standard Systems REF]	Package 4- var 45	19,845 €	11,316 €	391.96 €	5.44	1	10.01	3	29.90	0.82	2.5	2.5	1	58.41	31.04%	0%
	[ETICS_EPS-80 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [Standard Systems REF]	Package 5 - var 46	20,122 €	11,262 €	394.76 €	5.12	1	10.10	3	29.90	0.82	2.5	2.5	1	57.68	31.89%	0%
	[ETICS_EPS-100 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [Standard Systems REF]	Package 6 - var 47	20,384 €	11,227 €	397.62 €	4.89	1	10.17	3	29.90	0.82	2.5	2.5	1	57.16	32.50%	0%

			Initial Global Cost	Exploration Cost (30	Total Cost (30 years)	Nic (kWh/m².year)		Nvc (kWh/m².year)		Nac (kWh/m².year)		Conversion Rates			(kWh/m².year)	n due to base	
			Private	Private	Private	Total	η	Total	η	Total	η	Nic	Nvc	Nac	Total	Total	
Pack 01: [ETICS_EPS-60 mm] + [Horizontal_Slab MW 100mm] + [REF Windows]	[ETICS_EPS-60 mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [Solar Collector + multi-split + water heater]	PAC 1 + S1 - var 48	22,536 €	11,798 €	431.87 €	6.80	4.9	9.76	5.17	29.90	0.92	2.5	2.5	1	16.98	79.95%	54%
	[ETICS_EPS-60 mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [heat pump]	PAC 1 + S2 - var 49	25,369 €	9,756 €	441.83 €	6.80	5.00	9.76	4.9	29.90	3.2	2.5	2.5	2.5	9.00	89.38%	72%
	[ETICS_EPS-60 mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [multi-split + DHW heat pump	PAC 1 + S3 - var 50	19,543 €	7,373 €	338.56 €	6.80	4.9	9.76	5.17	29.90	3.77	2.5	2.5	2.5	13.45	84.12%	78%
	[ETICS_EPS-60 mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [multi-split + DHW heat pump + PV]	PAC 1 + S4 - var 51	20,026 €	6,829 €	337.80 €	6.80	4.9	9.76	5.17	29.90	3.77	2.5	2.5	2.5	5.26	93.79%	90%
Pack 02 : [ETICS_EPS-80 mm] + [Horizontal_Slab MW 100mm] + [REF Windows]	[ETICS_EPS-80 mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [Solar Collector + multi-split + water heater]	PAC 2 + S1 - var 56	22,813 €	11,811 €	435.53 €	6.46	4.9	9.83	5.17	29.90	0.92	2.5	2.5	1	16.84	80.11%	54%
	[ETICS_EPS-80 mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [heat pump]	PAC 2 + S2 - var 57	25,646 €	9,836 €	446.32 €	6.46	5.00	9.83	4.9	29.90	3.2	2.5	2.5	2.5	8.97	89.41%	72%
	[ETICS_EPS-80 mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [multi-split + DHW heat pump	PAC 2 + S3 - var 58	19,820 €	7,386 €	342.21 €	6.46	4.9	9.83	5.17	29.90	3.77	2.5	2.5	2.5	13.31	84.29%	79%
	[ETICS_EPS-80 mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [multi-split + DHW heat pump + PV]	PAC 2 + S4 - var 59	20,303 €	6,842 €	341.46 €	6.46	4.9	9.83	5.17	29.90	3.77	2.5	2.5	2.5	5.26	94%	90%
Pack 03: [ETICS_EPS-100 mm] + [Horizontal_Slab MW 100mm] + [REF Windows]	[ETICS_EPS-100 mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] +[Solar Collector + multi-split + water heater]	PAC 3 + S1 - var 64	23,076 €	11,827 €	439.03 €	6.19	4.9	9.88	5.17	29.90	0.92	2.5	2.5	1	16.73	80%	54%
	[ETICS_EPS-100 mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [heat pump]	PAC 3 + S2 - var 65	25,909 €	9,862 €	449.95 €	6.19	5.00	9.88	4.9	29.90	3.2	2.5	2.5	2.5	8.94	89%	72%
	[ETICS_EPS-100 mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [multi-split + DHW heat pump]	PAC 3 + S3 - var 66	20,082 €	7,402 €	345.71 €	6.19	4.9	9.88	5.17	29.90	3.77	2.5	2.5	2.5	13.19	84%	79%
	[ETICS_EPS-100 mm] + ['Horizontal_Slab MW 100mm] + [REF Windows] + [multi-split + DHW heat pump + PV]	PAC 3 + S4 - var 67	20,566 €	6,858 €	344.95 €	6.19	4.9	9.88	5.17	29.90	3.77	2.50	2.50	2.50	5.26	94%	91%
Pack 04: [ETICS_EPS-60 mm] + [Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard]	[ETICS_EPS-60 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [Solar Collector + multi-split + water heater]	PAC 4 + S1 - var 72	24,419 €	11,594 €	452.99 €	5.44	4.9	10.01	5.17	29.90	0.92	2.5	2.5	1	16.41	81%	54%
	[ETICS_EPS-60 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [heat pump]	PAC 4 + S2 - var 73	27,253 €	9,660 €	464.31 €	5.44	5.00	10.01	4.9	29.90	3.2	2.5	2.5	2.5	8.89	90%	72%
	[ETICS_EPS-60 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [multi-split + DHW heat pump	PAC 4 + S3 - var 74	21,426 €	7,168 €	359.68 €	5.44	4.9	10.01	5.17	29.90	3.77	2.5	2.5	2.5	12.87	85%	80%
	[ETICS_EPS-60 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [multi-split+DHW heat pump + PV]	PAC 4 + S4 - var 75	21,910 €	6,625 €	358.92 €	5.44	4.9	10.01	5.17	29.90	3.77	2.50	2.50	2.50	5.26	94%	92%

			Initial Global Cost	Exploration Cost (30	Total Cost (30 years)	Nic (kWh/m².year)		Nvc (kWh/m².year)		Nac (kWh/m².year)		Conversion Rates			(kWh/m².year)	n due to base	
			Private	Private	Private	Total	η	Total	η	Total	η	Nic	Nvc	Nac	Total	Total	
Pack 05: [ETICS_EPS-80 mm] + [Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard]	[ETICS_EPS-80 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [Solar Collector + multi-split + water heater]	PAC 5 + S1 - var 80	24,696 €	11,610 €	456.69 €	5.12	4.9	10.10	5.17	29.90	0.92	2.5	2.5	1	16.29	81%	55%
	[ETICS_EPS-80 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [heat pump]	PAC 5 + S2 - var 81	27,530 €	9,688 €	468.14 €	5.12	5.00	10.10	4.9	29.90	3.2	2.5	2.5	2.5	8.86	90%	72%
	[ETICS_EPS-80 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [multi-split + DHW heat pump	PAC 5 + S3 - var 82	21,703 €	7,185 €	363.37 €	5.12	4.9	10.10	5.17	29.90	3.77	2.5	2.5	2.5	12.75	85%	80%
	[ETICS_EPS-80 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard]+ [multi-split+DHW heat pump + PV]	PAC 5 + S4 - var 83	22,187 €	6,641 €	362.61 €	5.12	4.9	10.10	5.17	29.90	3.77	2.50	2.50	2.50	5.26	94%	92%
Pack 06: [ETICS_EPS-100 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard]	[ETICS_EPS-100 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [Solar Collector + multi-split + water heater]	PAC 6 + S1 - var 88	24,959 €	11,628 €	460.21 €	4.89	4.9	10.17	5.17	29.90	0.92	2.5	2.5	1	16.20	81%	55%
	[ETICS_EPS-100 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [heat pump]	PAC 6 + S2 - var 89	27,792 €	9,714 €	471.77 €	4.89	5.00	10.17	4.9	29.90	3.2	2.5	2.5	2.5	8.85	90%	72%
	[ETICS_EPS-100 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [multi-split + DHW heat pump	PAC 6 + S3 - var 90	21,966 €	7,203 €	366.89 €	4.89	4.9	10.17	5.17	29.90	3.77	2.5	2.5	2.5	12.67	85%	81%
	[ETICS_EPS-100 mm] + ['Horizontal_Slab MW 100mm] + [PVC Frame + double glass standard] + [multi-split+DHW heat pump + PV]	PAC 6 + S4 - var 91	22,449 €	6,659 €	366.14 €	4.89	4.9	10.17	5.17	29.90	3.77	2.5	2.5	2.5	5.26	94%	93%

Annex 4 – Solar systems

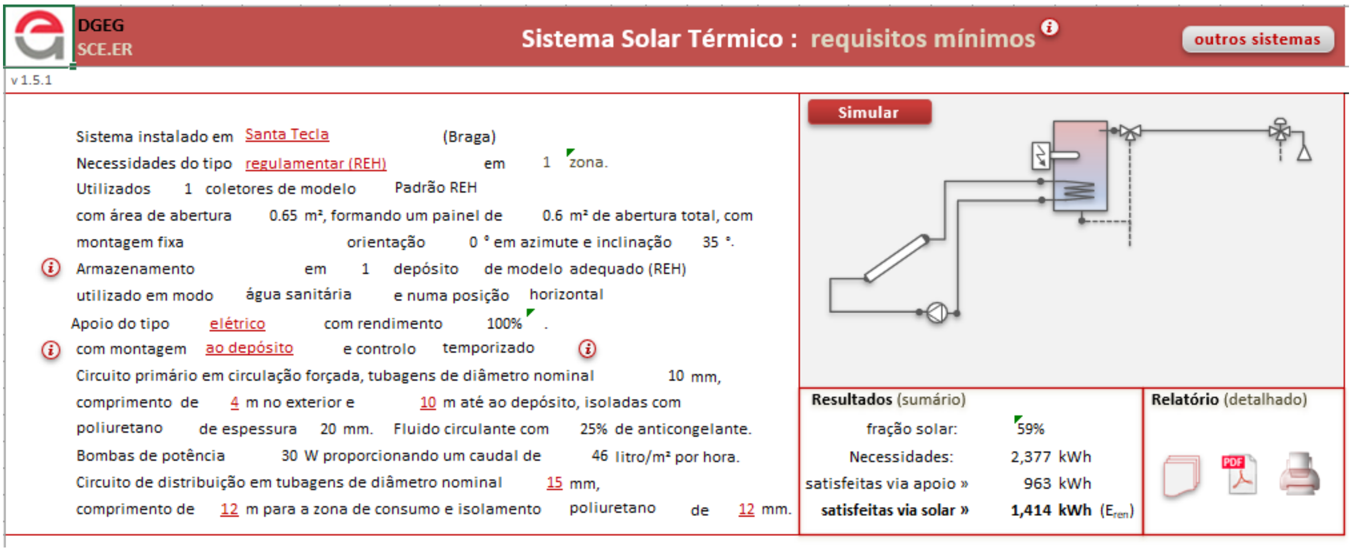

Figure 85: SCE – Thermal solar system – minimum requirement

Figure 86: Thermal solar system (JUNKERS TSS300 FCC-2)

[145]

Gama	Excellence		Comfort		Smart
Modelo	**FKT-2 S**	**FKT-2 W**	**FKC-2 S**	**FKC-2 W**	**FCC-2 S**
Montaje	vertical	horizontal	vertical	horizontal	vertical
Dimensiones: ancho x alto x fondo [mm]	1.175x2.170x87	2.170x1.175x87	1.175x2.017x87	2.017x1.175x87	1.032x2.026x67
Área total [m²]	2,55	2,55	2,37	2,37	2,09
Área de apertura [m²]	2,43	2,43	2,25	2,25	1,94
Área del absorbedor [m²]	2,35	2,35	2,18	2,18	1,92
Volumen del absorbedor [l]	1,6	1,96	0,94	1,35	0,8
Peso en vacío [kg.]	44,8	44,8	40	40	30
Presión trabajo máx. [bar]	10	10	6	6	6
Caudal nominal [l/h]	50	50	50	50	50
Carcasa	Fibra de vidrio con tecnología SMC	Fibra de vidrio con tecnología SMC	Fibra de vidrio con tecnología SMC	Fibra de vidrio con tecnología SMC	Aluminio
Aislamiento	Lana mineral, de 55 mm de espesor	Lana mineral, de 55 mm de espesor	Lana mineral, de 55 mm de espesor	Lana mineral, de 55 mm de espesor	Lana mineral, 25 mm
Absorbedor	Altamente selectivo	Altamente selectivo	Altamente selectivo	Altamente selectivo	Altamente selectivo
Recubrimiento absorbedor	PVD	PVD	PVD	PVD	PVD
Circuito hidráulico	Doble serpentín	Doble serpentín	Parrilla de tubos	Parrilla de tubos	Parrilla de tubos
Curva de rendimiento instantáneo según EN 12975-2 (basada en el área de apertura)					
Factor de eficiencia η_0	0,79	0,802	0,766	0,77	0,761
Coef. pérdidas línea [W/m² K]	3,86	3,833	3,216	3,871	4,083
Coef. pérdidas secundaria [W/m² K²]	0,013	0,015	0,015	0,012	0,012

Figure 87: Datasheet – thermal solar system (JUNKERS TSS300 FCC-2)

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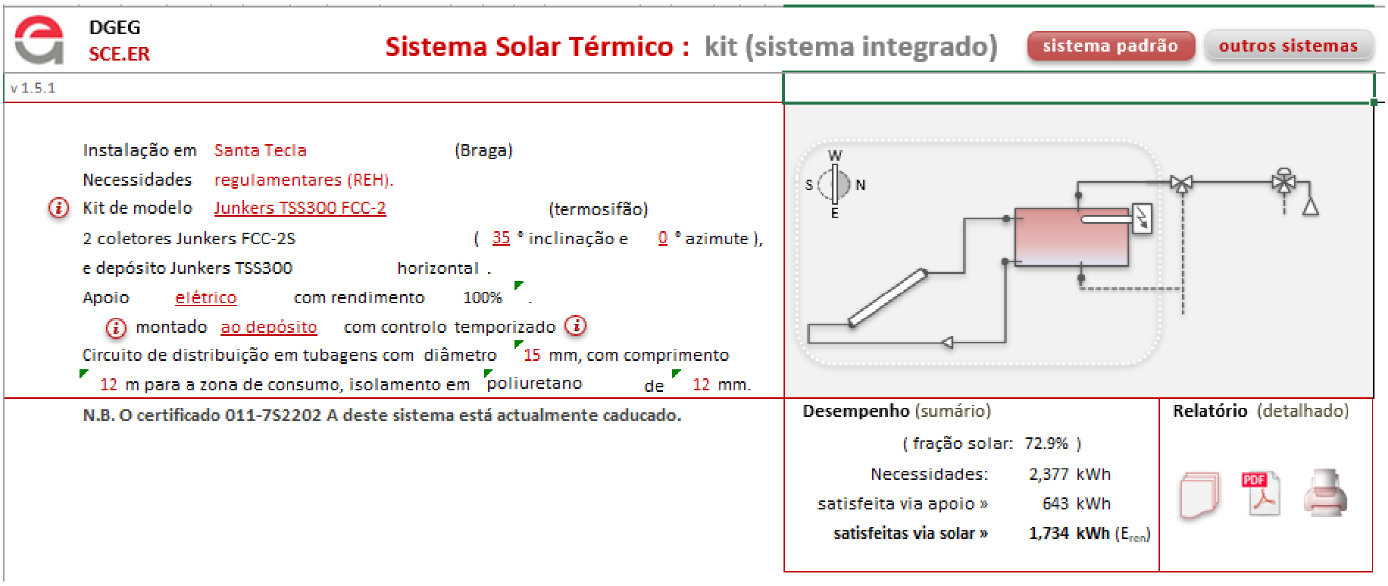


Figure 88: SCE – thermal solar system (JUNKERS TSS300 FCC-2)

Performance of grid-connected PV

European Commission

PVGIS-5 estimates of solar electricity generation:

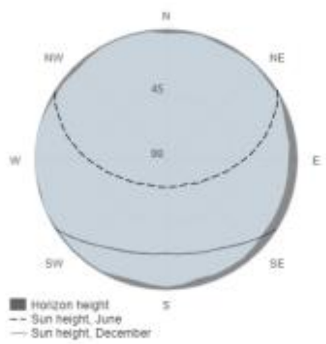
Provided inputs:

Latitude/Longitude:	41.550, -8.410
Horizon:	Calculated
Database used:	PVGIS-SARAH
PV technology:	Crystalline silicon
PV installed:	0.18 kWp
System loss:	14 %

Simulation outputs

Slope angle:	35 °
Azimuth angle:	0 °
Yearly PV energy production:	258.27 kWh
Yearly in-plane irradiation:	1828.04 kWh/m²
Year-to-year variability:	11.51 kWh
Changes in output due to:	
Angle of incidence:	-2.74 %
Spectral effects:	0.78 %
Temperature and low irradiance:	-6.88 %
Total loss:	-21.51 %

Outline of horizon at chosen location:



Monthly energy output from fix-angle PV system:

Monthly in-plane irradiation for fixed-angle:

Monthly PV energy and solar irradiation

Month	E_m	H(i)_m	SD_m
January	14.5	96.4	4.1
February	17.2	115.7	4.4
March	21.5	148.0	4.1
April	23.0	162.6	2.3
May	25.7	184.9	2.6
June	25.9	189.1	1.8
July	28.4	209.8	1.5
August	28.1	207.1	2.2
September	24.8	180.6	2.5
October	19.2	134.2	3.2
November	15.1	101.8	3.3
December	14.7	97.8	2.2

E_m: Average monthly electricity production from the given system [kWh].

H(i)_m: Average monthly sum of global irradiation per square meter received by the modules of the given system [kWh/m²].

SD_m: Standard deviation of the monthly electricity production due to year-to-year variation [kWh].

Figure 89: Performance of the grid-connected photovoltaic system

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ANNEX 5 – VARIATION OF CLIMATIC PARAMETERS (CCWORLDWEATHERGEN)

Summary of combined HadCM3 A2 ensemble climate change predictions for the selected weather site

Selected scenario: A2 scenario ensemble for the 2020's

			JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Daily mean temperature	**TEMP**	(°C)	0.49	0.50	0.43	0.46	0.78	0.82	0.85	1.11	0.90	1.00	0.35	0.25	0.66
Maximum temperature	**TMAX**	(°C)	0.56	0.59	0.42	0.53	0.96	1.05	1.15	1.23	1.05	1.13	0.37	0.36	0.78
Minimum temperature	**TMIN**	(°C)	0.47	0.41	0.41	0.36	0.61	0.60	0.55	0.92	0.77	0.88	0.34	0.20	0.54
Horizontal solar irradiation	**DSWF**	W/m²	0.76	1.41	-1.24	4.58	8.23	6.19	5.92	3.05	4.04	2.60	1.64	1.62	3.23
Total cloud cover	**TCLW**	% points	0.38	-0.50	0.00	1.13	-1.50	-1.88	-2.63	-2.38	-2.88	-1.63	-2.13	-3.00	-1.42
Total precipitation rate	**PREC**	%	0.14	-6.47	5.69	-11.15	-18.01	-23.72	-15.33	-2.99	-27.47	-3.96	-3.48	-2.35	-9.09
Relative humidity	**RHUM**	% points	-0.11	-0.20	-0.69	-1.02	-0.97	-1.84	-2.41	-2.19	-1.49	-0.87	-0.52	-0.84	-1.10
Mean sea level pressure	**MSLP**	hpa	-0.06	0.47	-2.08	1.89	0.10	-0.59	-0.58	-1.28	0.24	-0.18	-0.92	-1.53	-0.38
Wind speed*	**WIND**	%	0.35	-1.54	2.37	0.69	1.44	1.15	4.39	1.76	2.19	-2.00	0.57	0.33	0.97

* Please note that wind speed resides on a 96x72 grid whilst all the other data is on a 96x73 grid

Figure 90: Variation of climatic parameters for weather file "085450" (2020)

Summary of combined HadCM3 A2 ensemble climate change predictions for the selected weather site

Selected scenario: A2 scenario ensemble for the 2050's

			JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Daily mean temperature	**TEMP**	(°C)	1.57	1.54	1.23	1.41	1.77	2.47	2.94	2.78	2.50	2.23	1.43	1.30	1.93
Maximum temperature	**TMAX**	(°C)	1.51	1.62	1.22	1.54	2.55	3.00	3.62	3.21	2.91	2.20	1.49	1.25	2.18
Minimum temperature	**TMIN**	(°C)	1.25	1.56	1.33	1.14	1.55	1.75	2.02	2.19	2.28	1.89	1.30	1.35	1.63
Horizontal solar irradiation	**DSWF**	W/m²	-1.78	-2.05	2.17	11.75	14.80	15.85	17.51	11.98	7.53	6.91	2.25	-0.23	7.22
Total cloud cover	**TCLW**	% points	5.13	1.13	-3.38	-3.38	-4.00	-5.38	-7.88	-6.25	-5.13	-5.38	-3.38	-1.00	-3.24
Total precipitation rate	**PREC**	%	5.60	4.68	-3.37	-17.69	-35.96	-31.40	-22.79	-29.46	-26.17	-23.55	-11.33	2.39	-15.75
Relative humidity	**RHUM**	% points	0.98	0.02	-1.43	-2.57	-3.27	-4.67	-6.27	-5.30	-3.80	-2.49	-1.17	-0.80	-2.56
Mean sea level pressure	**MSLP**	hpa	1.60	-0.38	-1.89	-0.10	-0.26	-1.00	-2.33	-1.69	-1.09	-0.87	0.26	-2.57	-0.86
Wind speed*	**WIND**	%	0.46	-0.40	0.58	0.80	4.99	6.84	8.17	4.29	2.04	-2.89	-2.45	0.41	1.90

* Please note that wind speed resides on a 96x72 grid whilst all the other data is on a 96x73 grid

Figure 91: Variation of climatic parameters for weather file "085450" (2050)