Renovation Passport towards a Near Zero Energy Building

Carmen Margarida Fernandes Machado

Thesis to obtain the Master of Science Degree in

Mechanical Engineering

Supervisor: Prof. Paulo Manuel Cadete Ferrão

Examination Committee

Chairperson: Prof. Edgar Caetano Fernandes
Supervisor: Prof. Paulo Manuel Cadete Ferrão
Member of the Committee: Prof. Carlos Augusto Santos Silva

January 2021

Aos meus pais e avós.

Declaration

I declare that this document is an original work of my own authorship and that it fulfils all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

Acknowledgments

A realização desta tese com a supervisão do professor Paulo Ferrão foi um verdadeiro privilégio, pois tive a oportunidade de aprender muito com o professor, que me transmitiu conhecimentos essenciais para a concretização deste trabalho, mas também me despertou para outras áreas científicas, com as quais não tinha contactado de perto. Gostaria de agradecer ao professor Paulo Ferrão toda a disponibilidade, apoio, inspiração e orientação que me proporcionou ao longo da realização desta tese.

Gostaria também de agradecer ao Eng. Ricardo Gomes, por todo o apoio prestado na introdução a como trabalhar com softwares como o EnergyPlus, bem como todas as discussões e trocas de ideias, fundamentais para a realização da tese, para as quais esteve sempre disponível. Do mesmo modo, gostaria de agradecer ao Eng. Mário Matos pelas orientações iniciais e introduções à temática da certificação energética de edifícios, bem como da monitorização dos consumos energéticos, também nos edifícios.

Durante a execução deste trabalho tive a oportunidade de ingressar na ADENE - Agência para a Energia - enquanto bolseira de investigação, onde pude desenvolver os meus conhecimentos sobre eficiência energética e hídrica, com o apoio fundamental dos meus colegas e mentores aos quais gostaria de deixar uma palavra de gratidão. Aproveito também para agradecer à ADENE por ter disponibilizado alguma da informação utilizada nesta tese.

Aos meus colegas e amigos na GALP, em particular, na Refinaria de Sines, queria deixar uma palavra de agradecimento por todas as aprendizagens, apoio e incentivo que me proporcionaram, sendo que foram esses os factores que fizeram do meu primeiro contacto com o mundo profissional uma verdadeira experiência enriquecedora.

Aos meus pais e avós gostaria de deixar um agradecimento profundo por todo o apoio e carinho incondicional de sempre e para sempre.

Ao José, por todo o carinho, motivação e por ter sido o verdadeiro companheiro nesta aventura que foi escrever as nossas teses de mestrado. Que continuemos a partilhar novas aventuras e conquistas.

À Maria, a minha amiga de sempre, por todo o incentivo, motivação e cumplicidade infindável.

Aos meus amigos, que comigo partilharam este percurso académico, que culmina neste trabalho. Obrigada por todas as boas e divertidas memórias que criámos durante estes anos. A muitas mais!

Resumo

Neste trabalho é proposto um enquadramento para implementar um esquema nacional de promoção à eficiência energética e neutralidade carbónica em edifícios, baseado no conceito de passaporte de renovação de edifícios, com ênfase em edifícios residenciais. O conceito visa a concretização do objectivo de tornar um edifício num edifício de necessidades quase nulas de energia (NZEB, em inglês Near Zero Energy Building). Este novo esquema é baseado e construído sobre o esquema nacional em vigor, o Sistema de Certificação Energética dos Edifícios e sobre a sua estrutura já existente (por exemplo, como é o caso dos peritos qualificados - PQ). O conceito de passaporte de renovação é proposto como uma plataforma digital, que apresenta informação e aconselha o proprietário/ utilizador do edifício sobre a oportunidade de implementar medidas de reabilitação de edifícios, embora a plataforma possa ser acedida por vários utilizadores, com diferentes propósitos. Propõe-se alcançar o objectivo principal, um edifício neutro em carbono, de necessidades quase nulas de energia, atingindo 3 etapas de renovação e reabilitação, a primeira que se foca na melhoria da eficiência e performance energética, a segunda na implementação de tecnologias de conversão de energia renovável *in situ* e a terceira e última, com foco em atingir o edifício NZEB e neutro em carbono, alinhadas com as estratégias nacionais actuais, como a ELPRE (Estratégia de Longo Prazo para a Renovação de Edifícios), o PNEC (Plano Nacional Integrado Energia e Clima 2021-2030) e o RNC 2050 (Roteiro para a Neutralidade Carbónica 2050).

Palavras-chave: Passaporte de Renovação, Edifício de Necessidades Quase Nulas de Energia, Edifício Neutro em Carbono, Medidas de Melhoria de Performance Energética, Etapas de Renovação.

Abstract

In this work, a framework to implement a national scheme to promote energy efficient and carbon neutral buildings, based on the concept of building renovation passport, with emphasis on residential buildings, is proposed. The concept aims to achieve a near zero energy building (NZEB) and carbon neutral building, built upon the already existing energy performance certificate (EPC) scheme (in Portuguese, Sistema de Certificação Energética dos Edifícios) and its infrastructure (eg. the qualified experts - QE). The concept of the renovation passport is proposed as a digital platform, which displays information and advises the building owner/user about the opportunity to implement building rehabilitation measures, despite being accessible to several different users, with different purposes. The main goal of a carbon neutral NZEB is proposed to be achieved by reaching 3 renovation and rehabilitation milestones, the first is focused on energy efficiency and performance improvement, the second, on *in situ* renewable energy conversion technologies implementation and the third and last, focused on reaching the carbon neutral NZEB, aligned with current national strategies, such as ELPRE (Estratégia de Longo Prazo para a Renovação de Edifícios, in English, Long Term Strategy for Building Renovation), PNEC (Plano Nacional Integrado Energia e Clima 2021-2030, in English, National Integrated Plan for Energy and Climate) and RNC 2050 (Roteiro para a Neutralidade Carbónica 2050, in English, Carbon Neutrality Road Map).

Keywords: Renovation Passport, Near Zero Energy Building, Carbon Neutral Building, Energy Performance Improvement Measures, Renovation Milestones.

Contents

List of Tables

List of Figures

List of Acronyms

ADENE Agência para a Energia / Portuguese Energy Agency. xvii, 17, 18, 40, 41, 47, 53, 57, 68, 71, 72, 80

ASHRAE American Society of Heating, Refrigerating and Air-Conditioning Engineers. 38

BIM Building Information Modelling. xx, 39, 40, 50, 56, 60–62, 78

CEB Council of Europe Development Bank. 55

COP Coefficient of Performance. 70

DGEG Direcção-Geral de Energia e Geologia / Directory General for Energy and Geology. xvii, 46, 47, 76

DHW Domestic Hot Water. 18, 49, 67, 68, 70, 76

ELPRE Estratégia de Longo Prazo para a Renovação de Edifícios / Long Term Strategy for Building Renovation. xx, 2, 32, 33, 54, 59, 68

EPBD Energy Performance in Buildings Directive. 1, 21

EPC Energy Performance Certificate. 2, 3, 19, 22, 29–31, 33–37, 39–41, 53, 54, 56, 57, 59–61, 67, 68, 70, 71, 75, 76, 79, 80

EU European Union. 1, 2, 6, 20, 21, 24, 27, 31, 57

FEE Fundo de Eficiência Energética / Energy Efficiency Fund. 54, 55

GDPR General Data Protection Regulation. 63

GHG Greenhouse Gas(es). 1, 5, 33, 36

HVAC Heating, Ventilating and Air-Conditioning. xx, 42–44

IEA International Energy Agency. 57

IFRRU 2020 Instrumento Financeiro de Reabilitação e Revitalização Urbanas / Financial Tool for Urban Rehabilitation and Revitalisation. 54, 55

IMI Imposto Municipal sobre Imóveis / Municipal Property Tax. 34, 35

IMT Imposto Municipal sobre Transmissões Onerosas de Imóveis / Municipal Tax on Property Onerous Transfer. 34, 35

INE Instituto Nacional de Estatística / Statistics Portugal. 47

IoT Internet of Things. 50, 56, 60–63, 78

IPCC Intergovernmental Panel on Climate Change. 2, 5, 6, 46, 57

NZEB Near Zero Energy Building. xix, 2, 3, 6–8, 10–12, 29–31, 33, 36, 37, 45, 47–49, 56, 60, 71, 75, 79, 80

PED Positive Energy District. 80

PNEC Plano Nacional Integrado Energia e Clima 2021-2030 / National Integrated Plan for Energy and Climate 2021-2030. 2, 31, 33, 55, 59

PORDATA Base de Dados Portugal Contemporâneo / Present-day Portugal Database. 47

PQ Perito Qaulificado / Qualified Expert. 17, 30

PV Photovoltaic. 7, 75

QE Qualified Expert / from the Portuguese "Perito Qualificado". 30, 35, 37, 40, 44, 45, 47–54, 56, 57, 59, 61, 65, 67, 68, 71, 76, 78, 79

RECT Renewable Energy Conversion Technology(ies). xviii, xx, 8–11, 13, 14, 29–33, 36, 37, 47–49, 53, 67, 71, 74–78, A1

RNC 2050 Roteiro para a Neutralidade Carbónica 2050 / Carbon Neutrality Road Map 2050. xx, 2, 31, 33, 34, 59

SCE Sistema de Certificação Energética de Edifícios / Building Energy Certification System. xvii, 17, 41, 68, 71

SCOP Seasonal Coefficient of Performance. 70

SDG Sustainable Development Goal(s). 3, 57

SEER Seasonal Energy Efficiency Ratio. 70

SI The International System of Units. 19

SME Small and Medium Enterprise. 2

ZEB Zero Energy Building. 7–11, 13

Chapter 1

Introduction

1.1 Motivation & Purpose

This work is motivated by the will to contribute to the objectives of the European Green Deal and is particularly focused in near zero energy buildings, namely, already-existing residential buildings, in cities.

The European Green Deal [1], ”aims to transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use” . The European Green Deal acts as an instrument to facilitate the adoption of the EU Directive 2018/844 (commonly referred to as EPBD, Energy Performance of Buildings Directive) by EU Member States, which, among others, focuses on achieving ”a highly energy efficient and decarbonised building stock and to ensure that the long-term renovation strategies deliver the necessary progress towards the transformation of existing buildings into nearly zero-energy buildings, in particular by an increase in deep renovation” [2].

Clarifying some concepts, net zero emissions of greenhouse gases (GHG) describes the process of globally balancing, over a specified period, the anthropogenic GHG emission by eliminating said gases from the atmosphere through natural (land, forest and oceans) and artificial (carbon capture, direct air capture, storage and possible utilisation) ways of removing as well as avoiding their emission altogether (by converting energy from renewable, non-GHG-emitting sources) (adapted from [3])[1].

Moreover, resource efficiency can be understood as ”using the Earth’s limited resources in a sustainable manner while minimising impacts on the environment”, which makes it possible to ”create more with less and to deliver greater value with less input” [4].

Understanding what is proposed by both of the concepts described above (net zero GHG emissions and resource efficiency), the main contribution this work intends to deliver is to propose a new framework, for a national scheme implementation, that may contribute to achieve carbon neutral buildings by 2050 (as intended by the EU [5], in the European Climate Law), in Portugal. The purpose is to build from the already existing national scheme on energy efficiency improvement on buildings, the Energy

[1] ”Net zero CO_2 emissions: Net zero carbon dioxide (CO_2) emissions are achieved when anthropogenic CO_2 emissions are balanced globally by anthropogenic CO_2 removals over a specified period.” [3]

Performance Certificate (EPC), which classifies the building, as is, according to its energy performance and suggests measures to improve said performance, ultimately, to achieve the highest classification possible.

Adding to that, the building renovation rate, in the EU, which is currently ”0.4 to 1.2%” [1] would need to ”double to reach the EU’s energy efficiency and climate objectives” [1]. Also, the EU intends to use building renovation to address ”the twin challenge of energy efficiency and affordability” [1], which, while presenting challenges associated with renovation itself, promotes lower energy bills, the reduction of energy poverty, and stimulates the construction sector, as well as small and medium enterprises (SME) and local jobs [1]. Besides being in line with EU carbon neutrality and building energy performance improvement commitments, this thesis, by proposing the Renovation Passport, as a framework for a national carbon neutral buildings scheme (by 2050), would also be aligned with the National Energy Climate Plan 2021-2030 (Plano Nacional Integrado Energia e Clima - PNEC), for Portugal, whose ”strategy for long term renovation of the national residential and non-residential building stock, both public and private” aims to ”promote the building stock’s energy renovation and the NZEB” (adapted from [6]). The Long Term Strategy for Building Renovation (Estratégia de Longo Prazo para a Renovação de Edifícios - ELPRE), which aims to rehabilitate and increase the energy efficiency of buildings, reduce energy bills and dependence and improve levels of comfort, air quality, health benefits, work productivity and reduce energy poverty levels, as well as stating the execution of the national goals on energy and climate are inseparable from building renovation (adapted from [7]), and finally, the Carbon Neutrality Road Map 2050 (Roteiro para a Neutralidade Carbónica 2050 - RNC 2050), which aims to identify the pathways for decarbonisation and carbon neutrality by 2050 (adapted from [8]), an effort of which the built environment is part of, do also inspire the building Renovation Passport strategy.

Since isolated energy efficiency measures, *per se* are not enough to achieve the 2050 goal of carbon neutrality, the proposed framework presents the Renovation Passport as the scheme to adopt to, not only improve the building’s energy efficiency, but also to take a step forward and create a plan, which guides the building owner/user to take the necessary steps to achieve a near zero energy building (NZEB) along the building life cycle. The Renovation Passport aims to set clear milestones that the building should reach, by certain dates, to ultimately achieve carbon neutrality, along with offering guidance on what actions to take and the kind of maintenance needed to ensure a correct functioning of the building and its systems.

The Renovation Passport is introduced as a voluntary scheme to be implemented by building owners/users. However, as a national scheme to be implemented with associated legislation, it is proposed to offer tax compensations to buildings which reach the milestones and tax aggravations, to those which do not.

The need for building renovation, to improve its energy performance and reach NZEB is further reinforced by the fact that, according to the IPCC, ”in 2014, the buildings sector accounted for 31% of total global final energy use, 54% of final electricity demand, and 8% of energy-related CO_2 emissions (excluding indirect emissions due to electricity)” [9]. When accounting for CO_2 emissions from electricity generation that number jumps to ”23% of global energy-related CO_2 emissions, with one-third of those from direct fossil fuel consumption” [9].

On a final note, it is also the intention of this work to be consistent with the Sustainable Development Goals (SDG), namely, SDG 7, ”access to affordable, reliable, sustainable and modern energy for all” [10], SDG 11, ”inclusive, safe, resilient and sustainable” ”cities and communities” [11] and, lastly, SDG 13, ”urgent action to combat climate change and its impacts” [12].

1.2 Overview

This thesis is divided in 6 chapters. The first, Introduction, discusses the motivation and the purpose of this work. The second, Literature Review, addresses important concepts that help shape the definition of the new renovation passport national scheme, towards a carbon neutral NZEB, such as the need for climate change mitigation, the definition and best practices for NZEB and a pathway to identify the most cost-efficient and better suited energy performance improvement measures. Furthermore, the current national Energy Performance Certificate (EPC) scheme is presented as well as other European initiatives and projects, which address issues covered by the renovation passport, such as the building logbook, tackled by the iBRoad project and building sustainability, covered by the Level(s) Framework.

The third chapter, Methodological Framework, introduces the proposed idea of how to develop the new renovation passport scheme, based on the already existing EPC scheme, by presenting each of the 6 components proposed for the renovation passport, Milestones which need to be covered to achieve a carbon neutral NZEB and fiscal incentives that could be granted if the milestones are accomplished; Physical and Technical Characteristics of the Building; Energy Performance Improvement and Near Zero Energy Building. The latter’s implementation includes a three step process before reaching the Near Zero Energy Renovated Building; Inspection & Audit; Maintenance & Construction and Building Owner/User, where the different possible renovation passport users are presented, as well as potential funding means which may be accessed to cover the investment costs.

The fourth chapter presents the renovation passport concept as a digital platform which acts as an information repository and that advises the building owner/user about alerts and notifications, regarding construction, maintenance, inspection and energy performance. It further proposes how the different components of the renovation passport could interact with each other, inside this digital platform.

Then, on chapter five, a case study is presented, where the methodology proposed on chapter three is tried and tested and finally, on chapter six, the final remarks, considerations and conclusions are discussed.

Chapter 2

Literature Review

2.1 Climate Change Mitigation

Before focusing on a building user/owner point of view on energy use and consumption, one needs to widen their perspective, in order to better understand the scope of the problem associated with energy, on a global scale. Energy, for the average citizen, is seen as a consumable good which translates into services such as thermal comfort (space heating and cooling), transportation, personal hygiene (hot water), food preparation (cooking and warming), technology and entertainment access, lighting, appliances functionalities, etc. That consumable good can be acquired in many forms, like fuels (diesel, gasoline, natural gas, etc) or electricity. Therefore, energy, in its many forms, is perceived as the key to keep the world, and its citizens, with their activities, running.

Moreover, besides being a basic need to sustain civilisations, as we know them, energy is, in itself, an indicator of wealth, security, prosperity and sovereignty of a country and, as such, it has become a target, under the eyes of the United Nations, as a Sustainable Development Goal to be met by 2030, to ”ensure universal access to affordable, reliable and modern energy services” [10].

Humans have been making use of energy for millennia, but most notably and more intensely, since the industrial revolution, which drove to a fast economical, scientific and population development. That development needed to be backed up by enough resources (primary energy, food, water) to provide for the growing population which in turn, put an enormous amount of pressure on the natural environment, as those resources were (and still are) being depleted much faster than they can renew themselves.

This pressure causes the destruction of several habitats/environments and the biodiversity associated to them, and does also include a significant contribution to GHG emissions, and therefore to climate change.

The factual data has been agreed upon by the international scientific community, which clearly indicates humans, and their activities, are responsible for the changes in climate, during the last decades. According to IPCC, ”anthropogenic greenhouse gas emissions have increased since the pre-industrial era, driven largely by economic and population growth, and are now higher than ever. This has led to atmospheric concentrations of carbon dioxide, methane and nitrous oxide that are unprecedented in at least the last 800,000 years. Their effects, together with those of other anthropogenic drivers, have been detected throughout the climate system and are extremely likely to have been the dominant cause of the observed warming since the mid-20th century" [13].

Since global warming and climate change are already on-going phenomena, humanity must turn its mind and efforts to adaptation and mitigation, imposing new laws and goals to reduce emissions, primary and final energy consumption, improve energy efficiency, etc, in order to minimise climate change.

Consequently, investment and research should be made on several solutions (solutions, since there is not a single solution which can solve every current climate change related issue), all of them working towards the same goal. It is, as one of these solutions, that energy use in buildings comes into the picture and, particularly, the need to renovate the existing building estate towards lower energy consumption and higher energy self-sufficiency.

According to the IPCC team, led by Rogelj *et al.*, "the largest energy savings potential is in heating and cooling demand, largely due to building envelope improvements and high efficiency and renewable equipment" [9], claiming that "energy savings from shifts to high-performance lighting, appliances, and water heating equipment account for a further 24% of the total reduction" [9].

Still as stated by this team, CO_2 emissions and energy consumption reduction can be achieved through further "adoption of energy-efficient technologies such as heat pumps and, more recently, light-emitting diodes" [9], "integrated and renewable energy technologies (with clean power generation)" [9], as well as "consumer choices, behaviour and building operation" [9]. In figure **??**, an example of some climate change mitigation measures for the buildings sector, is illustrated.

Upon the urgent need to act on "very long-living infrastructure", which characterises much of what is found in most European Union countries, urgent developments and measures need to be taken. However one must proceed with caution, opting for the "most advanced renovation technologies", in order to "avoid lock-in into less efficient measures", as well as avoiding the persistence of "inefficient carbon and energy-intensive buildings" [9].

2.2 Near Zero Energy Building

2.2.1 Definition

As reported by the European Directive 2010/31/EU, concerning energy performance of buildings, a near zero energy building, also referred to as a "nearly zero-energy building", is used to describe a building which "has a very high energy performance". "The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby" [14].

Several approaches on definitions for near zero energy buildings (NZEB) have been considered and many methods are used to calculate energy balances within those buildings. D'Agostino, on her paper "Assessment of the progress towards the establishment of definitions of Nearly Zero Energy Buildings (nZEBs) in European Member States" [15], summarises a few of those definitions and methods, that will be described hereafter.

First of all, the term ”NZEB” can refer both to ”near zero energy building” (this definition addresses energy consumption in building operation) or ”near zero emissions building” (this definition addresses carbon emissions as a result of building operation) [15]. In this thesis, when talking about NZEBs, the first description should be considered.

Another definition for NZEB can be a ”residential or commercial building with greatly reduced energy needs and/or carbon emissions”, with the low amount of energy being ”achieved through efficiency gains” and ”supplied by renewable energy” [15].

NZEBs can be characterised according to their grid connection [15], as described below:

1. **Autonumous ZEB:** This building ”does not require connection to the grid”, as they can ”supply their own energy needs” by being able to ”store energy for night-time or winter-time use” [15].

2. **Net ZEB:** This is a ”yearly energy neutral building”, as it supplies, to the grid, as much energy as it consumes. It does not use any kind of fossil fuel for ”heating, cooling, lighting or other energy uses” [15].

3. **+ZEB:** This is a ”energy plus building”, as it supplies, to the grid, more energy than it consumes [15].

NZEBs can also be characterised according to the ”energy demand and installed renewable typology” considered [15], as described below. A zero energy building (ZEB) is a more general abbreviation which includes the several definitions presented henceforth.

1. **PV ZEB:** This building has a ”relatively small electricity demand and a photovoltaic installation” [16].

2. **Wind ZEB:** This building has a ”relatively small electricity demand and a small on-site wind turbine” [16].

3. **PV-SolarThermal-HeatPump ZEB:** This building has a ”relatively small heat and electricity demand and a photovoltaic installation in combination with a solar thermal collector, a heat pump and heat storage” [16].

4. **Wind-SolarThermal-HeatPump ZEB:** This building has a ”relatively small heat and electricity demand and a wind turbine in combination with a solar thermal collector, a heat pump and heat storage” [16].

Moreover, a ZEB can be defined based on the ”boundary and metric” [17] methods considered, as presented below. Each of the definitions is more appropriate than others for a specific end, ”depending on the project goals and the values of the design team and building owner” [17].

1. **Net Zero Site Energy Building:** This building ”produces at least as much energy as it uses in a year, when accounted for at the site” [17], hence, considering final energy.

2. **Net Zero Source Energy Building:** This building "produces at least as much energy as it uses in a year, when accounted for at the source"[1] [17].

3. **Net Zero Energy Costs Building:** For this building "the amount of money the utility pays the building owner for the energy the building exports to the grid is at least equal to the amount the owner pays the utility for the energy services and energy used over the year" [17].

4. **Net Zero Energy Emissions Building:** This building "produces at least as much emissions-free renewable energy as it uses from emissions-producing energy sources" [17].

5. **Off-site ZEB:** For a off-site zero energy building, renewable energy is purchased from off-site sources[2] and for an off-site zero emission building, emissions credits are purchased instead [17].

Lastly, Portuguese legislation defines a NZEB, according to the Portuguese Decree-Law 118/2013, article 16, as buildings with near zero energy needs, with high energy performance and whose energy needs are mostly met by energy from renewable energy sources, majorly delivered on-site or nearby sources (adapted from [18]). Additionally, this Portuguese Decree-Law states that new buildings, licensed after 31st December 2020 or, new buildings, owned and occupied by a public entity, licensed after 31st December 2018, must have near zero energy needs (adapted from [18]).

Nowadays, according to the Portuguese ministerial ordinance, Portaria 98/2019 [19], a residential NZEB must have RECT covering at least 50% of the annual primary energy needs [19], must have its nominal annual value of useful energy needs for heating (N_{ic}, see equation 2.1, from Portuguese Dispatch 15793-I/2013 [20]) be equal or less than 75% of the maximum annual value of useful energy needs for heating (N_i, see equation 2.2, from Portuguese Dispatch 349-B/2013 [21]) [19] as well as having its nominal annual value of primary energy needs (N_{tc}, see equation 2.3, from Portuguese Dispatch 15793-I/2013 [20]) being equal or less then 50% of maximum annual value of primary energy needs (N_t, see equation 2.4, from Portuguese Dispatch 349-B/2013 [21]) [19]. Furthermore, in case the building is located on Portuguese climate zone I1[3] and $\frac{N_{ic}}{N_i} \leq 0.6$ and the maximum solar factor ($g_{T,\text{max}}$) is equal or less then 0.15, then it is considered that the building only has occasional effective heating needs, so that its (N_{ic}) value is considered null [19].

$$N_{ic} = (Q_{tr,i} + Q_{ve,i} + Q_{gu,i})/A_p \tag{2.1}$$

$$N_i = (Q_{tr,i_{\text{ref}}} + Q_{ve,i_{\text{ref}}} + Q_{gu,i_{\text{ref}}})/A_p \tag{2.2}$$

$$N_{tc} = \sum_j \Big(\sum_k \frac{f_{i,k} \cdot N_{ic}}{\eta_k}\Big) \cdot F_{pu,j} + \sum_j \Big(\sum_k \frac{f_{v,k} \cdot \delta \cdot N_{vc}}{\eta_k}\Big) \cdot F_{pu,j} + \sum_j \Big(\sum_k \frac{f_{a,k} \cdot Q_a/A_p}{\eta_k}\Big) \cdot F_{pu,j} + \sum_j \frac{W_{vm,j}}{A_p} \cdot F_{pu,j} - \sum_p \frac{E_{ren,p}}{A_p} \cdot F_{pu,p} \tag{2.3}$$

[1] "Source energy refers to the primary energy used to generate and deliver the energy to the site. To calculate a building's total source energy, imported and exported energy is multiplied by the appropriate site-to-source conversion multipliers." [17]

[2] Off-site sources are to be considered as sources "outside the boundaries of the building site" [17]

[3] I1: Portuguese winter climate zone 1, characterised by a number of heating degree-days, of base 18 ° C, of equal or less than then 1300, according to Portuguese Dispatch 15793-F/2013 [22].

$$N_t = \sum_j \Big(\sum_k \frac{f_{i,k} \cdot N_i}{\eta_{\text{ref},k}}\Big) \cdot F_{pu,j} + \sum_j \Big(\sum_k \frac{f_{v,k} \cdot \delta \cdot N_v}{\eta_{\text{ref},k}}\Big) \cdot F_{pu,j} + \sum_j \Big(\sum_k \frac{f_{a,k} \cdot Q_a/A_p}{\eta_{\text{ref},k}}\Big) \cdot F_{pu,j} \quad (2.4)$$

Where

$\boldsymbol{N_{ic}}$ nominal annual value of useful energy needs for heating, in $\frac{kWh}{m^2 \cdot Year}$, supplied by system k [20].

$\boldsymbol{Q_{tr,i}}$ heat transfer by transmission through the building envelope, in the heating season, in kWh [20].

$\boldsymbol{Q_{tr,i}}$ heat transfer by ventilation, in the cooling season, in kWh [20].

$\boldsymbol{Q_{tr,i}}$ thermal gains, in the cooling season, stemming from solar gains through windows/skylights/glass doors, from lighting, equipment and occupants, in kWh [20].

$\boldsymbol{A_p}$ useful interior floor area, measured from the inside, in m^2 [20].

$\boldsymbol{N_i}$ maximum annual value of useful energy needs for heating, in $\frac{kWh}{m^2 \cdot Year}$ [21].

$\boldsymbol{_{ref}}$ Refers to reference values [21].

$\boldsymbol{N_{tc}}$ nominal annual value of primary energy needs, in $\frac{kWh}{m^2 \cdot Year}$, which consists of the sum of the several specific nominal (primary energy) needs for heating, cooling, domestic hot water, mechanical ventilation and contributions from RECT [20].

$\boldsymbol{_k}$ technical systems [21].

$\boldsymbol{_j}$ every energy source, including renewable ones [20].

$\boldsymbol{_p}$ renewable energy sources [20].

$\boldsymbol{f_{i,k}}$ fraction of useful energy needs for heating, supplied by system k [20].

$\boldsymbol{\eta_k}$ energy efficiency of system k, which is equal to 1 for renewable systems [20].

$\boldsymbol{F_{pu,j}}$, $\boldsymbol{F_{pu,p}}$ useful to primary energy conversion factor, in $\frac{kWh_{PE}}{kWh}$ [20].

$\boldsymbol{N_{vc}}$ nominal annual value of useful energy needs for cooling, in $\frac{kWh}{m^2 \cdot Year}$, supplied by system k [20].

$\boldsymbol{f_{v,k}}$ fraction of useful energy needs for cooling, supplied by system k [20].

$\boldsymbol{\delta}$ this value is always equal to 1, except for cooling uses (N_{vc}), where it can take the value of zero whenever the thermal gains utilisation factor is superior to the corresponding reference factor, which in turn represents the conditions at which the risk of overheating is minimised [20].

$\boldsymbol{f_{a,k}}$ fraction of useful energy needs for domestic hot water preparation, supplied by system k [20].

$\boldsymbol{Q_a}$ nominal annual value of useful energy needs for domestic hot water preparation, in $\frac{kWh}{Year}$, supplied by system k [20].

$\boldsymbol{W_{vm,j}}$ electric energy needs for ventilator operation, in $\frac{kWh}{Year}$ [20].

$\boldsymbol{E_{ren,p}}$ consumed energy from RECT, in $\frac{kWh}{Year}$ [20].

$\boldsymbol{N_t}$ maximum annual value of primary energy needs, in $\frac{kWh}{m^2 \cdot Year}$, which consists of the sum of the several specific nominal (primary energy) needs for heating, cooling and domestic hot water, considering the absence of energy consumption associated to mechanical ventilation and from contributions from RECT [21].

2.2.2 Best Practices

Torcellini *et al.* make their approach on defining a good zero energy building (ZEB) strategy, stating that at the core, firstly, energy efficiency should be encouraged and, only then must it move on to "use renewable energy sources available on-site", claiming "it is almost always easier to save energy than to produce energy" [17]. As encouragd by Torcellini *et al.*, this is the strategy the Renovation Passport is based upon, in order to reach a NZEB as before considering renewable energy conversion, energy efficiency improvement measures are to be implemented.

This clear idea for NZEBs of first reducing (energy consumption) and then converting energy, from renewable on-site sources, is furthermore corroborated by Dall'O *et al.*, stating that the strategy could be a "hierarchical" "3-step sequence", which starts with "retrofitting building materials to reduce energy demand", then "installing energy-efficient equipment" and finally "installing micro-generation technologies" [23], as well as by Xing *et al.*, that also describe an "hierarchical approach" whose first step is "retrofitting building fabrics to higher standards" (to reduce the demand), moving on to installing "energy efficient equipments" and lastly, establishing a "on-site low and zero carbon energy supply technologies with smart grid connections and control", as they illustrate on figure 2.1.

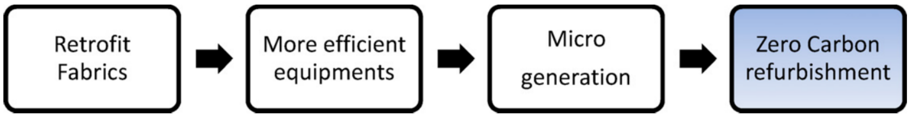


Figure 2.1: "Hierarchical process", proposed by and illustrated in Xing *et al.*, to achieve a NZEB [24].

After defining the core of the ZEB strategy, Torcellini *et al.* propose some recommendations/ considerations for the development of the remaining ZEB strategy , such as grid connection being "allowed and necessary for energy balances" [17] and prioritising supply-side technologies, preferably renewable energy technologies that are "available on-site or within the footprint" [17] of the building.

For the first recommendation, they explain that grid connection offers the possibility of surplus electricity (or other possible forms of energy, such as thermal energy and biogas) produced *in loco* to be fed to the grid and, the other way around, provide the building with electricity and/or natural gas when necessary. Using the grid for the energy balance is a way to not so strictly define a ZEB, since its "excess production can offset later energy use" [17], unlike what is considered for "autonomous ZEB" (1), as presented before. However, having the grid to act as storage may not be in line with what is practised, expected or wanted by the grid responsible operators, as it may put a lot of pressure on grid management[4].

This thesis follows the grid connection strategy. A clear advantage, besides energy security, that buildings connected to the grid (such as "Net ZEBs" (2) and "+ZEBs" (3), as considered previously) have over those which are not, is the dimension of the renewable energy conversion technology (RECT) units on-site. If the building is not connected to the grid, to ensure energy demands are met during peaks, the RECT units will probably have to be oversized and either there is an oversupply which is wasted or energy storage solutions must be considered. Howbeit, one must have in mind that on-site energy storage should also be considered in a "high market penetration scenario", where the grid "may not always need the excess energy" [17].

For the latter, they created an hierarchy of the renewable energy supply options to be considered

[4]Currently, the Portuguese legislation which regulates renewable energy "auto-consumption" is Decree-Law 162/2019 [**?**].

for a ZEB, based on how well they follow the hierarchisation criteria, which are how much do they minimise ”overall environmental impact by encouraging energy-efficient building designs and reducing transportation and conversion losses”, if they will be ”available over the lifetime of the building” and if they are ”widely available and have high replication potential for future ZEBs” [17]. The hierarchy considered can be seen on figure 2.2.

Option Number	ZEB Supply-Side Options	Examples
0	Reduce site energy use through low-energy building technologies	Daylighting, high-efficiency HVAC equipment, natural ventilation, evaporative cooling, etc.
	On-Site Supply Options	
1	Use renewable energy sources available within the building’s footprint	PV, solar hot water, and wind located on the building.
2	Use renewable energy sources available at the site	PV, solar hot water, low-impact hydro, and wind located on-site, but not on the building.
	Off-Site Supply Options	
3	Use renewable energy sources available off site to generate energy on site	Biomass, wood pellets, ethanol, or biodiesel that can be imported from off site, or waste streams from on-site processes that can be used on-site to generate electricity and heat.
4	Purchase off-site renewable energy sources	Utility-based wind, PV, emissions credits, or other “green” purchasing options. Hydroelectric is sometimes considered.

Figure 2.2: Hierarchy of Renewable Energy Supply Options for a Zero Energy Building, as illustrated in Torcellini *et al.* [17].

2.2.3 Energy Performance

After having understood the different definitions for ZEBs, one can move on to understand how to evaluate the building’s energy performance, defined by the European standard 15316:2007 as the ”calculated or measured amount of energy delivered and exported actually used or estimated to meet the different needs associated with a standardised use of the building, which may include, *inter alia*, energy used for heating, cooling, ventilation, domestic hot water and lighting” [25]. The energy performance is mainly assessed trough energy balances to the building itself. In order to perform the energy balances, the system (building) boundary needs to be defined, which can be described as ”boundary that includes within it all areas associated with the building (both inside and outside the building) where energy is consumed or produced”[5], as stated in European standard 15603:2008 [26].

According to D’Agostino, ”three system boundaries can be distinguished in reference to energy need, energy use, imported and exported energy” [15], where the energy need is ”the total energy to satisfy building needs that mainly consist of heating, cooling, ventilation, domestic hot water (DHW), lighting, and appliances” [15], the energy use ”considers the building technical system as well as losses and conversions” [15] and consumed energy can either be from RECT (which can be exported), for cooling, heating and electricity or possibly imported from the grid, in the form of fuels, electricity, district heating and cooling [15]. Figure 2.3 represents a NZEB considering these three system boundaries, while figure

[5]”note: Inside the system boundary the system losses are taken into account explicitly, outside the system boundary they are taken into account in the conversion factor.” [26]

2.4 illustrates the connections between the building itself and the grid, as well as pointing out which are the imports and the exports (referring to the building) to consider for the energy balance.

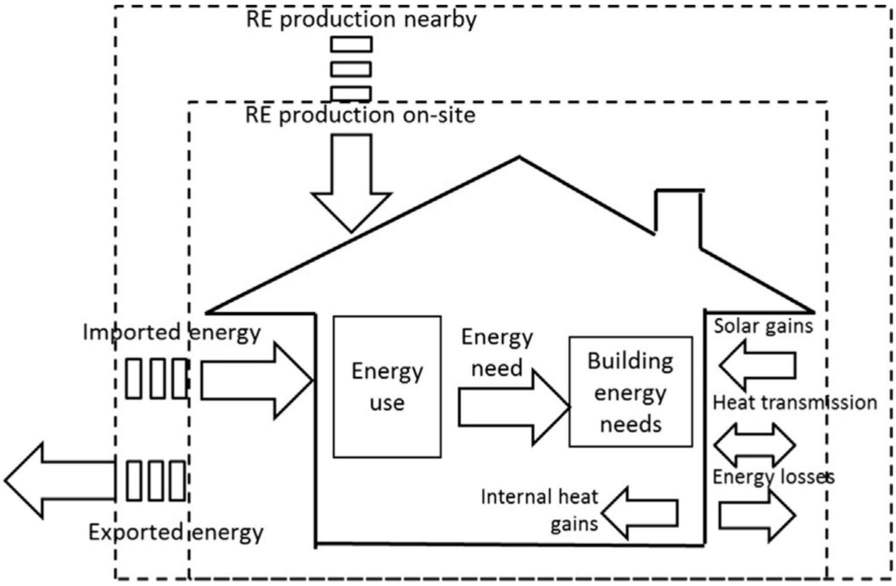


Figure 2.3: Example of possible boundaries considered for a NZEB, as illustrated in D'Agostino [15].

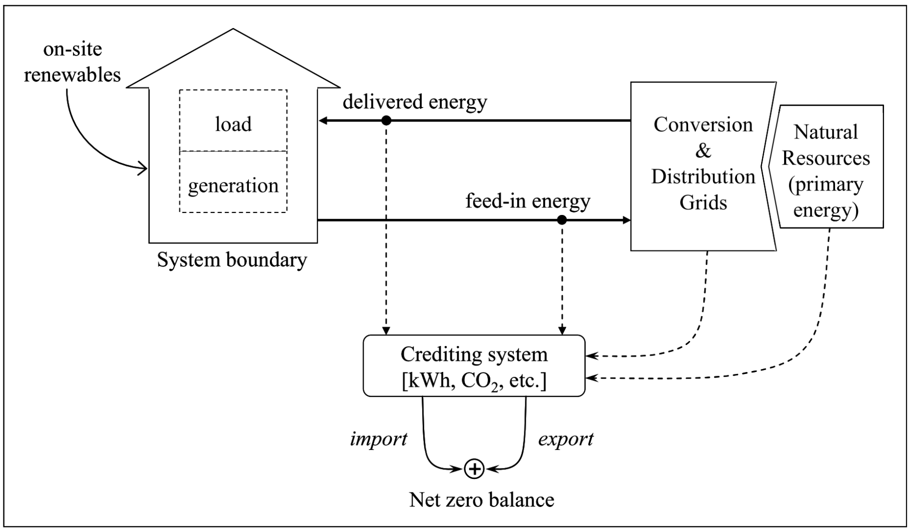


Figure 2.4: "Connection between buildings and energy grids", as illustrated in Sartori *et al.* [27].

After defining the boundaries of the system, to calculate the energy balance, some other factors need to be outlined. In accord with Dall'O *et al.*, most of the European countries adopted primary energy, as balance metric, a year, as balance period[6] and renewable energy options to be the ones available on-site [23], thus expressing the values in $\frac{kWh}{m^2.y}$.

In Portugal, the same units are used for the energy efficiency indicator for buildings (primary energy per square meter of useful floor area and per year, for the certified energy uses, like space heating and cooing and domestic hot water preparation [18]). This units are the ones considered in the context of the Renovation Passport as well.

[6] According to Marszal *et al.*, the time period used for the energy balance of a building can be the "full life cycle", the "operating time of the building (e.g. 50 years)", as well as year, season and month [28].

Therefore, comparing to what as been presented so far, choosing the definitions of "Net Zero Source Building" (2) and the "On-Site Supply Options" (figure 2.2) both suggested by Torcellini *et al.*. Henceforth, these should be the criteria followed in this thesis.

Following these guidelines, Dall'O *et al.* [23] propose equation 2.5 to calculate the yearly energy balance, for a net zero energy building, while Sartori *et al.* [27] propose another definition, which includes net and plus zero energy buildings, on equation 2.7, as the balance between what is consumed by the building (demand from grid/imports) must be the same or more than what is converted on-site, through RECT. Referring to the first equation, 2.5, the primary energy demand must be the same as the sum of renewable (primary) energy converted on-site and potentially acquired renewable (primary) energy delivered from off-site ("certified purchased green energy" [23]), that must be certified, "limited to a certain value" and the "most equivalent" to renewable energy obtained on-site. As for the energy demand, accounted for in primary energy, it refers to the following uses, "winter heating (including ventilation)", "summer cooling (including ventilation)", "hot water supply" and "electricity use" [23].

$$\sum_{m=1}^{12} (EP_G - EP_{RE} - EP_{GP})_m = 0 \tag{2.5}$$

Where

$\boldsymbol{EP_G}$ is the global primary energy, in $\frac{kWh}{m^2.y}$.

$\boldsymbol{EP_{RE}}$ is the "primary energy from renewable sources" [23], in $\frac{kWh}{m^2.y}$.

$\boldsymbol{EP_{GP}}$ is the "certified purchased green" [23] primary energy, in $\frac{kWh}{m^2.y}$.

m represents the month.

The global primary energy can be calculate through equation 2.6, also presented by Dall'O *et al.* [23].

$$EP_G = EP_H + EP_W + EP_C + EP_{EL} \tag{2.6}$$

Where

$\boldsymbol{EP_H}$ refers to primary energy associated with final energy used for space heating, in $\frac{kWh}{m^2.y}$.

$\boldsymbol{EP_W}$ refers to primary energy associated with final energy used for obtaining hot water, in $\frac{kWh}{m^2.y}$.

$\boldsymbol{EP_C}$ refers to primary energy associated with final energy used for space cooling, in $\frac{kWh}{m^2.y}$.

$\boldsymbol{EP_{EL}}$ refers to primary energy associated with electricity use, in $\frac{kWh}{m^2.y}$.

$$|\text{export}| - |\text{import}| \geq 0 \tag{2.7}$$

A visualisation of the energy balance, for a net zero building can be seen on figure 2.5, as illustrated on Sartori *et al.* [27]. One can read the graph beginning from the "starting point", which corresponds to the building current energy demand supplied by the grid (as read on the x-axis), then, following the good practices discussed above for ZEBs (on section 2.2.2, where, first, energy demand/ import should be reduced and second, energy must be obtained from RECT/ exported [23]), energy efficiency measures must be applied. Following their application, the building's energy demand drops to a lower value, on the x-axis (as indicated by the arrow in the graph). Finally, RECT units are installed, so that the building starts delivering energy on-site (this energy can then be exported to the grid, as read in the y-axis) which corresponds to its own demand. The net zero balance line represented corresponds to a line that follows the equation $y = x$, as, for net zero, demand must be equal to renewable energy transformed on-site.

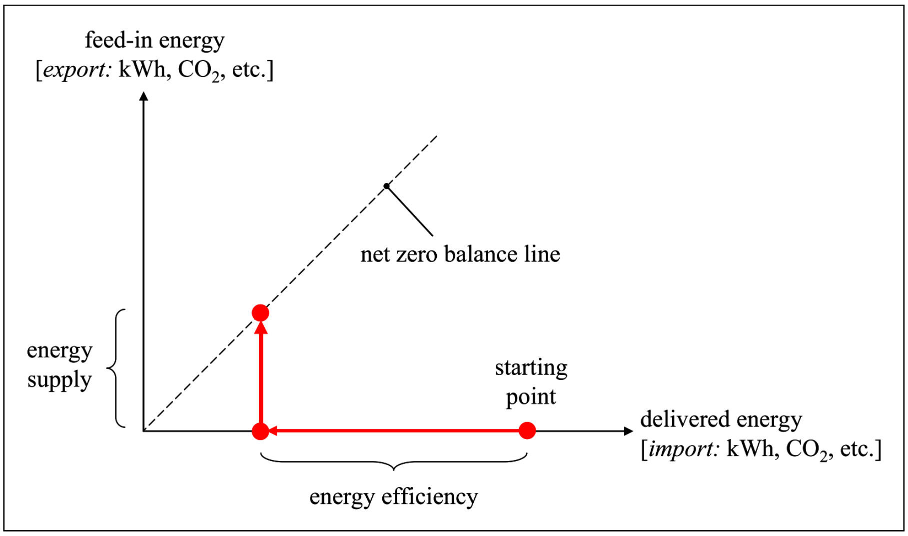


Figure 2.5: "Graph representing the net zero balance of a Net ZEB", as illustrated in Sartori *et al.* [27].

2.3 Defining a Pathway for Energy Conservation Measures Identification

Building renovation requires action, which is done through improvement measures to be implemented. As this thesis focus on energy, those measures aim at the reduction of energy consumption, respecting the user's comfort and needs, which, in turn have immediate results on financial savings and decreased emissions.

However, in order to start the implementation of those measures, one can use a guideline to know which to implement and when/in which order. A way to provide guidance can be taken and adapted from curves which group and relate the energy savings attributed to the measures' implementation and the financial savings obtained through them.

2.3.1 Supply Curve of Conserved Energy

According to Meier *et al.*, a supply curve of conserved energy allows for a quick analysis and comparison of several "conservation measures", understanding their "magnitude and costs" [29], as well as focusing efforts on a determined set of measures, with funded reasons, instead of others, to achieve the best outcome possible. An example of a supply curve of conserved energy can be seen in figure 2.6.

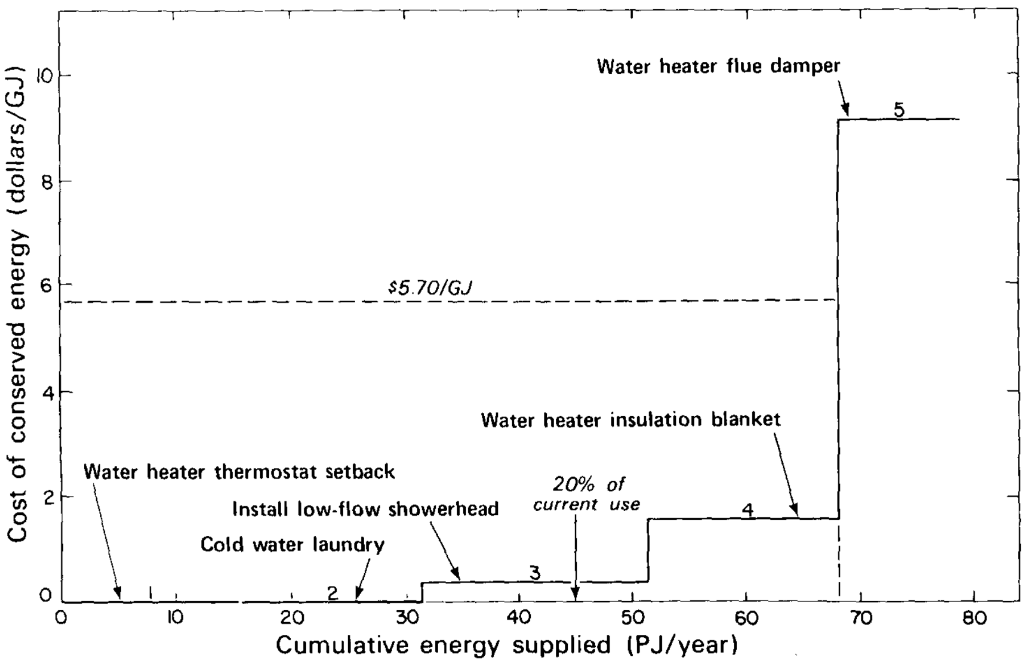


Figure 2.6: Example of a Supply Curve of Conserved Energy, as illustrated in Meier *et al.*, where it has the following description: "A gas water heating conservation supply curve for California's residential sector. Each step corresponds to a conservation measure: the y-coordinate is the cost of conserved natural gas and the x-coordinate the cumulative energy saved. Total gas used for residential water heating in California in 1978 was 216 PJ." [29].

A "conservation measure" can be assumed as economically viable if its "cost of conserved energy" is lower than the price to be paid for the energy which was saved by applying that "conservation measure" [29]. One can calculate the "cost of conserved energy" (CCE) using formula 2.8, taken from Meier *et al.*.

$$\text{Cost of Conserved Energy (CCE)} = \left(\frac{I}{\Delta E}\right) \frac{d}{[1-(1+d)^{-n}]} \tag{2.8}$$

Where

I is the investment.

Δ**E** is the energy savings.

d is the discount rate.

n is the amortisation period.

The first fraction of the formula takes the investment done on the "conservation measure" and divides it by the saved energy (energy savings obtained when applying the conservation measure). The second fraction is the "capital recovery formula" that aims to annualise the investment.

The final result of this equation represents a "cost to save a unit of energy" [29], which can be expressed in this unit, $\frac{€}{kWh}$, or equivalent. This value can then be used to better compare several "conservation measures" and their corresponding investments of "differing magnitude, lifetime or even discount rate" [29]. Meier *et al.* considers an "investment", the difference in price one pays, for example, for buying a more efficient appliance instead of a standard one.

After understanding how to achieve the values of the y-axis of the supply curve of conserved energy, one can move on to the x-axis, thus, fully grasping how to construct this graphic.

A supply curve of conserved energy is a series of steps, arranged by height, from the shortest to the longest, where each step represents a measure. The vertical height of the step is the ”cost of conserved energy” and its horizontal length is ”energy savings” [29], in a cumulative way (in the case of figure 2.6, the horizontal length represents ”annual energy savings” [29]) .

”The order in which conservation measures are performed will affect the energy savings attributed to each of them” [29]. If a measure is applied first, the savings associated with it would be higher than if the measure was applied after others. ”However, the total energy savings, after completion of the entire sequence, will not change” [29].

Summing up, by reading a supply curve of conserved energy, one can understand the ”potential for conserved energy”, for each measure alone and for the pool of measures considered in the graphic. Yet, it does not indicate how likely it is that this potential can be realised [29].

2.3.2 Other Curves

A similar curve, in the sense that the information it contains and the way the information is arranged (from least expensive energy performance improve measures to the most expensive ones) are alike, can be seen on figure 2.7.

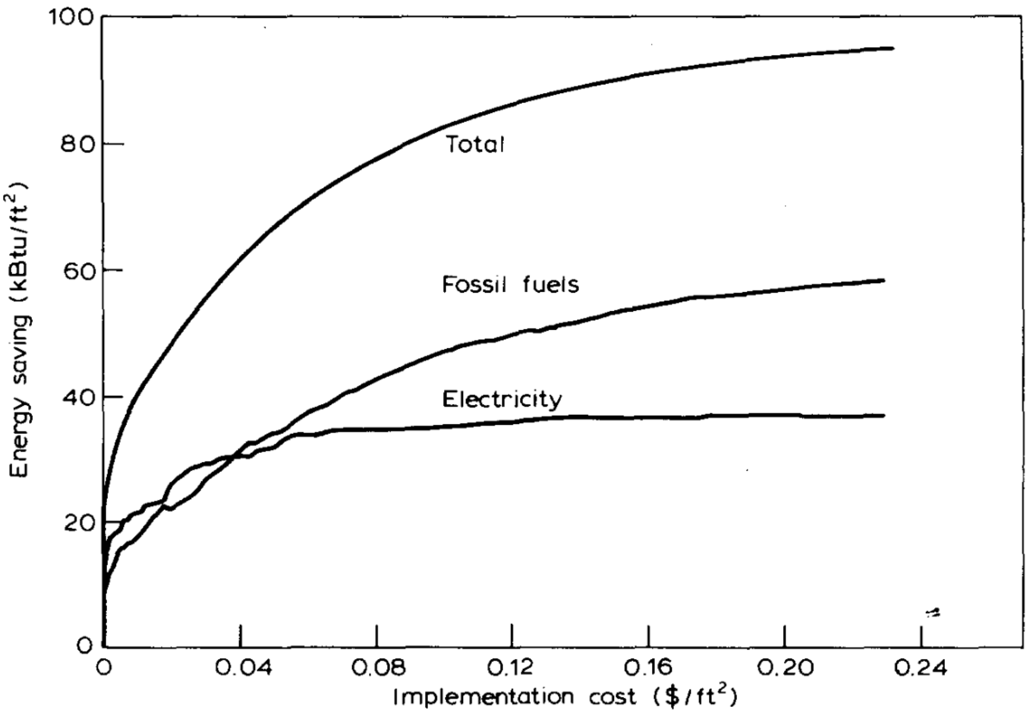


Figure 2.7: ”Plot of the cumulative estimated energy saving per unit floor area as a function of the cumulative implementation cost per unit floor area” as illustrated by Hirst [30].

Figure 2.7 aggregates the findings of a study, performed by Hirst, in 1982, on 48 hospitals, spread across four states (New York, Pennsylvania, Virginia, and Tennessee) of the United States of America, that brought together information on the energy audits performed on those hospitals [30]. This figure represents a ”plot of the cumulative estimated energy saving per unit floor area as a function of the cumulative implementation cost per unit floor area” [30].

In this graph three curves are represented, one regarding electricity, one regarding fossil fuels and finally, the total one, which is the sum of the previous two. The curves were obtained by organising the information, 881 recommendations (*i.e.*, proposed energy efficiency improvement measures) from the energy audits to the 48 hospitals, "in terms of increasing implementation cost per unit energy saving" [30], *i.e.*, $\frac{€}{kWh}$, or equivalent units. This value resembles the cost of conserved energy, discussed above (see equation 2.8), without the capital recovery expression. After arranging the $\frac{€}{kWh}$ value associated to each measure, in ascending order, the values for energy savings, in $\frac{kWh}{m^2}$, or equivalent, and implementation cost $\frac{€}{m^2}$, or equivalent, are expressed, in a cumulative way.

The question this graph tries to answer, for the cases considered in this study is 'how much does it cost to save a certain amount of energy?'. For example, regarding the total curve, a certain amount of energy per floor area can be saved (about 20 $\frac{kBtu}{ft^2}$, seen on the y-axis) with zero implementation cost (seen on the x-axis), which means some savings can be achieved by simply changing the use patterns and behaviours. These should be the measures considered first, due to their low/no price, when considering improving the energy performance of a building.

Analogous to the supply curve of conserved energy, this curve also presents which measures to implement first (the ones with the lowest payback and highest energy saving potential), for that, it would only be necessary to label each value of the curve to the associated measure, much like on figure 2.6.

The two graphs, shown on figures 2.6 and 2.7, are constructed in different ways and refer to different units, however, the information which can be drawn from them is similar, which in broad terms can be considered as what measures to adopt and in which order, when considering energy renovation of a building, thus offering two ways to visualise data related with energy performance improvement measures.

2.4 Energy Performance Certificate - EPC - in Portugal

According too ADENE[7], the official entity that issues the energy certificates in Portugal (Sistema de Certificação Energética de Edifícios - SCE), an energy certificate gives information about the energy performance of the building to the consumer, including cost reduction with energy utilisation, improvement of thermal comfort and access to funding and tax benefits (adapted from [31]).

The certificate is emitted by a "qualified expert" (peritos qualificados - PQ [32]), certified by ADENE, and they are responsible to carry out the building energy performance assessment and, for that, they perform an audit to the building where they obtain information on the following building characteristics, shown on 2.1.

[7]https://www.adene.pt

Table 2.1: Building characteristics subject to energy audit.

Construction Description	Envelope	Heating and Cooling Solutions	Ventilation	Others[8]
Location	Walls and Doors	Space Heating	Natural Systems	Lighting
Construction Year	Covering/Roof	Space Cooling	Forced Systems	Appliances
Typology	Pavement/Floor	Domestic Hot Water	-	-
Floor Number	Windows	-	-	-
Pavement Area	-	-	-	-

After performing the energy audit and collecting other information like energy bills and user behaviour, the qualified experts have enough information to deliver the energy performance certificate, which is usually arranged as follows (like it is illustrated on an energy certificate example, provided by ADENE [33] or in the Portuguese Dispatch n.º 15793-C/2013, annex 1 [20]):

1. Summary;
    - Building identification[9] and address;
    - Performance indicators on space heating, space cooling and domestic hot water;
    - **Energy class** (of the considered building);
    - Renewable energy share of total consumed energy;
    - CO_2 emissions.
2. Building description;
    - Building construction description (see table 2.1);
    - Heating and cooling solutions[10] (see table 2.1);
    - Ventilation system (see table 2.1).
3. Thermal behaviour of building elements;
4. Heat losses and gains;
    - Winter heat losses;
    - Summer heat gains.

[8]Currently other energy uses, including some types ventilation, which are not space heating and cooling and DHW preparation, are not included, for residential buildings, as energy uses subject to energy certification. However, in the context of the Renovation Passport, these uses, since they are part of total energy consumption, may be subject to metering and evaluation.

[9]The building is characterised according to one of the four building categories considered on the Portuguese directive, Portaria nº349-A/2013, residential building, small commerce and services building with no climatisation, residential building, small commerce and services building with climatisation and large commerce and services building (with or without climatisation) [34].

[10]An example of heating and cooling solutions found in a common residential building can be a natural gas water heater and an air conditioning unit providing both space heating and cooling.

5. Energy performance improvement measures proposal;
   - List of suggested improvement measures;
   - Estimated investment cost;
   - Estimated energy bill savings;
   - New energy class after improvements.
6. Technical systems recommendations;
7. Further information and definitions used in the certificate;
8. Main indicators summary;
9. Climate data;
10. Walls, covering/roof, pavement, thermal bridges[11] and windows;
    - Description of materials, thickness and insulation;
    - Total area and orientation;
    - Overall heat transfer coefficient - U-value[12];
    - Solar factor (for windows only);
    - Associated improvement measures.
11. Heating, cooling and ventilation systems;
    - Equipment description, brand, installation date, maintenance performed;
    - Energy Consumption ($\frac{kWh}{\text{year}}$);
    - Installed power (kWh);
    - Seasonal/nominal performance;
    - Associated improvement measures.

As supported by the description above, the EPC focuses strongly on attributing an energy class to the building as a whole, as well as attributing performance indicators relative to energy used for thermal comfort (space heating and cooling and domestic hot water). Then, measures to improve the energy performance of the building are suggested, and ultimately lead to increasing the energy class (of the

[11] According to Gorse *et al.*, on *A Dictionary of Construction, Surveying and Civil Engineering*, a thermal bridge is defined as an ”area of the building fabric that has a higher thermal transmission than the surrounding parts of the fabric, resulting in a reduction in the overall thermal insulation of the structure. It occurs when materials that have a much higher thermal conductivity than the surrounding material (i.e. they are poorer thermal insulators) penetrate the thermal envelope or where there are discontinuities in the thermal envelope. Heat then flows through the path created — the path of least resistance—from the warm space (inside) to the cold space (outside). The higher thermal transmission of this part of the fabric results in a reduction in the thermal performance (an increase in U-value) as heat flows through the fabric, and the surfaces of the interior side of the bridge become cooler. The use of the term ‘thermal bridge’ is somewhat misleading as it implies that the thermal envelope must be ‘bridged’ in some way for a thermal bridge to occur; this is, in fact, not the case. Thermal bridges can occur in unbridged construction where discontinuities exist in the thermal envelope” [35].

[12] The U-value/ factor is expressed using the following SI units: $\frac{W}{m^2.K}$.

building as a whole and for each energy use in particular) as much as possible (preferably to the letter A +, which is the best conceivable).

The energy class and performance indicators are defined by law (Portuguese Decree-Law nº118/2013 [18] and dispatch, Despacho (extrato) n.º 15793-J/2013 [20]). The building's energy class is obtained by comparing the building's current performance to the performance of the same building, subject to standard conditions, which are considered to run the test and act as benchmarking. For example, for a residential building, the energy class is determined, according to the Portuguese Dispatch n.º 15793-J/2013 [20], through the "energy class ratio" (adapted from "rácio de classe energética"), given by equation 2.9. On figure 2.8, the energy class attributed to each interval of R_{Nt} values, for a residential building, can be found.

$$R_{Nt} = \frac{N_{tc}}{N_t} \tag{2.9}$$

Where

$\boldsymbol{R_{Nt}}$ is the energy class ratio.

$\boldsymbol{N_{tc}}$ corresponds to the value of the nominal yearly needs of primary energy (expressed in $\frac{kWh}{m^2 \cdot Year}$) of the building.

$\boldsymbol{N_t}$ corresponds to the regulated limit value for the nominal yearly needs of primary energy (expressed in $\frac{kWh}{m^2 \cdot Year}$) for the building.

Classe Energética	Valor de R_{Nt}
A +	$R_{Nt} \leq 0{,}25$
A	$0{,}26 \leq R_{Nt} \leq 0{,}50$
B	$0{,}51 \leq R_{Nt} \leq 0{,}75$
B -	$0{,}76 \leq R_{Nt} \leq 1{,}00$
C	$1{,}01 \leq R_{Nt} \leq 1{,}50$
D	$1{,}51 \leq R_{Nt} \leq 2{,}00$
E	$2{,}01 \leq R_{Nt} \leq 2{,}50$
F	$R_{Nt} \geq 2{,}51$

Figure 2.8: Energy classes (on the left), for a residential building, attributed to the corresponding value of R_{Nt} (on the right), as defined on Portuguese Dispatch n.º 15793-J/2013 [20].

2.5 European Union Projects on Building Energy Renovation

The EU has lately been working on implementing the commitments signed at the Paris Agreement [36], such as promoting "the mitigation of greenhouse gas emissions while fostering sustainable development", in order to pursue the goal of limiting the "the increase in the global average temperature to well below 2°C above pre-industrial levels" with further efforts to limit it to "1.5°C above pre-industrial levels", developing mitigation and adaptation to climate change efforts, adopting "finance flows" coherent with ”climate-resilient development” and promoting both public and private sectors to participate in the ”implementation of nationally determined contributions”, to name a few [36].

With that agenda in mind, on December 2019, the EU announced the European Green Deal and more recently, on March 2020, the European Climate Law was announced and the European Climate Pact is to be under public consultation until May 2020. The European Green Deal proposes for the EU to become a net zero emission economy by 2050 (as cited on section 1.1), the European Climate Law ”aims to write into law the goal set out in the European Green Deal” [5] and at the time of its announcement, the president of the European Commission, Ursula von der Leyen stated the following: ”We are acting today to make the EU the world's first climate neutral continent by 2050. The Climate Law is the legal translation of our political commitment, and sets us irreversibly on the path to a more sustainable future. It is the heart of the European Green Deal. It offers predictability and transparency for European industry and investors. And it gives direction to our green growth strategy and guarantees that the transition will be gradual and fair.” [37]. Lastly, the European Climate Pact ”aims to engage citizens and communities in action for our climate and environment” [38].

All of these packages, and more importantly the EPBD (which, as a EU Directive, is to be transcribed into each Member State national legislation), assert the building sector is one key area to achieve the proposed goals, through efforts on enhancing energy efficiency, reporting energy performance, engaging on a ”'renovation wave' of public and private buildings”, with ”national long-term renovation strategies” [1], addressing energy poverty and accounting for ”circular economy”, ”digitalisation” and ”climate-proofing of the building stock” [1].

Some European projects have been paving the way to reach what is necessary for the building sector, such as the iBRoad project and the Level(s) framework.

2.5.1 iBRoad Project

The iBRoad project[13] focuses on the renovation of already existing buildings with the purpose of improving their energy performance, sustainability, comfort and the overall goal of a having, in Europe, a ”highly efficient and decarbonised building stock by 2050” [40], by providing a renovation plan ”for single-family houses” [40]. The key beneficiary of iBRoad is the building owner.

The project intents to ”guide the building owner through their building renovation process” [40], deconstructing possible barriers which usually prevent the owner to do so and it is based in two main tools. The first, the building ”LogBook” (iBRoad-Log), ”a repository of building- related information” (which includes ”actual energy consumption, energy performance, maintenance requirements, design plans, etc”), which can be considered like a ”dynamic building identity card” [40]. The second, ”Individual Building Renovation Roadmap” (iBRoad-Plan), a ”a customised long-term horizon renovation plan for the specific building and use”, made step-by-step, which contains a ”Roadmap Graph” (a ”visual overview of all renovation steps foreseen” as an ”overview of the results and recommendations”) and a ”Roadmap detailed version” (”full presentation of each individual step”) [40]. On figure 2.9, both tools are repre-

[13] Is funded by the Horizon 2020, an EU ”research and innovation programme”, that ”promises more breakthroughs, discoveries and world-firsts by taking great ideas from the lab to the market” [39].

sented, the LogBook and the iBRoad-Plan as well as the information inserted, delivered and exchanged between those tools.

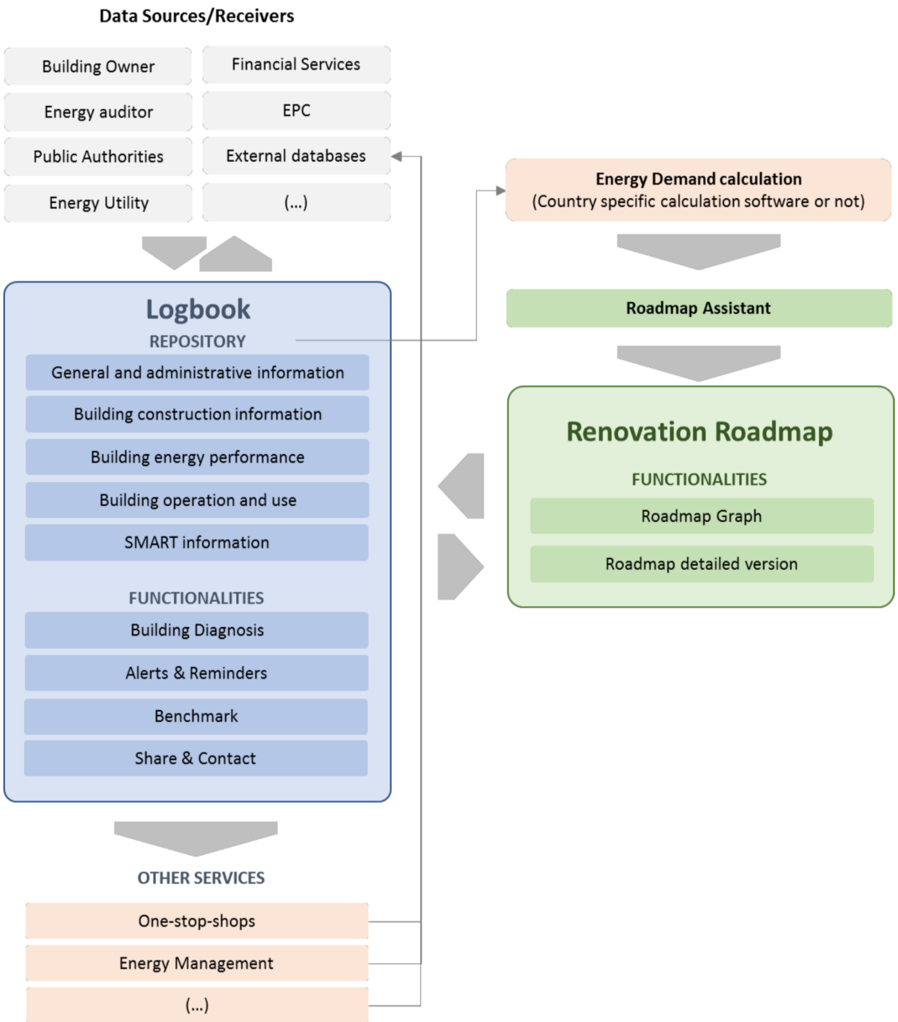


Figure 2.9: "iBRoad concept" as illustrated by Monteiro *et al.* [40]. In this figure both tools (the LogBook and the iBRoad-Plan) and the flow of information from, to and between them are represented.

The essential information needed to produce the LogBook and the iBRoad-Plan are similar to what is found on table 2.1, energy bills, user behaviour (the same as for the EPC), list of accredited energy performance auditors and companies that work on renovation solutions, energy performance certificate (if possible), "state of the art" building renovation solutions, financial incentives available for building renovation, proof of former renovation/maintenance work performed on the building, and real estate information such as "market price of the building" and "benchmark/statistical data for comparison purposes" [40]. For the LogBook, that information can be arranged on the layers shown on figure 2.10. Those layers will contain not only the information inputted but also information acquired during the elaboration of the iBRoad project for a particular building.

The LogBook tool has the purpose of serving as a "building data repository" [40] (divided in the five modules presented on figure 2.10), delivering the current "building diagnosis" [40], based on information stored on the repository, providing "alerts and reminders" [40] on energy performance, available financial incentives or maintenance needs, benchmarking, by comparison with other buildings in the neighbour-

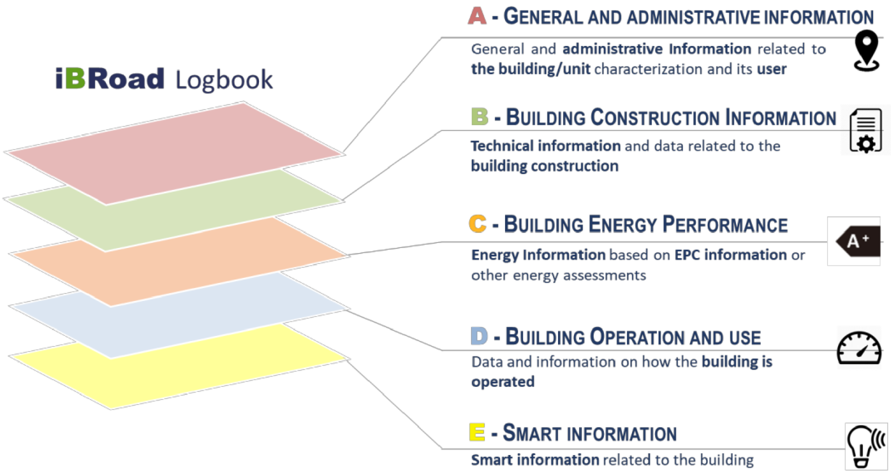


Figure 2.10: LogBook "modules" as illustrated by Monteiro *et al.* [40]. In each layer, a different type of information is arranged and it contais both the information introduced at first, and the information obtained during the iBRoad project process.

hood, linking users with "external databases" [40], providing sharing and contacting with third parties, to better exchange services and also displaying the "renovation roadmap" [40]. These are referred by the iBRoad project as "LogBook functionalities", as seen on figure 2.11.

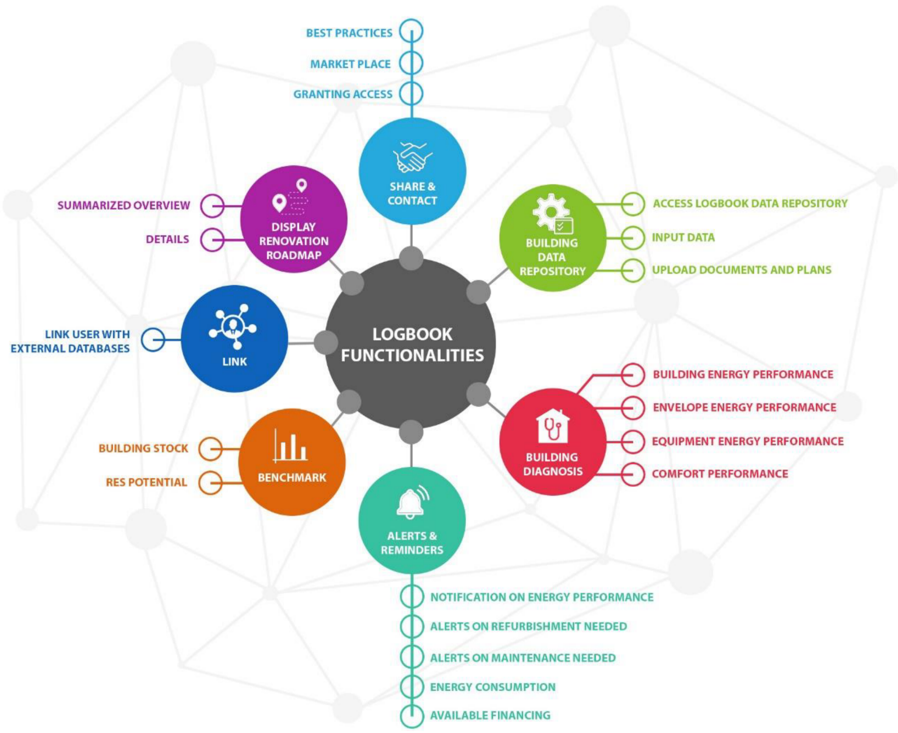


Figure 2.11: "LogBook functionalities" as illustrated by Monteiro *et al.* [40].

The iBRoad-Plan tool, is in itself of of the functionalities of the LogBook and aims to display both the "summarised overview" (which presents "renovation measures, the energy demand and the CO2 emissions for each renovation step, the cost of the measures, the subsidies and the energy costs before and after the renovation") [40] and the "detailed version" (which presents all "technical and financial details") [40] of the individual building renovation roadmap, with what is "necessary to carry out the renovations properly" [40].

Figure 2.12: iBRoad-Plan functionalities as illustrated by Monteiro *et al.* [40].

2.5.2 Level(s) Framework

Level(s) is a "a voluntary reporting framework to improve the sustainability of buildings" [41] developed by the European Commission - Environment, since 2017, with a testing phase until March 2020. It aims to standardise a set of "indicators (whose "calculation is supported, wherever possible, by EN and ISO reference standards" [42]) and metrics" to measure the "environmental performance of office and residential buildings", taking into account their full life-cycle [41].

This framework focuses not only on renovation, but also on the design and construction phase of a building, as well as in the end-of-life phase, therefore, it intents to be used as a reference for every step of a building's existence, across the whole EU, in such a way that allows for comparison between results and performances, uniting countries on the same "policy objectives" [41]. The desired outcome of Level(s) is designing, constructing, occupying, operating, refurbishing, disposing and maintaining a sustainable building (*i.e.*, a building that uses "less energy, water and materials", achieving a "better environmental performance", being "healthier and more comfortable" for its occupants as well as being "less costly to run and financially more valuable in the long term" [42].

The degree at which the building performance is taken depends on the needs and wants of the user (who commended it). Level(s) provides several "layers" of approach, from a simpler (with "basic requirements") to a more complex one (with "more challenging performance assessment schemes and tools") [42], particularly, "three defined levels of expertise and comprehensiveness – a common level (Level 1), a comparative level (Level 2) and a performance-optimised level (Level 3) - with each in turn requiring an increased level of competence and expertise in data handling and manipulation" [42]. From here, it is understood that the assessment can be done in more or less detail, and throughout a determined phase, for example, during renovation, construction or the whole life cycle.

The main inputs, outputs and tools necessary for a Level(s) study are presented on table 2.2 and figure 2.13.

Table 2.2: Level(s) study inputs & outputs.

Inputs	Study Tools	Outputs
Object of Assessment	Six Macro-Objectives	Core Indicators
Functional Unit	Life Cycle Tools	Value and Risk Rating
Reference in-use Conditions	-	-
Reference Study Period	-	-
System Boundary	-	-
Reference Unit	-	-

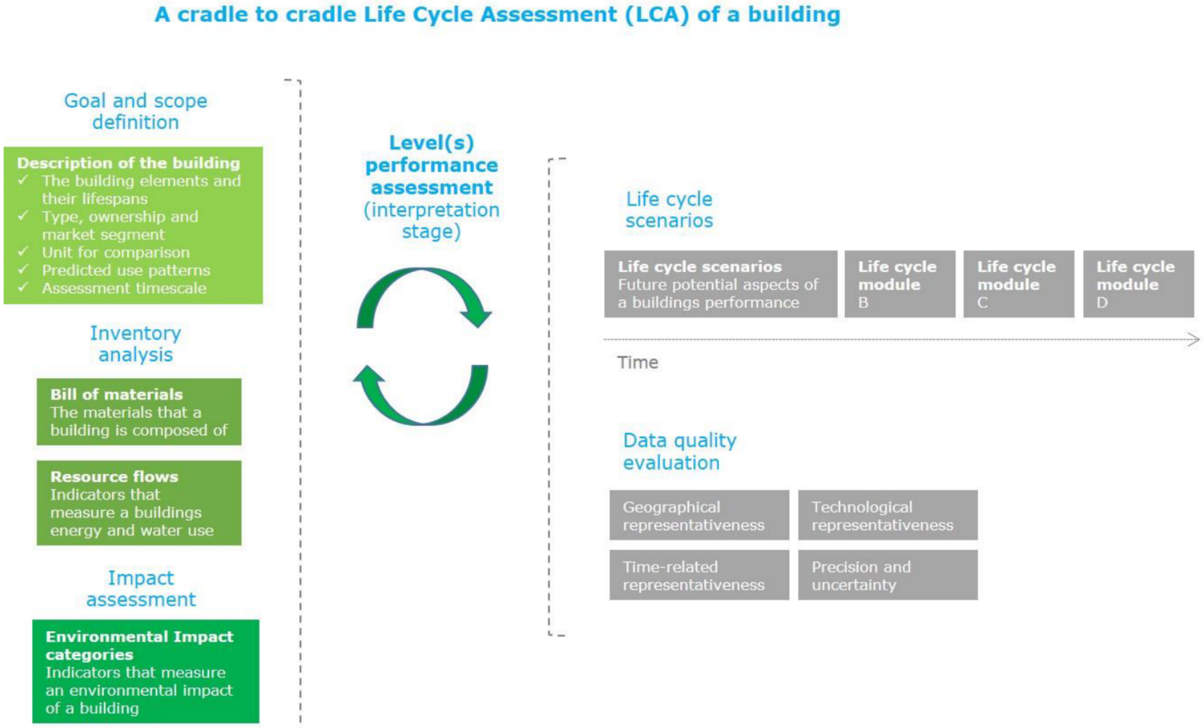


Figure 2.13: Necessary steps to perform a life cycle assessment on a building, as proposed by the Level(s) framework, as illustrated on *Level(s): A guide to Europe's new reporting framework for sustainable buildings* [41].

The inputs are named according to life cycle assessment terminology [42]. The object of assessment refers to the "building and its elements" [42] and the functional unit refers to "building type, ownership and market segment" [42], so that the information contained on these two inputs is similar to the one referred on table 2.1, plus building identification (as enumerated on section 2.4) and intended use. The reference in-use conditions refer to user behaviour and lifespan of building elements [42]. The reference study period is the "timescale for the performance assessment" [42]. The system boundary, which, in this case is not related to physical boundaries of the building, but instead refers to the "life cycle stages that shall be taken into account when making the performance assessment" [42]. The "setting of the system boundaries follows the 'modularity principle'" [42], which "means that the unit processes influencing the building's environmental performance during its life cycle shall be assigned to the module in the life cycle where they occur". Finally, the reference unit refers to the measurement unit to be "used for comparative purposes".

Regarding the study tools, the six macro-objectives establish the goals to be achieved on the building's performance and the life cycle tools [42] (presented on table 2.3 and on figure 2.13) allow for a performance assessment under the scope of "life cycle thinking" [42]. The six macro-objectives to be reached during the building's life cycle are the following:

1. "Greenhouse gas emissions along a buildings life cycle" [41].
2. "Resource efficient and circular material life cycles" [41].
3. "Efficient use of water resources" [41].
4. "Healthy and comfortable spaces" [41].
5. "Adaptation and resilience to climate change" [41].
6. "Optimised life cycle cost and value" [41].

Which are included on the following "thematic areas" [41], as illustrated on figure 2.14

1. "Life cycle environmental performance" (macro-objectives 1, 2 and 3) [41].
2. "Health and comfort" (macro-objective 4) [41].
3. "Cost, value and risk" (macro-objectives 5 and 6) [41].

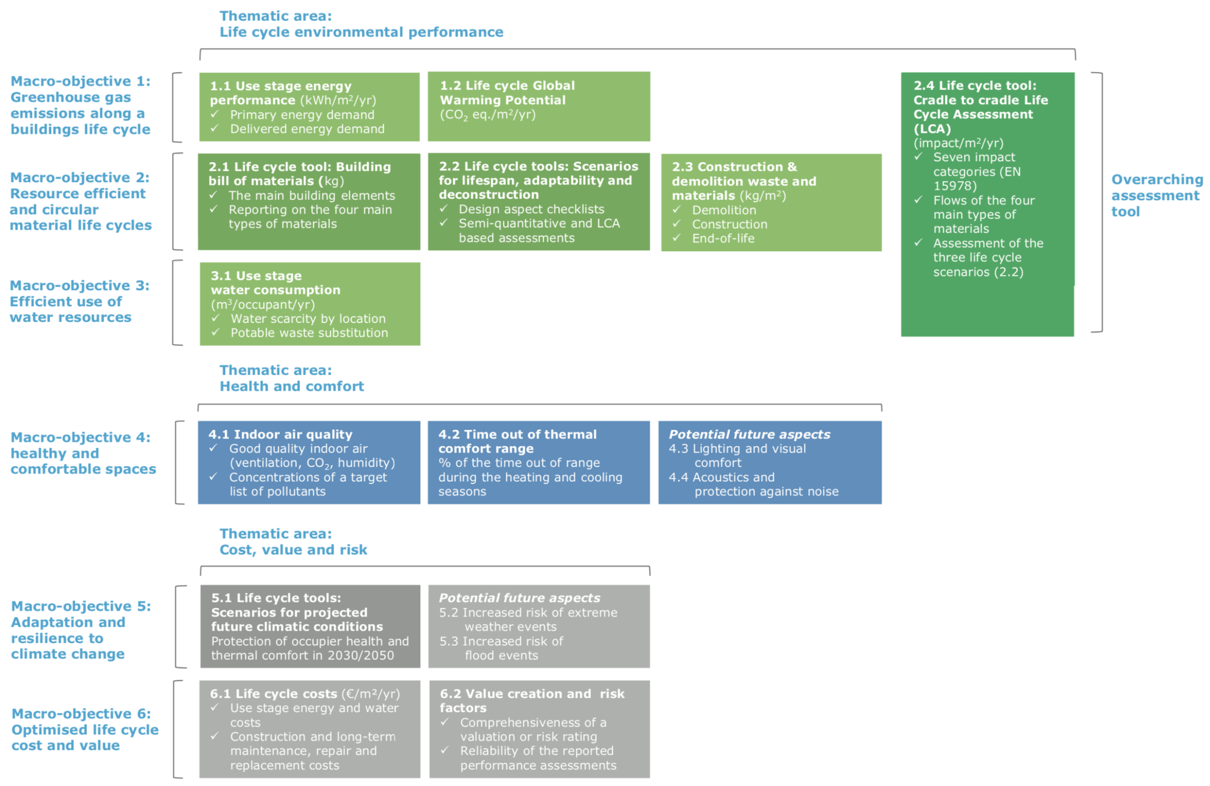


Figure 2.14: Level(s) framework overview, as illustrated on *Level(s): A guide to Europe's new reporting framework for sustainable buildings* [41].

Table 2.3: Level(s) life cycle tools.

Life Cycle Tool
Building Bill of Materials
Life Span, Adaptability and Deconstruction
Construction and Demolition Waste and Materials
Cradle to Grave Life Cycle Assessment
Scenarios for projected future climatic conditions

As for the outputs, they represent the current building performance results, in the form of core indicators (presented on figure 2.14, with the numbers 1.1, 1.2, 2.1, 2.2, 2.3, 3.1, 4.1, 4.2 and 4.3), by comparing with the goals defined by the macro-objectives, which are to be reported in standard values, to allow for comparison throughout the EU and value and risk rating (see figure 2.14, numbers 6.2), which is a self-evaluation tool, embedded in the Level(s) study itself, that classifies the quality and reliability of the data used to assess the building's performance.

Chapter 3

Methodological Framework

3.1 Purpose and Context

This work proposes a methodological framework to produce a Renovation Passport for a residential building, which ultimately leads to its energy and carbon neutrality, therefore reaching a carbon neutral NZEB. In this thesis the term chosen for the ultimate goal is 'carbon neutral NZEB' in a way that it is an expression which is practically the same as "net zero energy emissions building" [17], as defined on section 2.2.1, but since it contains the words 'carbon neutral', which immediately refers to the carbon neutrality goals for Europe and 'NZEB', which is a more common term when discussing sustainable buildings, it was considered as an expression which is easier to remember and, hopefully, to understand.

In this approach, a Renovation Passport intends to be an 'identity card' of the building and, at the same time, a guide, for its user, owner or interested parties, which advises them with the best tailored renovation and maintenance measures and sustainability best practices to reduce its carbon, energy and resource intensity footprint, throughout the building's utilisation life cycle stage. This will be very much like a maintenance record book for an automobile.

As presented in chapter 1, the Renovation Passport is proposed as a new framework, for a national scheme implementation, to achieve carbon neutral NZEBs. In order to do so, the Renovation Passport intends to grow from the already implemented scheme of building energy certification, the EPC, carry on with the good practices on energy efficiency it has been promoting, since its implementation, and add the carbon neutrality ultimate goal for the building, guiding the building user/owner through the line of RECT implementation to, in the end, reach a carbon neutral NZEB.

Besides building from the EPC, the Renovation Passport also shares ideas with the iBRoad project, as it is also meant to collect the characteristics of the building, similar to the repository (LogBook), the project presented.

At first, the Renovation Passport will be suggested as a framework for voluntary implementation, offering building owners/users which comply with the legislation requirements, benefits and for those who do not, penalties. Therefore, the main beneficiaries of the Renovation Passport are the building owners/users themselves and the key responsible agents for designing it and to oversee its correct implementation are the Renovation Passport auditors, otherwise known as Qualified Experts (QE - from the Portuguese, Perito Qualificado PQ). The QE are to be the same experts who issue the EPC, who are to be given proper training in order to adapt to the new Renovation Passport framework and to receive the necessary skills to design it for carbon neutrality.

The Renovation Passport is to reside on a digital platform, where the building user/owner would be able to access all the information needed to identify and characterise the building, to obtain a phased plan for energy performance improvement, a guide towards near zero energy and carbon neutrality, as well as to get information regarding building maintenance. Furthermore, the auditors would also be able to accede to the platform, as they are the ones responsible for inputting information on the building's energy performance current state, for designing the renovation and implementation of the renewable energy conversion technologies (RECT) and presenting them to the user/owner.

Besides upgrading the current role of QE and their set of skills, the Renovation Passport brings in an enormous potential for job creation, for training and lastly, for educating and raising awareness on the topics of best building use practices and sustainability. Some of the possible jobs, other than QE, that can originate from this service are QE mentors, credited inspection maintenance and construction hubs, web designers (for the platform) and data scientists (to treat the large amounts of information flowing and helping the QE with ever evolving calculation and decision making tools), to name a few.

3.2 Structuring a Renovation Passport

As presented on the previous section, the Renovation Passport has the goal to lead the user and interested parties towards reaching a carbon neutral NZEB, through the improvement of the energy performance and in a way that reduces the building's impact on environment. In order to encompass all these requirements, it is necessary for the Renovation Passport to have several components, as follows:

1. Milestones (see section 3.3).
2. Physical and Technical Characteristics of the Building (see section 3.4).
3. Energy Performance Improvement & Near Zero Energy Building (see section 3.5).
4. Inspection & Audit (see section 3.6).
5. Maintenance & Construction (see section 3.7).
6. Building Owner/Users Roles (see section 3.8).

Each of these components, explored in the next sections, does not act nor exist independently from the others, instead, information flows from one component to the other, goes back, across and so forth. A way to visualise the different components of the Renovation Passport can be seen on figure 3.1.

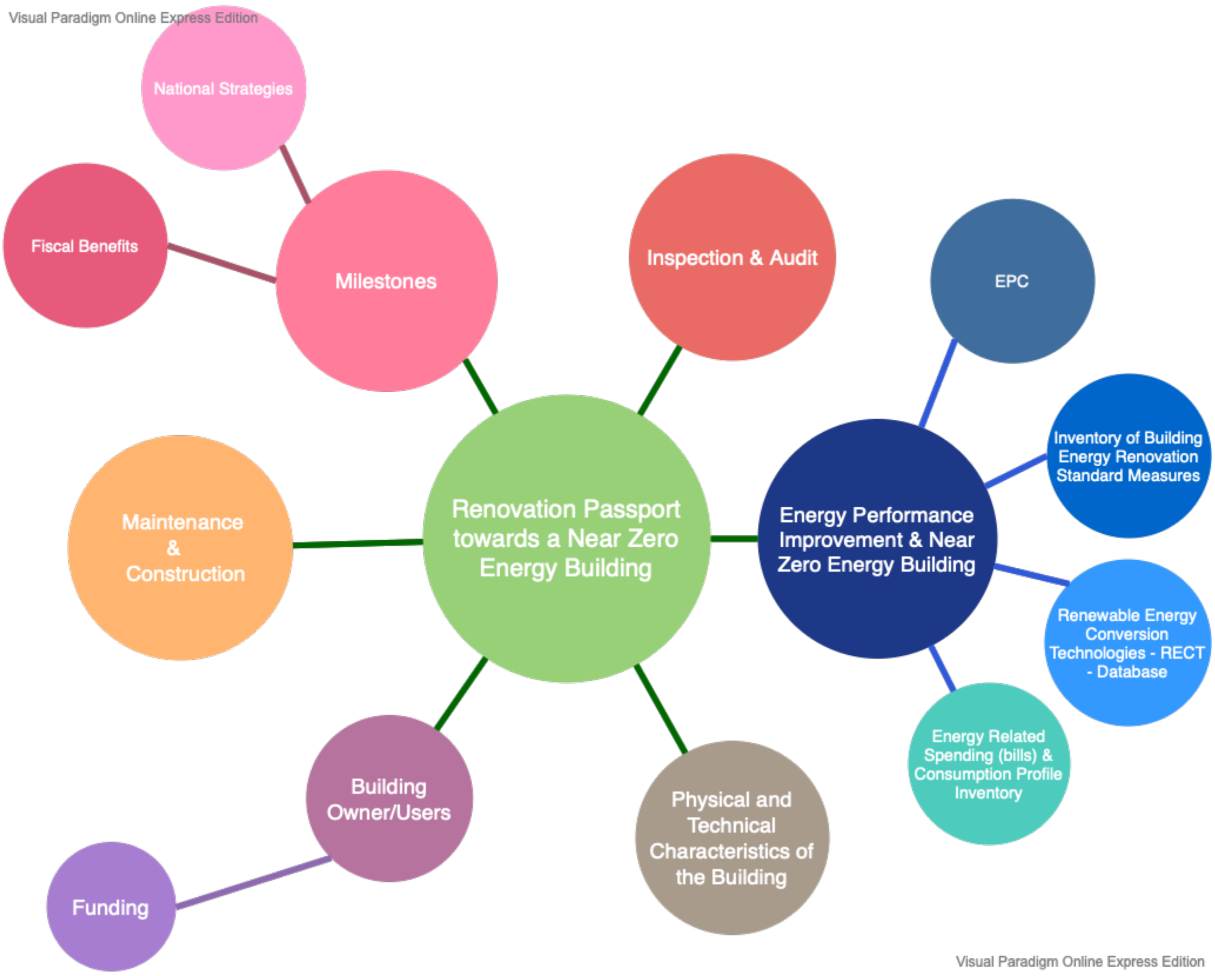


Figure 3.1: Proposed Components of a Renovation Passport.

3.3 Milestones

3.3.1 Milestones Motivation and Line-up with Current National Strategies

As presented before, the Renovation Passport intends to build from the existing Portuguese EPC framework, dedicated mostly to energy efficiency, by adding the need for carbon neutrality, as well as including a monitoring/follow-up agenda. To do so, it introduces the Milestones, which are the objectives of energy performance, that the building has to fulfil by a certain time. As discussed on chapter 2, on NZEB best practices and in order to follow what is conveyed through figure 2.5, the Milestones will first favour energy efficiency improvement and consumption reduction and then, RECT *in situ* deployment. Based on a climate neutral buildings objective for 2050, by the EU [5], *i.e.*, in 30 years, the key Milestones will be a decade apart from each other, meaning, they will be set for 2030, 2040 and 2050.

The Renovation Passport intends to be in line with the Portuguese Government recommendations and already existing energy and climate related plans, such as the National Integrated Plan for Energy and Climate 2021-2030 (Plano Nacional Integrado Energia e Clima 2021-2030, PNEC), the Carbon Neutrality Road Map 2050 (Roteiro para a Neutralidade Carbónica 2050, RNC 2050) and more recently, the Long Term Strategy for Building Renovation (Estratégia de Longo Prazo para a Renovação de Edifícios, ELPRE).

ELPRE's strategy (which is under consultation analysis [43]) proposes 4 packages for building renovation and energy improvement measures. The first one focuses on building envelope, where "passive measures" [7] can be implemented, to first reduce climatisation needs, addressing energy poverty[1] mitigation and improvement of comfort levels (from category VI to category III, or further, as per the European Norm EN 15251, see figure 3.2) at the same time [7].

Category	Explanation
I	High level of expectation and is recommended for spaces occupied by very sensitive and fragile persons with special requirements like handicapped, sick, very young children and elderly persons
II	Normal level of expectation and should be used for new buildings and renovations
III	An acceptable, moderate level of expectation and may be used for existing buildings
IV	Values outside the criteria for the above categories. This category should only be accepted for a limited part of the year

Figure 3.2: Comfort Categories, in buildings, as presented by the European Norm EN 15251 [46].

Then, ELPRE proposes its second package, which addresses energy efficiency solutions and equipment replacement, its third package, addressing RECT's and finally, the fourth package, which focuses on further improving user, in-building, comfort [7]. On figure 3.3 the proposed timeline for ELPRE's packages implementation can be seen.

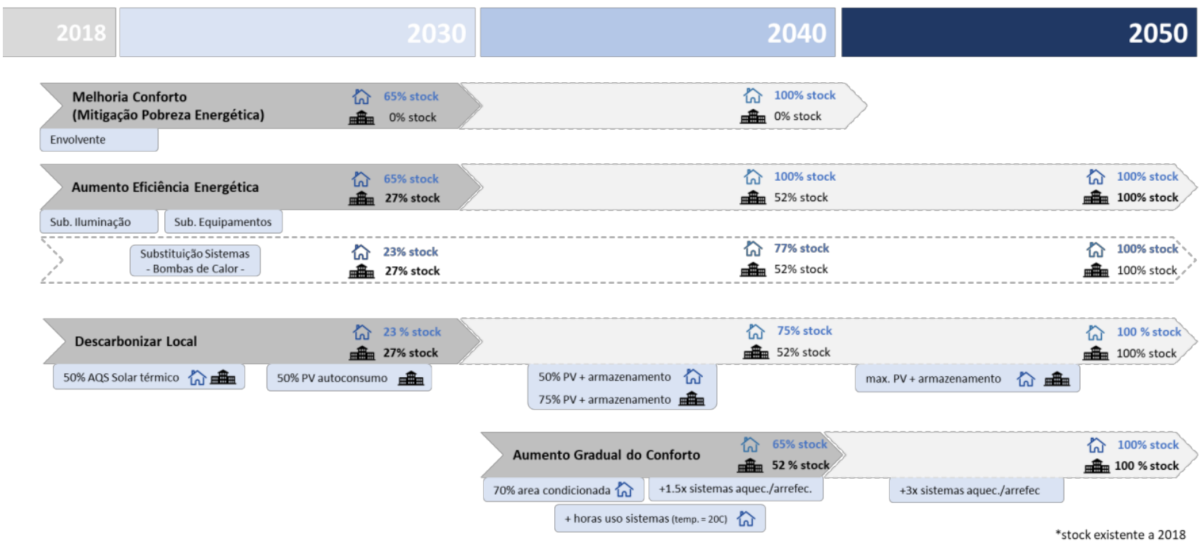


Figure 3.3: Timeline of ELPRE packages implementation, until 2050, as seen on ELPRE's report [7].

[1] According to [44], "energy poor households experience inadequate levels of these essential energy services, due to a combination of high energy expenditure, low household incomes, inefficient buildings and appliances, and specific household energy needs. It is estimated that more than 50 million households in the European Union are experiencing energy poverty". In 2018, 19.4% of the Portuguese population experienced an "inability" to keep their homes "adequately warm" [45].

Energy poverty happens when there is an inability to provide "adequate warmth, cooling, lighting" and "energy to power appliances" [44], which in turn has consequences on population's health, well-being and comfort, productivity, as well as on air pollution, "household budgets" and "economic activity" [44].

In line with ELPRE's strategy, the Renovation Passport proposes three key Milestones, as is detailed on table 3.1.

Table 3.1: Renovation Passport Milestones.

Milestone	Date	Energy	Carbon Neutrality[2]
Milestone 1	2030	Energy performance improvement	at least -35%[3]
Milestone 2	2040	50 to 75 % of consumed primary energy provided by RECT	at least -73%[4]
Milestone 3	2050	100% of consumed primary energy provided by RECT - NZEB	Carbon neutrality (-97%[5])

With Milestone 3, the Renovation Passport proposes a change to the national scheme of the EPC system, so that the definition of NZEB adopted is in line with what was discussed on chapter 2 and later, on section 3.5, a step further from the current definition of NZEB, according to Portuguese legislation, for residential buildings, defined earlier on section 2.2.1

. In order to achieve a carbon neutral NZEB, by 2050, the Renovation Passport proposes the value of N_{tc} to be very close to zero, *i.e*, close to 0% (more or less 5%, for example) of the N_t value, meaning the renewable energy component of equation 2.3 must be equal (or close) to the sum of all of the other components. This way, $\frac{N_{tc}}{N_t}$ is approximately zero as well and, therefore, the energy class of the building, becomes the highest possible (currently A+), as per equation 2.9.

Besides aiming for better energy performance and a carbon neutral and near zero energy building, the Renovation Passport improvements also have "co-benefits" [7], identified by ELPRE, on occupant health, work productivity, air quality improvement, property valorisation, as well as, the already mentioned, energy poverty mitigation.

The Renovation Passport, by focusing directly on building renovation and rehabilitation, also incorporates PNEC's recommendations for the built environment, namely reducing its carbon intensity, achieved through promoting energy efficiency (and electrification of technical systems), which is the core of the Energy Performance Improvement component as well as, promoting rehabilitation. Rehabilitation allows for improving the building's current condition(s), by applying new construction solutions and equipment, ameliorating the comfort levels for its users, as well as the quality of the building (as a construction) and its systems. Therefore, the Renovation Passport promotes the extension of buildings' lifetime, which in turn further advances the profitability of the already invested natural resources, the reduction of GHG emissions, minimises construction waste and contributes to nature and biodiversity preservation (adapted from PNEC). Milestone 1 carbon neutrality of 35% of $CO_{2_{eq}}$ emissions reduction, in comparison with 2005 values, is the value proposed by PNEC, for the national residential sector target, in 2030.

From the RNC 2050, the Renovation Passport adopts the values of $CO_{2_{eq}}$ emissions reduction proposed for 2040, 73% in comparison with 2005 values [8] and 2050, 97% in comparison with 2005 values

[2]Carbon neutrality measured in $CO_{2_{eq}}$, carbon dioxide equivalent, is "a metric measure used to compare the emissions from various greenhouse gases on the basis of their global-warming potential (GWP), by converting amounts of other gases to the equivalent amount of carbon dioxide with the same global warming potential" [47]

[3]$CO_{2_{eq}}$ emissions reduction, in comparison with 2005 values, as proposed by PNEC [48], for the residential sector.

[4]$CO_{2_{eq}}$ emissions reduction, in comparison with 2005 values, as proposed by RNC 2050 [8], for residential buildings.

[5]$CO_{2_{eq}}$ emissions reduction, in comparison with 2005 values, as proposed by RNC 2050 [8], for residential buildings.

[8], in Milestone 2 and Milestone 3, respectively. For 2050, RNC 2050 predicts the needs for heating and cooling in buildings, *i.e.*, the values of N_{ic} and N_{vc}, respectively, as per the EPC system, should be 66 to 68 % supplied by energy from renewable sources [8], thermal comfort could increase 3 times for heating and two times for cooling, regarding current standards and lastly, electrification of technical systems, solar thermal systems for domestic hot water and heat pumps for climatisation appear to be the most cost-effective solutions for decarbonisation in the building sector (adapted from [8]). On figure 3.4, the pathway for carbon neutrality, in the residential sector, proposed by the RNC 2050, can be seen.

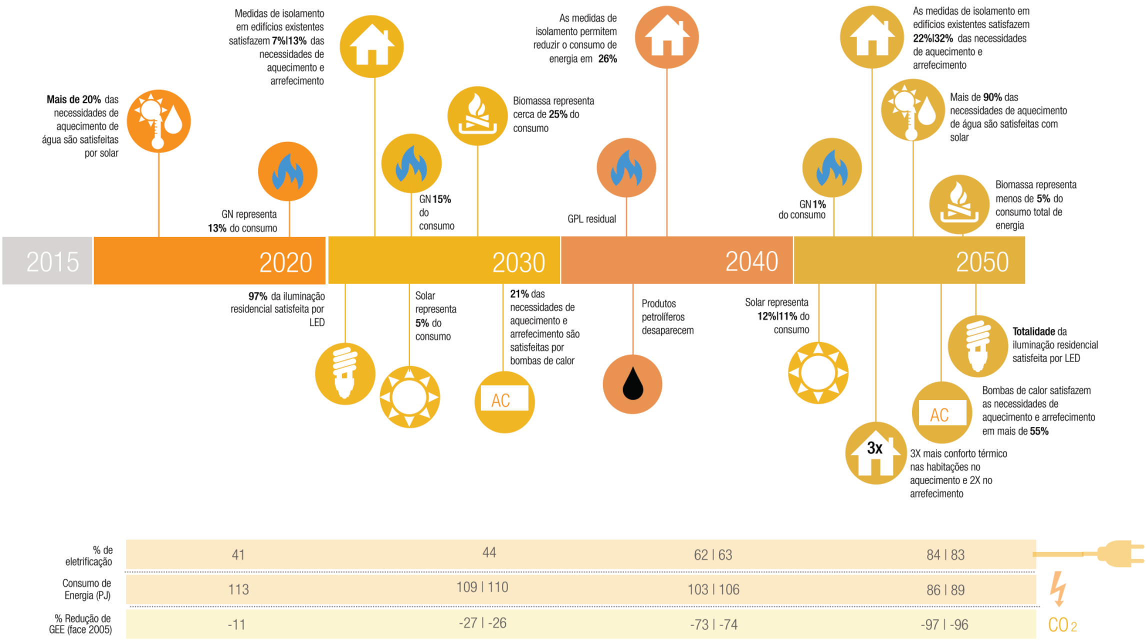


Figure 3.4: Pathway for carbon neutrality, in the residential sector, proposed by the RNC 2050 [8].

3.3.2 Fiscal Benefits

Current fiscal benefits associated with the present national scheme of the EPC system are related to the Imposto Municipal sobre Imóveis - IMI (Municipal Property Tax) and to the Imposto Municipal sobre Transmissões Onerosas de Imóveis - IMT (Municipal Tax on Property Onerous Transfer).

Nowadays, a building owner benefits from a reduction, for 5 years, of up to 25% of the IMI value for the considered year, when the building is energy efficient[6], according to what is predicted by Article 44 of the Statute of Fiscal Benefits [50], when the municipality (where the building is located) allows so, by ruling of the municipal assembly (adapted from [49]). Other buildings, either concluded more then 30 year ago or located in urban rehabilitation zones can also benefit from IMI reduction, for 3 years, if they meet the requirements of being subject of building rehabilitation interventions, promoted under the Regime Jurídico da Reabilitação Urbana [51] (Regulatory Framework for Urban Rehabilitation) and, in consequence of intervention works (as stated above), the building achieves a conservation status, two levels above of its previous one, achieves, at least conservation level ”good” and meets the requirements

[6] A building is considered to be energy efficient when its energy class is A or superior or when, after construction, rehabilitation, modification, expansion and conservation works, its energy class is, at least, two classes above the one considered before the works [49].

of energy efficiency and thermal quality, according to what is predicted by Article 45 of the Statute of Fiscal Benefits [50] (adapted from [49]).

Similar to this last case (buildings, either concluded more then 30 year ago or located in urban rehabilitation zones, according to what is predicted by Article 45 of the Statute of Fiscal Benefits [50]), these buildings can benefit from IMT exemption, as long as they fulfill the requirements mentioned above [49] (being subject of building rehabilitation interventions, promoted under the Regime Jurídico da Reabilitação Urbana [51] (Regulatory Framework for Urban Rehabilitation) and, in consequence of intervention works (as stated above), the building achieves a conservation status, two levels above of its previous one, achieves, at least conservation level "good"[7] and meets the requirements of energy efficiency and thermal quality).

The Renovation Passport, as a national scheme to be implemented, intends to contribute to a more ambitious approach on benefits for building owners/users who adopt this framework, by tapping onto the already existing tax benefits, associated with the EPC system, and further developing them, making them more attractive for investors, promoting more municipalities to allow and apply these benefits and creating the legal basis for their implementation.

To implement a benefits plan, national level research and a deep financial analysis would have to be performed, when and if the Renovation Passport framework is considered at legislative level, in order to have a well sustained and legal structure. Many factors should be considered in this analysis, such as compliance with the Renovation Passport Milestones and proof of improved energy performance and overall comfort. However, since carbon neutrality is a national target for 2050, which implies the decarbonisation of, as much as possible, several sectors, including the building sector, it might not be the best solution to allow for a 100% reduction of IMI, for example, in case the building achieves Milestone 3, without finding an alternate income source for the State, as, in theory, every building should reach carbon neutrality by 2050, and if total IMI reduction would be put to practice, the State would stop receiving that income. Nonetheless, for building owners/users, it would be an incentive to have some degree of tax benefit, specially, for boosting early adoption of the Renovation Passport scheme. With this in mind, the benefits plan would have greater tax reductions for the buildings which reach Milestones 1 and 2 (in 2030 and 2040) and a less pronounced reduction for Milestone 3, as this one would have a compulsory attribute (since carbon neutrality is a national target).

3.4 Physical and Technical Characteristics of the Building

The physical and technical traits of the building are the basic information from which the Renovation Passport is built upon. They are what characterise the building and can differentiate it from other buildings. The information that should be stored in this component's database is the one described at table 2.1, regarding construction, envelope, heating and cooling solutions, ventilation and others. Information in this database should be arranged in the described topics (table 2.1). It is the QE who is responsible

[7] According to Decree-Law 266-B/2012, building conservation levels are divided as following: 1 - Awful; 2- Bad; 3 - Average; 4 - Good and 5 - Excellent (adapted from [52]).

for putting up this information together and in a coherent manner, gathering data from *in loco* visits, from the building owner/user and from original construction elements such as plants and reports.

3.5 Energy Performance Improvement & Near Zero Energy Building

This component of the Renovation Passport is the most 'proactive', as it is the one which promotes actual change, in order to achieve a better (energy) building. The first approach of this component aims to guide the user to reduce energy consumption, of all sorts, and increase equipment energy efficiency, to promote a smarter and less intensive use of energy, contributing, in turn, to lower energy related expenses and to decrease GHG emissions, associated to transformation/conversion, transport and distribution of the energy used in the building. The second approach of this component intends to achieve a carbon neutral (NZEB), following the best practices (discussed on chapter 2, section 2.2.2) of firstly, reducing energy consumption (as per the first approach) and secondly, proposing *in situ* (*i.e*, within the building's boundaries) RECT units to make the building self-sufficient, in terms of energy.

This Energy Performance Improvement & Near Zero Energy Building component of the Renovation Passport can be organised in three phases. In the first two, the focus is precisely on energy performance improvement, by reducing consumption and enhancing equipment energy efficiency. In the last phase, the focus is on turning the building into a carbon neutral NZEB.

3.5.1 Inputs

The inputs needed are first, the EPC itself, which is the basis of the energy diagnosis of the building and second, others referred to as 'database inputs' as they are to be data which should reside in four organised databases:

1. Physical and Technical Characteristics of the Building (see section 3.4).
2. Inventory of building energy renovation standard measures.
3. Energy related spending (bills) and consumption profile inventory.
4. Renewable Energy Conversion Technologies Database.

The first database is one of the components of the Renovation Passport itself. It is of extreme importance to start the procedure, as it contains all the information that characterises the building, which support the identification of the elements of the building that can be considered for renovation and what renovation measures do not belong on the renovation works, of the building in case, as they refer to building elements that do not or cannot exist within the building.

The second database should be a repository of several standard energy renovation measures, which have been used in other renovation works or recommended in former EPC's, and serve as guide. Preferably, the standard energy renovation measures should be divided, within the database, in the same fields by which the Physical and Technical Characteristics of the Building database is divided, when it comes to energy related systems, therefore, aggregated on the topics of envelope, heating and cooling solutions, ventilation and others (see section 3.4).

The third database should gather information on current energy consumption and expenses (bills) as well as the energy consumption profile associated to the building's use, providing a picture of the current energy needs of the building. Regarding the energy expenses, the building user/owner could either manually enter the consumed energy amount and corresponding price, or the Renovation Passport digital platform could read those values directly from the building user/owner online account of the utility service they have contracted. As for the energy consumption profile, unless the building already has a system of energy meters implemented, which would directly deliver the consumption profile, a survey or a sample test (by installing meters during a fixed period) would have to be performed. Having the consumption profile defined allows for information to be drawn on how much energy is used and when is it used.

Finally, the fourth database should contain the necessary information to dimension RECT units, such as type of technology, functionality, amount of power generation, amount of power generation per square meter (in the case of solar panels), amount of energy storage capacity (for batteries), etc, hence being an important tool to quickly model the RECT units to be installed in the building, to cover its energy needs and reach a carbon neutral NZEB.

3.5.2 Phase 1

As the Renovation Passport framework embraces the already existing EPC system, the starting point for this component's first phase is precisely the EPC as it currently exists. In the end of this phase the measures that can be applied to the building are formulated/selected.

The first step the QE must take in this phase is to issue the building's EPC, as they would in the current national system, in order to understand the building's current energy performance and assigning an energy class. For this, the information from 'Physical and Technical Characteristics of the Building' is needed, so the QE can fill out the energy class calculation sheet (such as the one developed by Itencons[8]). The information may be collected from several sources and documents, however the most relevant and accurate is obtained through *in loco* energy audit.

Energy Audit Definition

According to Allouhi *et al.*, an energy audit can be described as "an inspection or survey analysis of energy flows in a structure, in a process or in a system, intended to reduce the amount of energy input without negatively affecting the outputs" [54] and it "is the primary phase in proposing possibilities to diminish energy expense and carbon footprints" [54].

Energy audits can be used for "decision-making in the area of energy management" [54] as they help to "understand, quantify, and analyse" [54] where energy utilisation occurs, by identifying the following:

[8] Itencons is the Instituto de Investigação e Desenvolvimento Tecnológico para a Construção, Energia, Ambiente e Sustentabilidade, in English, Institute for Research and Technological Development for Construction, Energy, Environment and Sustainability - Coimbra University [53].

1. ”Where waste takes place” [54].
2. ”Critical points” [54].
3. ”Discover opportunities where energy consumption can be reduced” [54].

Regarding the last point, energy audits help point out what energy performance improvement measures (”by means of eco-efficient and feasible practices and energy conservation methods” [54]) need to be put to practice, to improve that performance and reduce energy related costs.

Types of Energy Audits

Allouhi *et al.* propose the different types of energy audit are dependant on the following factors:

1. ”Function, type, size, and configuration of the structure energy systems” [54].
2. ”Depth to which the audit is required” [54].
3. ”Project specifications confirmed by the client” [54].
4. ”Scope and potentials proposed by the energy auditor” [54].
5. ”Level and magnitude of projected energy savings and cost reduction intended” [54].

Furthermore, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) suggests three levels of auditing, where the previous factors are explored in increasing depth. Those are the ”ASHRAE Level 1 – walk-through analysis/ preliminary audit” [54], the ”ASHRAE Level 2 – energy survey and analysis” [54] and finally ”ASHRAE Level 3 – detailed analysis of capital intensive modification” [54].

Techniques and Procedures

According to Allouhi *et al.*, an energy audit usually has ”four main phases”, each with a number of steps, as presented below (taken and adapted from Allouhi *et al.* [54]) :

1. Audit Preparation.
    - Defining audit level, criteria and scope.
    - Selection of audit team.
    - Setting objectives.
    - Planning the audit.
    - Data collection.
    - Preliminary analysis.
2. Audit Execution.
    - Data inventory and measurements.
    - Analysing energy use patterns.
    - Diagnosing energy systems.
    - Exploring and comparing opportunities.
    - Identifying potential improvement measures.
    - Economical assessment.
3. Audit Reporting.

- Writing the energy audit report.
- Communicating with the client.
- Prioritising and decision-making support.

4. Post-Audit Activities.
   - Implementing improvement measures.
   - Checking performances.
   - Maintaining measures.

Energy Audits in the Renovation Passport

In the context of the Renovation Passport, energy audits should be performed, at first to understand the current situation of the building, much like what happens for EPCs, *i.e*, before renovation takes place. In this first approach, waste, critical points and opportunities to reduce energy consumption should be identified, as stated above.

The depth at which the audit should be performed, should be enough to point out as many possibilities of energy improvement/renovation as possible (similar to what is done for EPCs). This way, the building user/owner would have more information to work with and could then choose, with guidance and expertise from auditors, which path of renovation to follow (meaning, the pool of energy performance improvement measures to apply) depending, among others, on how much they are willing to invest.

Auditors should keep track of the Energy Performance Improvement & Near Zero Energy Building component while it is being processed. While on phase 1 (for more details, refer to section 3.5), when the pool of renovation measures is being chosen, auditors should check and have a key aspect in mind, which is to guarantee the chosen pool does not cause "lock-in effects" [40], *i.e.* that it does not affect future renovation work by implementing measures which affect and/or do not allow future renovation to take place, thus, not ensuring a competent good long-term strategy.

After renovation and/or the achievement of a Milestone takes place, another energy audit should be performed to assess the new energy performance of the building. This audit should verify if the proposed improvements were achieved and, depending on user's will and power of investment, outline future possible renovations , in a continuous improvement mindset.

Following this 'after renovation energy audit', further energy audits should be replaced by maintenance inspections, unless they are demanded specifically, by regulation (to be implemented).

BIM

The second step to be taken aims at promoting a possible automisation of the process of obtaining the values for the building energy demand, as is, and consequently, understand its energy performance. This step is to create the building's model in BIM - Building Information Modelling[9]. The potential ap-

[9] According to Poljanšek, "BIM, short for Building Information Modelling, is a digital tool disrupting the construction industry as a platform for central integrated design, modelling, asset planning running and cooperation. It provides all stakeholders with a digital representation of a building's characteristics in its whole life-cycle and thereby holds out the promise of large efficiency gains. One particular area where standardisation on BIM is needed is the exchange of information between software applications used in the construction industry" [55].

plication of this tool is illustrated on figure 3.5. By modelling the building in BIM, the QE would benefit from the possibility to automate the process of verifying the impacts, on energy demand and consumption, from the chosen improvement measures, therefore, accelerating the whole Renovation Passport process.

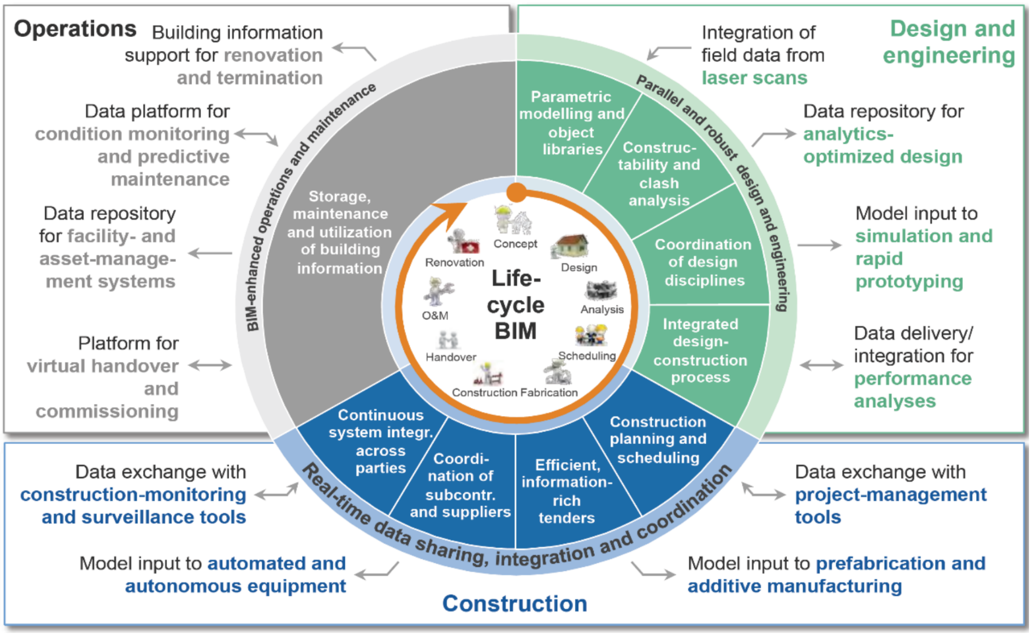


Figure 3.5: The potential application of BIM, throughout a building's lifecyle, as illustrated on [55].

Energy Performance Improvement Measures

Once the energy needs and energy class of the building are known, as well as the main energy consumers (in terms of installed equipment) have been identified, the QE can now suggest and recommend energy performance improvement measures customised for the building in case. Here is where the information from 'Inventory of building energy renovation standard measures' is required, as having a base to choose from, will help the QE decide the measures which can be applied to the building, as it is their job to compare information from these two databases, to choose the best and more suitable improvement measures. Their impact can be assessed by means of using the Itencons' tool or through BIM.

The information contained on 'Physical and Technical Characteristics of the Building' database is the the one described in section 3.4 and the one contained on the 'Inventory of building energy renovation standard measures' database could be provided by ADENE, as the potential entity responsible for the Renovation Passport scheme and the EPC system, drawn from improvement measures which were stated and reported on previous EPC, with specific details on measure description, implementation cost, energy saving potential, financial savings potential, measure lifetime, floor area affected by the measure (for comparison purposes, from building to building). It is important to categorise the measures to be applied. The most urgent measures to implement should be the ones that, on the one hand provide the greatest energy savings, both in kWh consumed and in €, in the energy bill, and on the other hand have the minimal possible cost and have the shortest payback time, or, in other words, measures that have the lowest cost of conserved energy (see section 2.3.1). This way, renovation which leads to lower consumption, which should be the first problem to solve, can be started.

Once the measures are chosen, the new values of energy consumption and the new consumption profile (the two desired outputs of phase 2), should be calculated, assuming the measures are applied to the building.

From improvement measures indicated in previous EPC's, which could be provided by ADENE's SCE database, the following values could be obtained, for residential buildings, as seen on table 3.2. With

Table 3.2: Information which could be provided by ADENE, through their SCE database, regarding common improvement measures, for residential buildings.

Measure definition/ naming
Measure associated with
Average floor area [m^2]
Average investment cost [€]
Average financial savings $\left[\frac{€}{Year}\right]$
Average energy savings $\left[\frac{kWh_{PE}}{m^2 \cdot Year}\right]$

the available data, the best way to organise the measures is to calculate the payback time for each one and arrange the measures from lowest to highest payback time. The payback time can be calculated through equation 3.1.

$$\text{Payback Time [Year]} = \frac{\text{Average investment cost [€]}}{\text{Average financial savings [€/Year]}} \tag{3.1}$$

The reason why the cost of conserved energy, in $\left[\frac{€}{kWh}\right]$, is not the criteria used to organise the improvement measures is simply because, with the available data and that can possibly be shared by ADENE, the cost of conserved energy cannot be accurately calculated. Given the available data, the closest which could be calculated would be what is described by expression 3.2.

$$\frac{\frac{\text{Average investment cost}}{\text{Average floor area}}}{\text{Average energy savings}} \tag{3.2}$$

Which would be described in the following units:

$$\frac{\frac{€}{m^2}}{\frac{kWh}{m^2 \cdot Year}} = \frac{€}{kWh} \cdot Year \tag{3.3}$$

Only by having the number of years of the lifetime of a measure could the cost of conserved energy be found, by diving the value resulting from expression 3.2 by the lifetime years of the measure. Since that information is not available, then the cost of conserved energy cannot be obtained.

Some of the most common energy performance improvement measures applied on buildings are focused on the following topics.

Building Envelope

The building envelope is what 'surrounds' the building, separates it and isolates the inside from the outside environment and its purpose is to add "external protection to enhance the quality and control the indoor conditions irrespective of transient outdoor conditions" [54]. It is composed by the opaque part, which includes "walls, roofs, floors, and insulation" [54] and the transparent part, which comprises "windows, skylights, and glass doors" [54]. On table 3.3, more details on building envelope parts, their purpose and retrofit opportunities can be found (taken and adapted from Allouhi *et al.* [54]).

Table 3.3: Parts of the Building Envelope, their Functions and Retrofit Opportunities

Section	Function	Critical Parameter	Retrofit Opportunities
Thermal Insulation	"Increase the thermal resistance and decrease energy consumption for the cooling and heating of the internal space" [54].	Thermal Resistance[10] & Conductivity of the insulating material[11] & Insulation Thickness[12].	The energy auditor should, by means of calculations and simulations, suggest the better suited insulation material and respective thickness, to increase the thermal resistance up to a point where energy savings related to its application are cost-effective.
Windows	Allow daylight in, a view to the exterior, ventilation and "protection against the external environmental conditions (heat, cold, wind, noise)" [54].	Opacity of glass & Conductivity of framing materials.	The auditor must propose the material that best reduces cooling and heating loads through solar gains, but affects the least daylight utilisation, as well as the most insulating framing material.
External Shading	"Prevent the penetration of solar radiation into the building in summer, while allowing the needed solar gains in winter" [54].	Reflection, Absorption and Scattering of Solar Radiation.	The auditor must choose the external shading that allows for better protection against solar radiation, without compromising daylight utilisation and minimising artificial lighting needs.
Air Infiltration	Breathing air renovation and air quality maintenance.	Air renovation rate & Outside temperature.	The auditor must propose air seal mechanisms to avoid great air renovation rates, which affect heating and cooling loads, while not compromising air quality. The auditor can also propose a mechanical ventilation system for better 'air management'.

Heating, Ventilation, and Air-Conditioning Systems

Heating, ventilation and air-conditioning systems, commonly referred to as HVAC systems, are the ones that "control air temperature, flow, and humidity levels to allow a suitable indoor environment for human activity" [54].

[10] Thermal Resistance: The thermal resistance of the wall, with insulation, increases according to this expression: $\Delta R = \frac{1}{U_(after)} - \frac{1}{U_(before)}$ [54].

[11] Conductivity of the insulating material: λ in $\frac{W}{m.K}$.

[12] Insulation Thickness: $s = \Delta R \times \lambda$.

According to Seyam [56], HVAC systems can be classified into two groups, central or local (decentralised). The central system serves the whole building or several thermal zones and is normally located "outside the served zones", in a "suitable central location whether inside, on top, or adjacent to the building" [56] while the local serves a particular zone of the building, which is normally located inside that zone. On figures 3.6 and 3.7, the sub-categories of each group (local and central HVAC system) are illustrated.

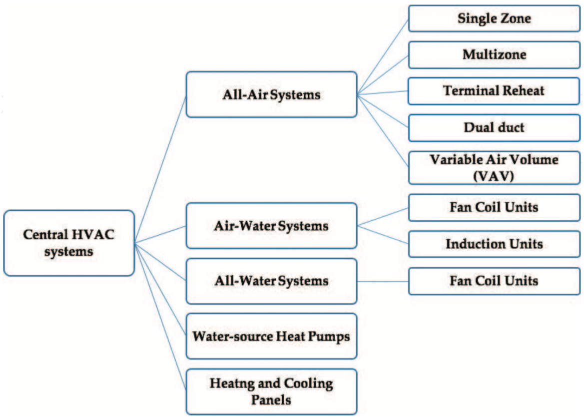


Figure 3.6: Central HVAC systems, as illustrated by Seyam [56].

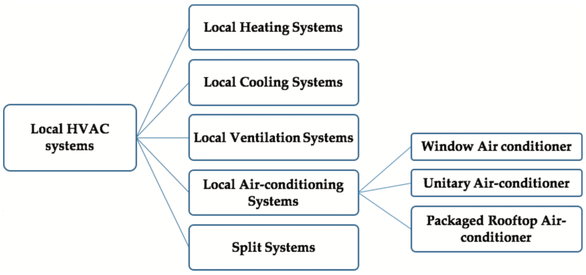


Figure 3.7: Local HVAC systems, as illustrated by Seyam [56].

Moreover, according to the EU Strategy for Heating and Cooling [57], the most common heating supply solutions are the ones presented on figure 3.8 and the most common cooling technologies are those stated below. Most of these technologies provide not only cooling but also heating as well as humidity regulation.

1. Electric cooling machines.
   - Air conditioners/Heat Pumps.
   - Chillers ("either water or air cooled, produce chilled water to cool the air in buildings" [57]).
2. Thermal cooling machines.
   - Sorption chillers (heat from fuel burning, district heating and cooling and waste heat).
   - Heat Pumps (heat from fuel burning, district heating and cooling and waste heat).
3. Free cooling machines.
   - Heat Pumps (cold from "rivers, lakes and seas" [57]).

HVAC systems, according to Ürge-Vorsatz *et al.* [58], account for approximately 62% of energy used in residential buildings and about 50% of energy used in commercial buildings. Therefore, reducing HVAC energy consumption means a great deal on reducing building energy consumption. Several parameters affect HVAC "energy use, efficiency, and cost of operation" [54], such as "design", "duty cycle", "type of occupancy", "type of HVAC equipment installed", as well as, "climatic conditions" [54]. For that reason, energy saving measures, such as the following, should be implemented.

1. "**System maintenance**" [54] : Ensures proper functioning of equipment and verifies other conditions such as "dirty heat exchange surface, clogged filters, and inoperable or malfunctioning dampers" [54].
2. "**Thermostat calibration and setback**" [54] : Avoiding too high heating temperatures and too low

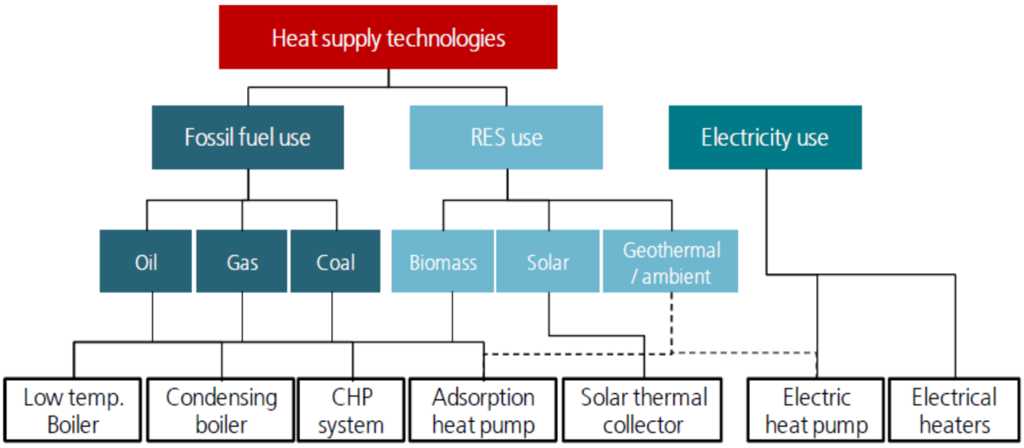


Figure 3.8: Heating supply technologies, as illustrated in the EU Strategy for Heating and Cooling [57].

cold temperatures, as they may not be strictly necessary, yet, increase the energy consumption a lot. Moreover, "smart thermostats" can also be installed, controlling the temperature based on time of day and season [54].

3. "**Equipment modification**" [54] : Retrofitting existing equipment to obtain more energy efficiency.
4. **Implementing "economiser systems and enthalpy controllers"** [54] : Systems which control temperature and humidity levels, while reducing consumption from HVAC equipment as much as possible.
5. "**Heat recovery techniques**" [54] : Recovering "heat from exhausts" [54] to apply elsewhere, thus reducing demand.

Lighting System

According to Ürge-Vorsatz *et al.* [58], lighting accounts for 10% of energy used in residential buildings and about 20% of energy used in commercial buildings. Some of the most common energy saving measures applied to lighting systems are the following, as stated by Allouhi *et al.* [54]:

1. **Install energy efficient lamps**.
2. **Install automatic lighting controls**: These controls automatically turn the lights on or off, by reading information from "occupancy sensors", "photosensors" and "dimmers" which adjust lighting to the level of daylight and also from "timers" [54].
3. **Taking advantage of natural lighting**: which can be reached through collecting daylight inside the building, distributing that light through the spaces as well as protecting and controlling the daylight which goes in, by means of shading and "movable screens", to protect against "visual discomfort" (and potentially thermal discomfort as well) [54].

3.5.3 Phase 2

In the second phase, after the measures to be applied are put into an hierarchy, by the QE, based on criteria involving investment cost, energy and financial savings, the QE must calculate the expected new energy consumption values and a new energy consumption profile, obtained from implementing the improvement measures. Once the measures have been put to a hierarchy, then they must be chosen by the QE, who must have in mind Milestone 1, *i.e.* at first, energy consumption must be reduced as much as possible (also to comply with NZEB best practices). However, when choosing the improvement measures, the QE must be aware of the payback time and not only opt for those that have the shortest one, but also, whose payback time is feasible and does not last for decades, for example. When the QE chooses the pool of measures to be considered, then, the next step is to calculate the energy and financial savings that come from investing on and applying the chosen measures to the building, these together with obtaining the new consumption profile, are the desired outputs of phase 2.

To know the total average energy savings of the pool of measures chosen, in a year, the sum of the value of average energy savings for each measure needs to be multiplied by the useful floor area of the building being studied, as expressed on equation 3.4.

$$\text{Total average energy savings} = A_{\text{floor}} \cdot \sum(\text{Average energy savings})_{\text{measure}} \tag{3.4}$$

Where

Total average energy savings is in $\frac{kWh}{Year}$.

A$_{\text{floor}}$ is the useful floor area of the building considered, in m^2.

$\sum$(**Average energy savings**)$_{\textbf{measure}}$ is the sum of all the average energy savings, of each measure, of the pool, in $\frac{kWh}{m^2 \cdot Year}$.

The logic is similar to calculate the total average financial savings, per year, of the pool of measures which would be the sum of the value of average financial savings for each measure, as expressed on equation 3.5

$$\text{Total average financial savings} = \sum(\text{Average financial savings})_{\text{measure}} \tag{3.5}$$

Where

Total average financial savings is in $\frac{€}{Year}$.

$\sum$(**Average financial savings**)$_{\textbf{measure}}$ is the sum of all the average financial savings, of each measure, of the pool, in $\frac{€}{Year}$.

It is important to know the total average energy savings, as carbon savings can be estimated from those, according to equations 3.6 and 3.7, which refer to the savings in carbon from consuming less electricity and less natural gas (which are, currently, the most consumed sources of energy, in residential buildings, in Portugal [59]).

$$\text{Carbon savings}_{\text{electricity}} = \text{Total average electric energy savings} \cdot \text{Specific emissions}_{\text{electricity}} \tag{3.6}$$

Where

Carbon savings$_{\text{electricity}}$ are the amount of $CO_{2_{eq}}$ which is avoided to be sent to the atmosphere, by consuming less electricity, in grams of $CO_{2_{eq}}$ per year $\frac{gCO_{2_{eq}}}{Year}$.

Total average electric energy savings is the amount of energy savings due to electric energy consumption reduction, in $\frac{kWh}{Year}$.

Specific emissions$_{\textbf{electricity}}$ are the specific carbon emissions of the electricity producing system, in Portugal, in July 2020, which are about 225 $\frac{gCO_{2_{eq}}}{kWh}$, according to [60].

$$\text{Carbon savings}_{\text{NG}} = \text{Total average natural gas savings} \cdot \text{Specific emissions}_{\text{NG}} \tag{3.7}$$

Where

Carbon savings$_{\textbf{NG}}$ are the amount of $CO_{2_{eq}}$ which is avoided to be sent to the atmosphere, by consuming less natural gas, in grams of $CO_{2_{eq}}$ per year $\frac{gCO_{2_{eq}}}{Year}$.

Total average natural gas savings is the amount of energy savings due to natural gas, for energy purposes, consumption reduction, in $\frac{kWh}{Year}$.

Specific emissions$_{\textbf{NG}}$ are the specific carbon emissions of natural gas combustion, which according to IPCC [61] are 50 $\frac{gCO_{2_{eq}}}{MJ}$ of natural gas, which is 180 $\frac{gCO_{2_{eq}}}{kWh}$[13].

Some useful conversion factors for 1 Nm^3 (normal cubic meter)[14] of natural gas, taken from DGEG, are shown on table 3.4, as a function of the heating value considered[15]

Table 3.4: Conversion factors for 1 Nm^3 of natural gas, as a function of the heating value, using values presented by DGEG, on their official conversion factors table, for 2018[16].

Unit	Low Heating Value	High Heating Value
MJ	38.69	42.81
kWh	10.75	11.89

If any other types of fuel are used in the building, the carbon savings can be found applying the same expressions to the corresponding values a specific emissions considered for that fuel. On table 3.5, some values of specific emissions, or conversion factors, from primary energy to CO_2 emissions, per energy source, in $\frac{kgCO_2}{kWh_{PE}}$[17], as defined in Portuguese Dispatch 15793/2013 [20], can be seen.

The sum of Carbon savings$_{\text{electricity}}$ with Carbon savings$_{\text{NG}}$ must be greater than or equal to 35% of the previous building energy consumption associated carbon emissions, prior to energy performance improvement measures being applied, according to what is specified for Milestone 1, on table 3.1. Note that this 35% reduction considers 2005 values. However, since those maybe hard to retrieve, then, energy related building carbon emissions of the last year(s) can be considered instead, which can be inferred through the previous energy bills (using the same expressions as in equations 3.6 and 3.7, but instead of electricity and natural gas savings, using actual electricity and natural gas consumption). This

[13] 1 kWh = 3.6 MJ and 1MJ = 0.2778 kWh.

[14] 1 m^3 of natural gas at the conditions of 0°C , of temperature and 101.325 kPa, of pressure, according to DGEG.

[15] According to Morgan and Shapiro, on *Fundamentals of Engineering Thermodynamics* [62] ”the heating value of a fuel is a positive number equal to the magnitude of the enthalpy of combustion. Two heating values are recognized by name: the higher heating value (HHV) and the lower heating value (LHV). The higher heating value is obtained when all the water formed by combustion is a liquid; the lower heating value is obtained when all the water formed by combustion is a vapor. The higher heating value exceeds the lower heating value by the energy that would be released were all water in the products condensed to liquid. Values for the HHV and LHV also depend on whether the fuel is a liquid or a gas”.

[16] Available on [63] (DGEG website), under the tab ”Conversões energéticas (1990 a 2019)”.

[17] The suffix PE refers to primary energy.

Table 3.5: Conversion factors, from primary energy to CO_2 emissions, per energy source according to Portuguese Dispatch 15793/2013 [20].

Energy Source	Conversion Factor $\left[\frac{kgCO_2}{kWh_{PE}}\right]$
Electricity	0.144
Diesel	0.267
Natural Gas	0.202
Pipe distributed LPG (propane)	0.170
Bottled GPL	0.170
Renewable	0.0

is expressed by equation 3.8.

$$\text{Carbon savings}_{\text{electricity}} + \text{Carbon savings}_{\text{NG}} \geq 0.35 \cdot \text{Prior annual carbon emissions} \tag{3.8}$$

This means that for Milestone 1, carbon emissions reduction should be achieved by improving energy efficiency and reducing energy consumption.

Again, if any other energy source is used in the building, the carbon savings of that source should be considered on the left side of equation 3.8.

It is also important to know the total average financial savings as they show the building owner/user how much is saved, in €, once the initial investment is done. Besides, the total average financial savings, together with the total average energy savings may be a decisive factor of eligibility for potential funding aid. Moreover, it is an element of motivation, for the building owner/user to invest on energy performance improvement.

3.5.4 Phase 3

In the final phase, the building's on-site renewable energy conversion potential is addressed, in order to achieve self-sufficiency. To do so, the QE must model the best and most suited RECT to implement in the building, to achieve a carbon neutral NZEB, through information made available by the 'Renewable Energy Conversion Technologies Database' and bearing in mind the new values of energy consumption and energy consumption profile, obtained in the previous phase 2 (see section 3.5.3).

The 'Renewable Energy Conversion Technologies Database' could be provided by ADENE, as the managing entity for the implementation of the Renovation Passport scheme, or other institutional entities such as DGEG - Direcção-Geral de Energia e Geologia (Directory General for Energy and Geology), INE - Instituto Nacional de Estatística (Statistics Portugal), PORDATA (Present-day Portugal Database) or even universities and research centres.

In case the QE cannot access an already assembled database, the QE must research and obtain information on the available technology, as well as market conditions, limitations and prices. If this is the case, it is advisable that the QE organises the information gathered in a database of their own, which can be used by them in the future.

To note that this section of the process should only be addressed after measures to significantly reduce energy consumption are implemented/studied/calculated, according to NZEB best practices. Having the new, *i.e.* after renovation, energy needs and consumption profiles, the QE must model the RECT unit that is to be considered for the building, that best fits the consumption peaks and overall necessary energy to keep the user comfortable, healthy and satisfied.

Normally, in Portugal, for buildings in the city, the most utilised RECT system is solar panels, both for electricity generation and water heating. However, other sources can be considered, depending on the building's situation.

Phase 3 is to be commenced after the objectives of Milestone 1 have been reached. The RECT must first be chosen to fulfil the requirements of Milestone 2 (50-75% renewable energy consumed and at least 73% $CO_{2_{eq}}$ emissions reduction) and then Milestone 3 (100% renewable energy consumed, *i.e.* a carbon neutral NZEB).

Based on the equations, presented on chapter 2, section 2.2.3, to calculate the energy balance in a NZEB, the following expressions will be considered for calculation and to verify if the the renovated building is achieving Milestone 2 and 3. Adapted from equation 2.7, proposed by Sartori *et al.* [27], equation 3.9 must be satisfied by the renovated carbon neutral NZEB.

$$|\text{import}| - |\text{export}| \geq 0 \tag{3.9}$$

Where |import| should be considered the same as the New Total Annual Energy Consumption (New Total AEC) and the |export| should be considered the same as the total energy, from renewable sources, converted by the *in loco* RECT units. These are annual values.

Since the energy balance is to be made in terms of primary energy (see section 2.2.3), the value of New Total Annual Energy Consumption (New Total AEC), which is in final energy needs to be converted to primary energy, using the adequate conversion factors. This value can be calculated through equation 2.6 (chapter 2, section 2.2.3), considering each of the values to be annual values. On table 3.6, the conversion factors, from final to primary energy, according to Portuguese Dispatch 15793/2013 [20], are shown.

Table 3.6: Final to Primary Energy Conversion Factors according to Portuguese Dispatch 15793/2013 [20].

Energy Source	Conversion Factor
Electricity (both Renewable and Non-Renewable)	2.5[18] $\frac{kWh_{PE}}{kWh_{FE}}$ [19]
Solid, Liquid and Gaseous Non-Renewable Fuels	1 $\frac{kWh_{PE}}{kWh_{FE}}$
Renewable Thermal Energy	1 $\frac{kWh_{PE}}{kWh_{FE}}$

When consuming electricity from the grid, it is necessary to know exactly the quantity of each energy source consumed and which percentage from that, is renewable, in order to calculate the correct (primary) energy balance.

Besides respecting the condition imposed by equation 3.9, the renovated NZEB should respect equation 2.5 (chapter 2, section 2.2.3) as much as possible, since this expression promotes solely the use of 'green' energy, therefore, promoting, not only near zero energy but also near zero emissions, *i.e.* carbon neutrality.

It is important to note that improvement measures associated with RECT (such as heat pumps and photovoltaic and thermal solar panels) are to be considered and evaluated in this phase. If in phase 1 it is identified that a technical system (eg. DHW preparation) needs to be replaced in order to achieve a better energy efficiency value, then a RECT based solution should be considered, as it is in line with the ultimate purpose of reaching a a carbon neutral NZEB. Since RECT are evaluated on phase 3, then those measures should be evaluated on phase 3, in an integrated matter with the previously chosen energy performance improvement measures pool and to avoid "lock-in effects" [40].

3.5.5 Renovated Carbon Neutral Near Zero Energy Building

In the end of the renovation, the main target is to have a carbon neutral NZEB, following what was defined on chapter 2, that a near zero energy building refers to energy consumption in building operation (section 2.2.1, that the NZEB should be considered as a "yearly energy neutral building" [15]), where, in a year, the building converts, from renewable sources, (nearly) as much energy as it consumes and that connection to the energy grid should be considered (section 2.2.2), as it enables energy exchanges between building and grid, which, for balance purposes, can be advantageous, allowing for "excess production" to "offset later energy use" [17].

At this stage, the building should have reached the requirements of Milestone 3 and the building owner/user can now profit from the highest level of tax benefits the Renovation Passport scheme offers.

3.6 Inspection & Audit

3.6.1 Audit

The purpose of energy audits in the context of the Renovation Passport is to assess the initial state of the building and later, to verify compliance with the rehabilitation objectives and milestones proposed (as explored on section 3.5.2). The type of audit discussed before is an energy audit performed by the QE *in situ*, however, if smart meters[20], to quantify energy consumption (how much energy is consumed

[18] Despite this value being taken from an official source, for many years, the Portuguese yearly energy balance has indicated this value is no longer up-to-date, meaning that the national system of energy conversion to electricity, accounting for the different energy sources, has a higher efficiency than the efficiency translated by this value.

[19] The suffix PE refers to primary energy and the suffix FE, to final energy.

[20] A smart meter, in a residential context, is a device which displays how much energy is being used "in near real time" and can also display how much money is being spent on that energy. "The smart meter shows a digital meter reading and uses a secure smart data network to automatically and wirelessly send the readings" to the "energy supplier at least once a month". Smart meters also allow for an accurate energy billing, instead of an estimated one [64].

when and where) are installed, then the energy audit could become an 'automatic' audit.

In the context of the Internet of Things[21] (IoT), an 'automatic' energy audit could be performed by a calculation tool/algorithm embedded in the Renovation Passport digital platform (such as BIM), which would read the data from the smart meters and verify the evolution of energy consumption, by comparing it with previous records, manufacturer information and expected demand. The integration of BIM as a tool to inspect "post-construction energy efficiency" could "provide simulation-based supervisory control while automatically detecting and diagnosing operational faults" [68].

The QE would have to define what values of energy consumption are acceptable and what values are not, based on previous records, manufacturer information and expected demand and, in case the energy consumption values are not compliant with what is determined by the QE, an alert and/or notification should be emitted for the building owner/user. This goes in line with the maintenance strategy, discussed ahead on section 3.7.

3.6.2 Maintenance Inspection

Maintenance inspections should be made to verify if the standard of energy performance which was obtained after energy renovation is being kept and, if not, how to fix it back to wanted/expected values. Besides overall energy performance, maintenance inspections should verify the conditions of technical equipment, namely, high energy consuming ones. Further details on how maintenance should be performed are discussed ahead, on section 3.7.

3.7 Maintenance & Construction

3.7.1 Maintenance

Regarding the maintenance component, the Renovation Passport intends to work similar to the approach taken by the automotive industry, in Portugal. Normally, a vehicle is due to go to the workshop after a determined number of kilometres, or after a determined period of time, to check certain parts or the vehicle, as a whole. More recently, some cars even display warnings for when a certain part is damaged, requires attention or simply, if it is time for the annual inspection.

As for the maintenance itself, there are two main types of maintenance, commonly used in machinery related industries, such as, for example, oil and gas, that can be performed, preventive and predictive maintenance. Preventive maintenance is to be "performed at predetermined intervals" [69], thus, being "time based" [69]. Furthermore, a "preventive maintenance programme provides the equipment with an environment in which it can perform its design function efficiently and reliably" [69]. As for predictive maintenance, it relies on "baseline and trend data to predict the root cause of the change in condition"

[21] According to the European Commission, "Internet of Things IoT represents the next step towards the digitisation of our society and economy, where objects and people are interconnected through communication networks and report about their status and/or the surrounding environment" [65]. Smart buildings [66] and smart homes [67] are some of "the most relevant IoT systems application domains" [66].

[69]. Moreover, a "predictive maintenance programme utilises effective condition monitoring to predict the need, scope and scheduling of corrective action" [69].

These industry concepts can be adapted to building maintenance. At first, when the Renovation Passport is first being deployed, the best approach would be to start performing preventive maintenance. Based on the recommendations of the manufacturers of the equipment installed on the building, a period of time for each action of preventive maintenance can be scheduled, as, on a starting phase, there would not be sufficient data to obtain and visualise a baseline or a trend, of that equipment's performance.

The equipment to be encompassed by the maintenance scope should primarily be those which are considered as great consumers. Since in Portuguese legislation, namely in the Decree-Law 118/2013 [18], great consumers are not defined for residential buildings, the QE would have to identify them, based on previous studies and equipment/device expected energy consumption. Probably, those devices would be the ones responsible for space heating and cooling and domestic hot water preparation, as these are the top three energy consumers, in residential buildings, according to Ürge-Vorsatz *et al.* [58].

During this initial phase, the Renovation Passport platform would issue a notification, based on the time interval defined either by the equipment manufacturer or by the QE, in case there are no manufacturer recommendations, to inform the building owner/user it is time to perform maintenance to the equipment, to be done until a certain date (just like what happens for vehicle inspection, in Portugal). Then, the building owner/user would have to book an accredited contractor to perform the maintenance activity (as a vehicle owner goes to an accredited inspection facility, in Portugal). Later, after the maintenance is done, the contractor would have to register the report on the status of the equipment, before and after maintenance and what activities were performed, in the Renovation Passport platform. Finally, the record of the performed maintenance would have to be verified and approved by the QE, as they are the ones who manage and verify if the building is performing correctly and as expected, for the Renovation Passport they designed.

However, after the initial Renovation Passport deployment phase, it would be wiser to change the approach towards predictive maintenance. At this point, the Renovation Passport would have already gathered enough information (in its databases), to create a performance baseline and trend associated with each equipment, so that new data acquired could already be compared with that baseline, thus enabling a change of equipment condition to be noticed and analysed. This way, not only is the corrective action needed much easier to identify, but also, maintenance costs and drawbacks (namely, equipment downtime[22]), can be avoided, as maintenance is only performed when needed, instead of at each time interval. Thus, preventing unnecessary maintenance which can also create more entropy by incorrectly assembling the equipment or badly tempering with it.

It is the QE, along with the Renovation Passport platform developers, who are responsible for analysing the previous records, to build the trend line and define the warning values, based on their experience, or manufacturer recommendations, which should prompt a notification for verification of the condition of the equipment/to perform maintenance of a certain equipment, to the building user/owner.

After defining the maintenance needs (through one of the maintenance concepts), maintenance must

[22]The downtime is the period the equipment is not working, *i.e.*, is not fulfilling its purpose.

be performed. To do so, the Renovation Passport proposes the following guidelines, to the accredited maintenance companies, who can be contracted by the building owner/user:

1. Follow equipment manufacturers maintenance recommendations.
2. Prioritise, when possible, repair over replacement.
3. Prioritise, when possible, part replacement over equipment replacement.
4. Ensure maintenance agents are qualified.
5. Comply with the maintenance schedule and avoid delays, as it can have extreme consequences on the equipment.
6. Report the maintenance activities performed.

The last of the guidelines, the reporting of the maintenance activities performed, is crucial for having a recorded history of maintenance, one of the features of the maintenance component of the Renovation Passport, as seen on table 3.7.

Table 3.7: Maintenance Features.

Renovation Passport - Maintenance - Features
Maintenance Guidelines
Recorded History of Maintenance Performed on the Building
Maintenance Notifications and Guidebook

The third feature, maintenance notifications and guidebook, is the one that warns the building user when any maintenance is required and informs and advises the user through the necessary steps to perform it correctly, much like a maintenance manual for vehicles works.

The QE are responsible for preparing the templates to be filled by the maintenance contractors, for verifying if maintenance is being carried out properly, as well as on time and for preparing the Guidebook which instructs the building owner/user on what to do (for example, after receiving a maintenance notification, the building owner/user should hire a certified contractor to perform said maintenance, on a determined time period).

3.7.2 Construction

Construction, which in this context could be understood as rehabilitation works, comes into place in the Renovation Passport as it is the phase where actual reconstruction and renovation takes place. The construction activities to be performed on the building, where the Renovation Passport strategy is being deployed, are the ones recommended by the QE, when they designed and selected the improvement measures to be implemented.

These activities can be done by certified construction entities which, similar to what happens for certified maintenance entities, could be hired by the building owner/user. The (certified) construction entity must fulfil all the requirements for the works, set by the QE as well as report and upload to the Renovation Passport digital platform, the current status of the construction/renovation works, with updated details on their progress. Whilst they do so, the QE must verify their reports and monitor the quality of the works.

It is important to note certified maintenance and construction entities are 'certified' because they fulfil certain quality requirements, which are to be defined by the entity which will manage the Renovation Passport national scheme. Since this new scheme is building up from the already existing one, the EPC system, it makes sense the entity in question could be ADENE. Thus, certified maintenance and construction entities would be evaluated by ADENE and by fulfilling certain parameters, related to performance quality, know-how, safety and sustainability, they would be given a 'seal of approval', which they could use in their marketing campaigns. Only certified entities could work on Renovation Passport related activities, in order to ensure the quality standard expected for the works. This certification of entities is itself a business opportunity, both for ADENE and for the entities themselves, as they can use that certification to attract new clients, who will choose them more confidently, based on the accreditation system.

3.8 Building Owner/Users Roles

3.8.1 Different Renovation Passport Users

The Renovation Passport is designed so that the building owner can be guided on how to renovate and turn their building into a NZEB, with costs and tax benefits associated with each Milestone, while the building user benefits from energy consumption reduction and auto-consumption solution, which lead to a reduction on energy expense. These, which can be two separate entities, or the same one, are the main User(s) of the Renovation Passport.

Nonetheless, building owners/users are not the sole addressees of the Renovation Passport. The brain behind the guidance and improvements, from which the building owner/user profits, is the QE. The QE are both creators of content, as they perform the energy audits and produce the correspondent report (where they state the energy class, as this step is coincident with the current EPC system), provide guidance for maintenance and construction certified entities and design the step by step renovation plan (with its corresponding energy improvement measures and RECT), as well as users, in the sense that they read and check inputs other users uploaded to the Renovation Passport, like maintenance certified entities, which produce the maintenance report, construction certified entities, which report the status of renovation works, building owner/user, who may insert proprietary related information, schedule preferences and images.

Furthermore, there are the maintenance certified entities, who both input maintenance reports and read previous ones, construction certified entities, who input construction status reports and also read previous ones and finally, funding authorities. Funding authorities which can support the building owner on their investment would have to be pointed out by the QE and/or ADENE, as the Renovation Passport framework managing entity and they could be government programmes, private companies, banks and credit agencies. The building owner would then be able to see what funding options are available for their case, in the digital platform. Once the building owner gives permission, through the digital platform, to certain funding authorities, these can have access to Renovation Passport budgets, as well as expected energy and financial savings, to be able to estimate and propose an adapted funding scheme, suited for the building owner. After being informed on the available options, the building owner could then submit an application to the most relevant funding opportunities.

A summary of the different types of the Renovation Passport users and their roles is presented on table 3.8.

Table 3.8: Renovation Passport User Roles Summary.

Number	Type of User	Role
1	Building owner	Pays for the renovation investment cost and benefits from potential real estate valorisation.
2	Building user	Benefits from energy consumption reduction financially and from increased levels of comfort, reduces their carbon footprint from the carbon neutral solutions. May or may not be the same entity as the building owner.
3	QE	Create content such as the EPC, energy audit reports, guidance for maintenance and construction entities and design the step by step renovation plan. The QE also refer to the Renovation Passport to read and check inputs from the building owner/user and certified maintenance and construction entities.
4	Maintenance & Construction certified entities	Perform works, deliver status reports and may access previous reports.
5	Funding authorities	Support the building owner on their investment and may access information regarding the Renovation Passport plan as well as expected savings and investment.

3.8.2 Funding

The EPC national system suggests, at the present time, three financial tools [49] that can help the building owner to support the expenses associated with implementation of energy efficient measures, which are Programa Casa Eficiente 2020 (Efficient Housing Programme 2020), Programa IFRRU 2020 2020 (Instrumento Financeiro de Reabilitação e Revitalização Urbanas - Financial Tool for Urban Rehabilitation and Revitalisation) and Fundo de Eficiência Energética - FEE (Energy Efficiency Fund). These programmes are currently in use to be applied in the EPC context, then, it makes sense they could be the same programmes to support the renovation needed to achieve the Milestones of the Renovation Passport. There are other programmes/financial tools which the building owner can turn to, listed below. For further detail on these, please refer to ELPRE report [7], where they are clearly and explicitly described.

- Programa de apoio ao acesso à habitação 1º Direito (Access to Housing Support Programme) [7] [70].
- Reabilitar para Arrendar – Habitação Acessível (Rehabilitate to Rent - Affordable Housing) [7] [71].

- FNRE - Fundo Nacional de Reabilitação do Edificado (National Fund for Built Environment Rehabilitation) [7] [72].
- Portugal 2020 [7] [73].
- POSEUR - Programa Operacional Sustentabilidade e Eficiência no Uso de Recursos (Operational Programme for Sustainability and Efficient Use of Resources) [7] [74].
- Programas Operacionais Regionais (Regional Operacional Programmes) [7] [75].
- ENCPE 2020 - Estratégia Nacional para as Compras Públicas Ecológicas 2020 (National Strategy for Ecological Public Procurement) [7] [76].
- ENAAC 2020 - Estratégia Nacional de Adaptação às Alterações Climáticas 2020 (National Strategy for Climate Change Adaptation) [7] [77].
- Fundo de Renovação e Conservação Patrimonial (Patrimonial Conservation and Renovation Fund) [7] [78].
- Plano de Promoção da Eficiência no Consumo de Energia Elétrica (Electric Energy Consumption Efficiency Promotion Plan) [7] (it is currently replaced by PNEC [48]).

The Programa Casa Eficiente 2020 (Efficient Housing Programme 2020) aims to grant loans, with attractive terms, to residential building owners, for operations which improve the environmental performance of the building, particularly related to energy and water efficiency, renewable energy deployment and urban waste management, with interventions which may be applied to building envelope and technical systems (adapted from [79]). The programme, for the period of 2018 to 2021, has a 200 M€ fund, with half being financed by the European Investment Bank and the other half by the commercial banks (in Portugal), that support and participate in the programme (adapted from [79]). The building owner should verify the expenses that can be covered by this loan, in the the programme regulation (article 22) [80] and the financial conditions are discussed, case-by-case, with the building owner and the commercial bank ([79]).

The IFRRU 2020 programme has a financial capacity of 1.400 M€, from entities like Portugal 2020, the European Investment Bank and the Council of Europe Development Bank (CEB). The building owner can apply to this programme for works related with urban rehabilitation and energy efficiency (adapted from [81]). The loans are granted by managing financial entities (banks that operate in Portugal) and they have better conditions than the usual market, for rehabilitation and energy efficiency improvement, for (not only but also) residential buildings (adapted from [81]). The building owner should verify what expenses are covered by the funding in the Guia do Beneficiário (Beneficiary Guide) [82] and have in mind, that since the programme intends to promote energy efficiency, the energy certificates before and after the works are completed, must show the evolution on the building's energy performance.

Finally, the FEE (Energy Efficiency Fund) is a financial tool which is able to fund the programmes and measures predicted on Plano Nacional de Acção para a Eficiência Energética (National Plan for Energy Efficiency Action), in all its lines of action (adapted from [83]). The last ”Aviso” (Warning), Aviso 25 was launched in 2018 and financially supported applications for energy efficiency improvement in buildings, with a financial capacity of 3.1 M€.

Fiscal incentives promoted by municipalities should also be considered, as described in section 3.3.2.

3.9 Renovation Passport Innovations Summary

The Renovation Passport innovations have been presented throughout the sections above. In this section they are presented, on table 3.9, in order to showcase, in a intuitive way, what are the new proposed features the Renovation Passport brings when comparing with the current national EPC system.

Table 3.9: Renovation Passport Innovations Summary.

Number	Innovation Description
1	Different NZEB definition from the EPC. The NZEB is considered as a ”yearly energy neutral building” [15] where, in a year, the building converts, from renewable sources, (nearly) as much energy as it consumes and that connection to the energy grid should be considered, instead of the NZEB definition presented on the Portuguese ministerial ordinance, Portaria 98/2019 [19] (see section 3.3.1).
2	The main clear purpose, aligned with current national strategies, is to reach a carbon neutral NZEB, instead of the highest energy class possible (see section 3.1). This purpose is proposed to be reached by following a renovation and rehabilitation plan, designed by the QE.
3	The Renovation Passport promotes the extension of buildings' lifetime, by promoting rehabilitation works, which in turn allow for improving the building's current condition(s), by applying new construction solutions and equipment, ameliorating the comfort levels for its users, as well as the quality of the building (as a construction) and its systems, therefore, increasing the potential for a longer building lifetime (see section 3.3.1).
4	Potential to automatically read energy consumption and evaluate its evolution, by deploying the use of smart meters, in an 'automatic' energy audit, IoT integrated logic (see section 3.6.1).
5	Potential to use BIM to obtain the new building energy demand values and profiles, after energy performance improvement measures' implementation, as well as to perform the 'automatic' energy audit (see section 3.5.2 and 3.6.1).
6	Having a maintenance plan to be followed (much like what happens for automobiles in Portugal) and the opportunity to book credited maintenance and construction entities to perform those activities (in/at the building), as well as having a record book with every detail about the performed work and applied modifications (see section 3.7).
7	Possibility for the building owner/user to have more involvement, advice and support from the QE, in subjects like potential available funding and verifying the compliance of maintenance and construction works with the Renovation Passport plan as well as the credited quality standards (see section 3.8.2 and 3.7).
8	Upgrading the current role of QE and their set of skills. Enormous potential for job creation, for training and lastly, for educating and raising awareness on the topics of best building use practices and sustainability. Some of the possible jobs that can originate from this service are QE mentors, credited inspection maintenance and construction hubs, web designers and data scientists (see section 3.1).

Chapter 4

Digital Platform Organisation Proposal

4.1 Presentation

The Renovation Passport, as a depository of a series of ever changing and interactive data, is best to exist as a digital platform. This platform should be designed primarily for the main users, the building owner and/or user, having in mind, of course, the other users, in order to create the most intuitive experience for all.

The main page should present the concept of Renovation Passport, what is its purpose, how does it work, what is the motivation behind it and how to navigate through the digital platform. This initial page, links to other interesting websites related to building renovation, energy performance and sustainability, should be accessible, for example, the EU Green Deal and other official EU relevant pages or agencies on those topics, United Nations Sustainable Development Goals (SDGs), IPCC reports, International Energy Agency (IEA) and ADENE news and reports, etc.

Then, the building owner/user should have access to all the different components of the Renovation Passport and each of the components should have its own tab, where all the specifications, purposes, targets and databases should be made available. On figure 4.1 an illustrative representation of these contents, to be displayed on the initial page of the digital platform is presented. Nevertheless, the user/owner should be made aware of how the different components/databases interact among each other, so a graphic, picture like, preferably interactive, data map should exist and thus, the user/owner easily understands the relationship between components. A more detailed overview of the Renovation Passport, its components and how information flows is illustrated on figure 4.2. This figure intends to present how information flows, in the Renovation Passport, whether it is done manually, by the QE or if it is done by using automatic tools, always with the supervision of QE, who is responsible for ensuring the Renovation Passport is working and being executed properly.

Ideally, the digital platform could be accessed through a website, for computer users and through, possibly, an app, for mobile devices users.

As the Renovation Passport builds from the current national EPC system and since the EPC is the first step for building rehabilitation, in the Renovation Passport context, the EPC itself, and more

Figure 4.1: Illustrative representation of the contents which are proposed to be displayed on the initial page of the Renovation Passport digital platform.

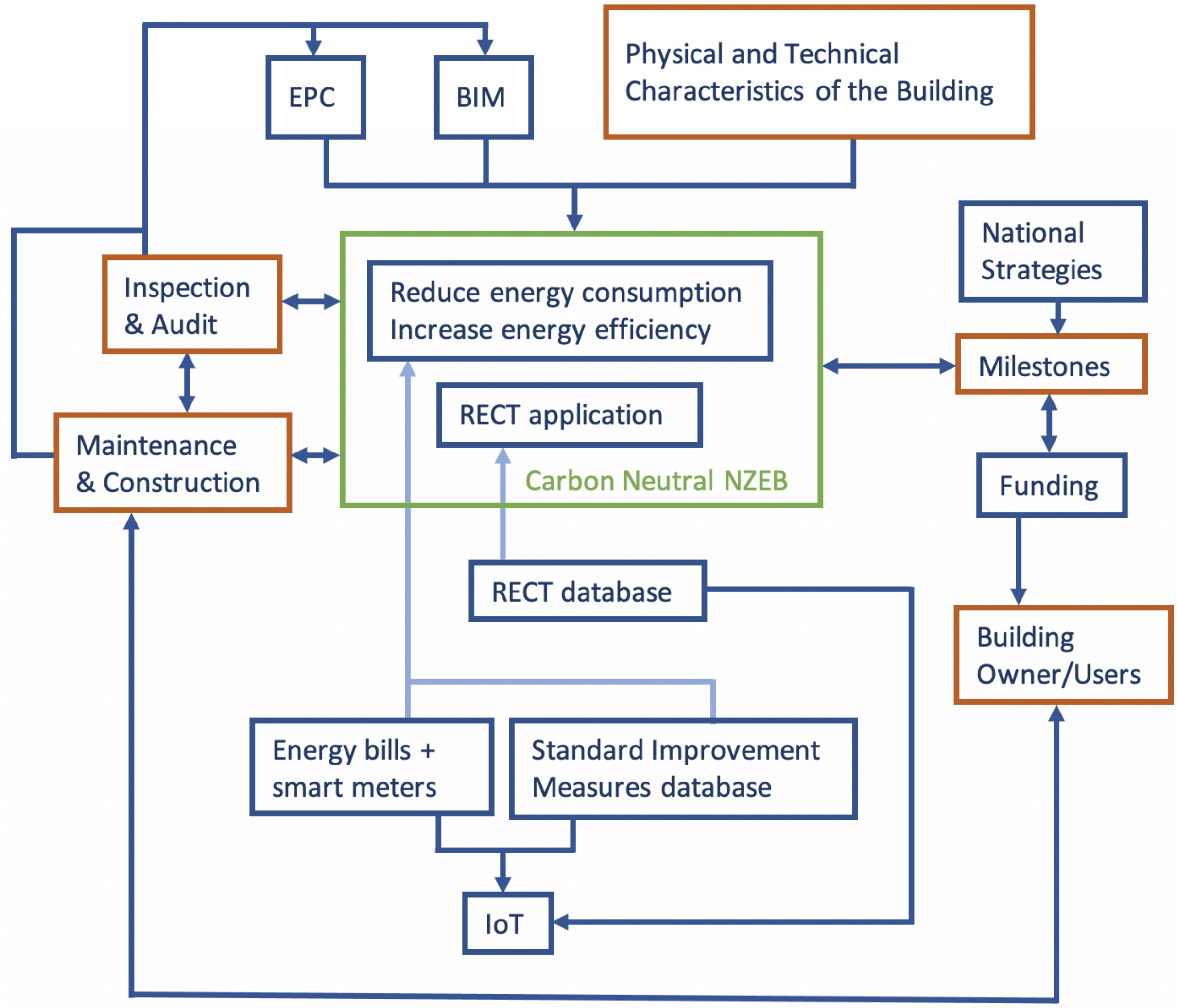


Figure 4.2: Renovation Passport information flow, where the Renovation Passport components are shown in orange and green.

importantly, the EPC results should be the first information the building owner/user sees, in the digital platform. Ideally, this would be the first status report, which should be in a very relevant place in the platform, either, on the initial page or in a special and very visible tab. The status report would inform the building owner/user of which phase is currently under progress and prompt the user for any type of necessary documentation or action. For example, during rehabilitation, the status report can inform the building user/owner that the renovation works related with opaque envelope is finished and the renovation works on glass windows are about to begin or, for example, ask the building owner/user to upload the latest proof of payment to the certified construction entity, etc.

The status report should be updated by the QE, regarding what works are going on and what are the immediate next ones, as well as to be a notification central, where every information the building owner/user must know, should be shown, like, for example, maintenance alerts or funding opportunities notifications. These notifications are signalled (by the QE) on their respective Renovation Passport component tab, but should make it to the notification central, in the status report so that the chances of the building owner/user missing them, are reduced.

4.2 Renovation Passport Components Interactivity

In this section, the way each of the components interacts with the others will be pointed out and further detailed. This interactivity is key for the Renovation Passport and should be well presented to the digital platform user. Although inputs and outputs are represented separately, in the next sections, it does not mean at some point of the Renovation Passport process they cannot revert directions or be transformed to others, but, on a first approach, this is how the components are connected and how information flows from one another.

4.2.1 Milestones

The Milestones component is the one that sets what goals to achieve and when. Regarding its inputs, it mainly draws information from current National strategies (like ELPRE, PNEC and RNC 2050) as well as from fiscal benefits programmes, as reviewed on section 3.3.2. As for outputs, the component which Milestones influences the most is the Energy Performance Improvement & Near Zero Energy Building one, as it sets the pace and purpose for renovation/rehabilitation. The necessary inputs and outputs for this component are summarised on table 4.1.

Table 4.1: Milestone component inputs and outputs.

Inputs	Outputs
Current National Strategies	Energy Performance Improvement & Near Zero Energy Building
Fiscal Benefits programmes	-

4.2.2 Physical and Technical Characteristics of the Building

This component is the basis for the remaining, as it is in here that the building is characterised. As stated on chapter 3, section 3.4, this component should be organised in a database containing the information and separated by subjects, such as referred in table 2.1.

Possible inputs to this component can be information from the fiscal documents on the building and other inputs from the user/owner and auditors/inspectors. As for outputs, this component directly feeds other components, such as the Energy Performance Improvement & Near Zero Energy Building one, where it is absolutely necessary to define the renovation strategy for energy performance improvement and reaching NZEB. The necessary inputs and outputs for this component are summarised on table 4.2.

Table 4.2: Physical and Technical Characteristics of the Building component inputs and outputs.

Inputs	Outputs
Fiscal Documents	Energy Performance Improvement & Near Zero Energy Building
Building Owner/User	EPC
Inspection & Audit	BIM

4.2.3 Energy Performance Improvement & Near Zero Energy Building

The Energy Performance Improvement & Near Zero Energy Building component has five very specific and necessary inputs, as stated on chapter 3, section 3.5, which are the EPC, the Physical and Technical Characteristics of the Building component itself, the Inventory of building energy renovation standard measures, Energy related spending (bills) and consumption profile inventory, which in turn, comes from information accessible to the User, and last but not least, the Renewable Energy Conversion Technologies Database. Apart from that, inputs from inspectors and auditors, building owner/user, BIM and IoT are also relevant for this component.

Regarding outputs, the most outstanding is that this component delivers the detailed renovation plan (towards NZEB) to the building owner/user, which are the core of the Renovation Passport purpose. Furthermore, adding to what was stated for the previous component, not only does the present component draw from advice given by the Inspection & Audit, but it also provides Inspection & Audit the expected renovation outcomes, which are the basis for the evaluations performed by the auditors/inspectors. The necessary inputs and outputs for this component are summarised on table 4.3.

4.2.4 Inspection & Audit

In this component, the inputs, are, naturally, those observed by the inspectors and auditors while performing their work. The results of those observations will, in turn, possibly, add on or update the information contained and/or needed for the following components, Physical and Technical Characteristics of the Building, where new and updated features can be reported, Maintenance & Construction, where the inspectors will verify if the standards are being met and if maintenance is being done prop-

Table 4.3: Energy Performance Improvement & Near Zero Energy Building component inputs and outputs.

Inputs	Outputs
EPC	Building Owner/User
Physical and Technical Characteristics of the Building	Inspection & Audit
Inventory of building energy renovation standard measures	Maintenance & Construction
Energy related spending (bills) and consumption profile inventory	-
Renewable Energy Conversion Technologies Database	-
Building Owner/User	-
Inspection & Audit	-
BIM	-
IoT	-

erly, as well as report the activities performed and finally, for Energy Performance Improvement & Near Zero Energy Building, as the QE will follow the renovation works, ensuring they are being done with the predicted quality and, in the end, verifying if the work performed under this component is delivering the expected results. The building owner/user may upload information to the digital platform regarding bills and contracts with maintenance and construction certified entities, among others. Furthermore, auditing is essential for creating and delivering the EPC. The necessary inputs and outputs for this component are summarised on table 4.4.

Table 4.4: Inspection & Audit component inputs and outputs.

Inputs	Outputs
Observations done during Audits and Inspections	Physical and Technical Characteristics of the Building
Energy Performance Improvement & Near Zero Energy Building	Maintenance & Construction
Building Owner/User	Energy Performance Improvement & Near Zero Energy Building
-	EPC
-	BIM
-	IoT

4.2.5 Maintenance & Construction

The Maintenance & Construction component mainly draws information from Inspection & Audit, as stated before, where inspections take place and deliver the status of equipment/components performance, if previous maintenance performed solved the previous existing problems and if, overall, the wanted quality standards of performance are being met. To know this, the Maintenance & Construction component takes information from Energy Performance Improvement & Near Zero Energy Building as well, as it is in there where those standards are defined.

Then, this component, delivers, to the building owner/user, the guide and detailed steps on what type of preservation and/or improvement works need to be performed where and when and what results should be achieved after those works take place. The necessary inputs and outputs for this component are summarised on table 4.5.

Table 4.5: Maintenance & Construction component inputs and outputs.

Inputs	Outputs
Inspection & Audit	Building Owner/User
Energy Performance Improvement & Near Zero Energy Building	BIM

4.2.6 Building Owner/Users

The Building Owner/Users are the key component and the reason why the Renovation Passport is elaborated in the first place. The Owner component is the one that invests and benefits from potential real estate market valuation and the User component is the one that benefits from the reduced energy bills and improved comfort levels. Therefore Owner/User component takes advantage of what is built in the other components, and all of them , directly or indirectly, have inputs in these component. But more specifically, the Owner receives immediate instructions from, predominantly, the Energy Performance Improvement & Near Zero Energy Building and Maintenance & Construction components. Besides, Funding authorities data is entirely crucial for a good management of the actions, proposed by the Renovation Passport, the Owner has to set in motion in order to obtain the desired results.

Regarding the outputs, the Owner component influences, mostly, the Physical and Technical Characteristics of the Building component, with building information the Owner withholds. The Energy Performance Improvement & Near Zero Energy Building, requires User's inputs to provide the best solution, satisfying the User's needs, as well as data referring to energy consumption values and profile. The necessary inputs and outputs for the Owner and User component are summarised on table 4.6 and 4.7.

Regarding notifications, the Owner should receive maintenance and available funding opportunities alerts, as well as any others which imply an action for modifications. The User should be alerted by sudden changes in energy consumption or on any matter that involves or implies the User's health, well-being and safety.

Table 4.6: Owner component inputs and outputs.

Inputs	Outputs
Energy Performance Improvement & Near Zero Energy Building	Physical and Technical Characteristics of the Building
Maintenance & Construction	Energy Performance Improvement & Near Zero Energy Building
Funding authorities	-
IoT	-

One important question arises, regarding the users, within the digital platform, is how to design the platform, in a way that its utilisation is the most optimal for each different User/Owner. It can either

Table 4.7: User component inputs and outputs.

Inputs	Outputs
Energy Performance Improvement & Near Zero Energy Building - new features	Energy Performance Improvement & Near Zero Energy Building - needs
-	IoT

be achieved by designing the platform considering every platform user will be seeing the same content and visuals or by enabling different information or, at least, a different arrangement of those contents, depending on what platform user is accessing the platform, which can be controlled by having different platform user logins, each with different interfaces.

Moreover, data protection should be considered as well. Nowadays, increasing attention is given to this question and actual rules are being put to practice, namely, in accordance to the GDPR (General Data Protection Regulation) [84]. Therefore, the platform developers should make sure no sensitive/personal information is disclosed to a party, unless the owner of said information has explicitly given permission to that party, so they can access it. This is perhaps easier to manage if each platform user has, indeed, different login options.

Chapter 5

Case Study

5.1 Presentation

In this chapter, a case study, of how to apply the concepts of the Renovation Passport is presented. This exercise intends to showcase some of the action a QE would have to perform to renovate, rehabilitate and improve the energy performance of the building. In this case, the Renovation Passport components which are considered are the Milestones, the Physical and Technical Characteristics of the Building and the Energy Performance Improvement & Near Zero Energy Building. The remaining components are not directly addressed but may be referred to indirectly.

The information regarding the chosen study case was kindly conceded by IN+[1] researcher Eng. Ricardo Gomes, who provided building drawings, characteristics, location and most importantly, the model of the building both in the software Google Sketchup[2] [86] (for graphic visualisation) and EnergyPlus [87] (for energy modelling). The inputs for the EnergyPlus programme were the ones considered as the physical and technical characteristics of the building.

The chosen residence is located in the Olivais Sul zone, in Lisbon, Portugal, on the right side of the 5th floor of a 6 storey building (see figure 5.1 and 5.2 for an overview of the building), inside an urban area, built between 1971 and 1980, at about 2 kilometres from sea shore and approximately 2 metres above sea level. The model of the north, south, east (shared with the adjacent building) and west (shared with the common interior spaces of the building) façades can be seen on figures 5.3, 5.4, 5.5 and 5.6, respectively. The apartment is a T3[3], with 3 bedrooms, 2 bathrooms, 1 living room, 1 kitchen, 1 entrance hall and 3 storage rooms. On figure 5.7 the apartment blueprint (on the right side of the figure) can be seen.

[1] IN+ is the Centre for Innovation, Technology and Policy Research, a research centre part of Instituto Superior Técnico, which aims to "promote sustainable applications in science, industry and society" [85].

[2] Currently owned by Trimble Inc.

[3] The typology of a residence is defined by the number of bedrooms [88]. In this case, a T3 is an apartment with 3 bedrooms.

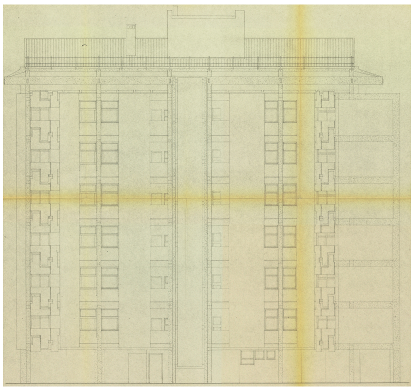


Figure 5.1: Case study building north façade.

Figure 5.2: Case study building south façade.

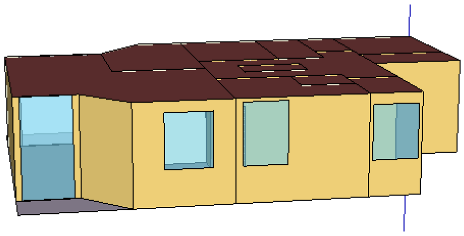


Figure 5.3: Case study residence north façade.

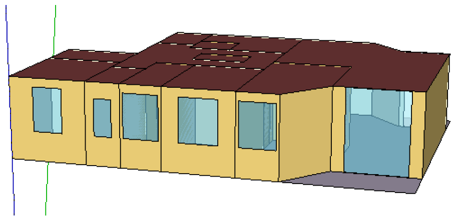


Figure 5.4: Case study residence south façade.

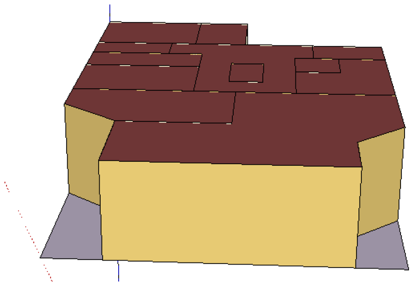


Figure 5.5: Case study residence east façade.

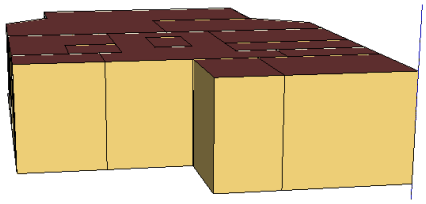


Figure 5.6: Case study residence west façade.

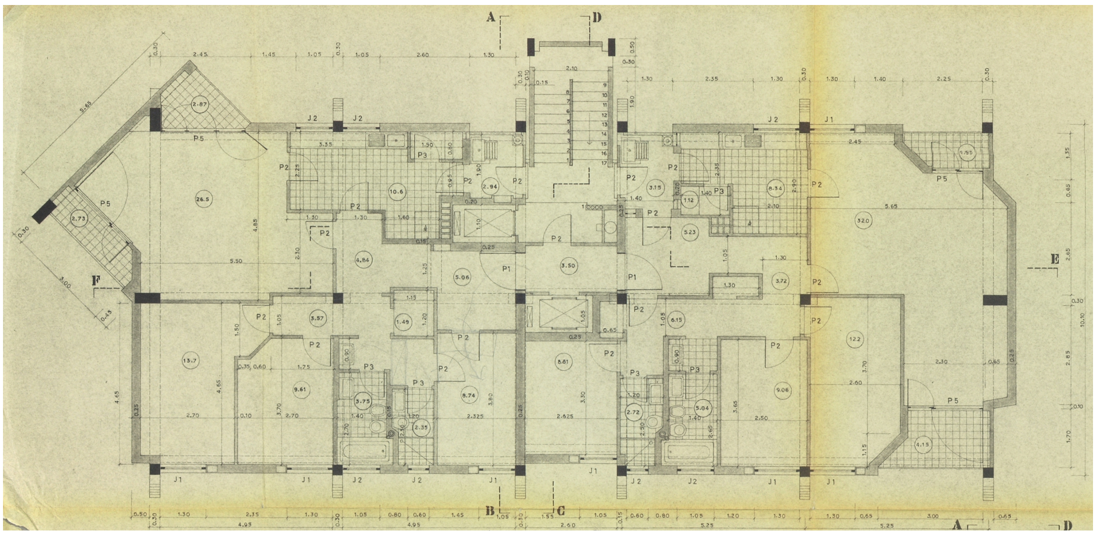


Figure 5.7: Case study residence blue print (please consider the right side apartment).

5.2 Residence Energy Class obtained through the EPC system

The residence energy class, as is, was obtained through an official calculation tool for the residential EPC, developed by Itencons [53]. This tool is designed to help the EPC's QE obtain the building's energy class, by filling in the cells with building information and technical characteristics, which are then used by the tool to calculate the expressions and equations mentioned on Portuguese Decree-Law nº118/2013 [18], Portuguese Dispatch n.º 15793/2013 [20] and Portuguese Dispatch 349-B/2013 [21].

The most relevant values, expressed on the above mentioned equation, necessary to obtain the energy class of the building are the following:

- N_{ic} nominal annual value of useful energy needs for heating, in $\frac{kWh}{m^2 \cdot Year}$ (see equation 2.1) [20].
- N_{vc} nominal annual value of useful energy needs for cooling, in $\frac{kWh}{m^2 \cdot Year}$ (see equation 5.1) [20].
- Q_a nominal annual value of useful energy needs for domestic hot water preparation, in $\frac{kWh}{Year}$ (see equation 5.2) [20].
- W_{vm} electric energy needs for ventilator operation, in $\frac{kWh}{Year}$ (see equation 5.3) [20].
- E_{ren} energy provided by local RECT units for regulated use (which include solar thermal, solar photovoltaic, wind, biomass, geothermal, mini-hydro power and heat pump systems, each with their specific expression for E_{ren}), in $\frac{kWh}{Year}$ [20].
- $E_{ren}AQS$ energy provided by local RECT units for domestic hot water (DHW) preparation [20].
- $E_{ren,ext}$ energy provided by local RECT units for other uses [20].
- N_{tc} nominal annual value of primary energy needs, in $\frac{kWh}{m^2 \cdot Year}$(see equation 2.3) [20].
- N_t maximum annual value of primary energy needs, in $\frac{kWh}{m^2 \cdot Year}$ (see equation 2.4) [21].

$$N_{vc} = ((1 - \eta_v)Q_{g,v})/A_p \tag{5.1}$$

$$Q_a = (M_{AQS} \cdot 4187 \cdot \Delta T \cdot n_d)/3600000 \tag{5.2}$$

$$W_{vm} = V_f/3600 \cdot \Delta P \cdot \eta_{tot} \cdot H_f/1000 \tag{5.3}$$

Where

$\boldsymbol{\eta_v}$ thermal gains utilisation factor in the cooling season [20].

$\boldsymbol{Q_{g,v}}$ gross thermal gains in the cooling season, in kWh [20].

$\boldsymbol{A_p}$ useful interior floor area, measured from the inside, in m^2 [20].

$\boldsymbol{V_f}$ daily average air flow through the ventilator, in $\frac{m^3}{h}$ [20].

$\boldsymbol{\Delta P}$ total pressure difference of the ventilator, in Pa [20].

$\boldsymbol{\eta_{tot}}$ ventilator total functioning efficiency [20].

$\boldsymbol{H_f}$ number of hours of ventilator functioning, per year, in (h) [20].

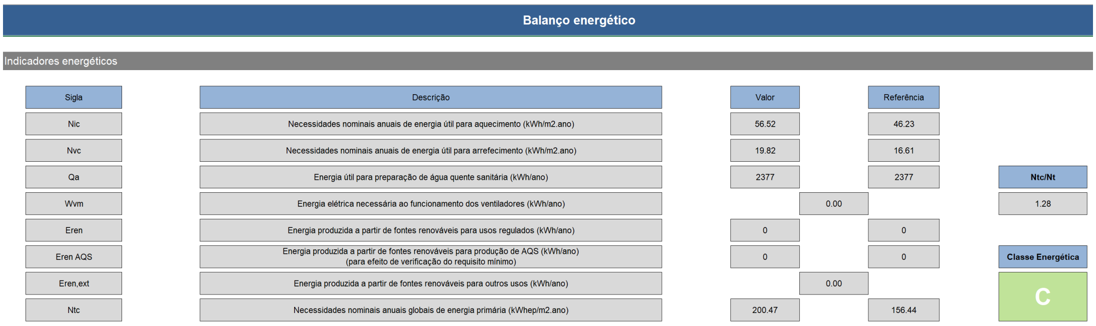
$\boldsymbol{M_{AQS}}$ average reference daily hot water consumption, in litres [20].

$\boldsymbol{\Delta T}$ necessary temperature increase for DHW preparation, with a reference value of 35 °C [20].

$\boldsymbol{n_d}$ number of days of hot water utilisation, per year [20].

The Itencons EPC tool is an excel[4] file, divided in several sheets. In the first one, the QE fills in the cells with information. The remaining ones, are essentially automatic calculation pages, based on the equations presented above, in full detail (please refer to [20, 21], where every part of these equations is presented, with their respective expressions). The Itencons excel tool filled with information and characteristics of the case study residence as is, is presented on A.1. The only technical system considered in the building was a natural gas water heater.

After filling this document with the residence's information, following its instructions and verifying consistency with [20, 21], the obtained energy class was C (seen on figure 5.8, as well as other energy indicators), with an energy class ratio of $R_{Nt} = 1.28$ (see chapter 2, section) and associated emissions of 3.32 tons of $CO_{2_{eq}}$ per year, as seen on table 5.1.



Balanço energético

Indicadores energéticos

Sigla	Descrição	Valor		Referência	
Nic	Necessidades nominais anuais de energia útil para aquecimento (kWh/m2.ano)	56.52		46.23	
Nvc	Necessidades nominais anuais de energia útil para arrefecimento (kWh/m2.ano)	19.82		16.61	
Qa	Energia útil para preparação de água quente sanitária (kWh/ano)	2377		2377	Ntc/Nt
Wvm	Energia elétrica necessária ao funcionamento dos ventiladores (kWh/ano)		0.00		1.28
Eren	Energia produzida a partir de fontes renováveis para usos regulados (kWh/ano)	0		0	
Eren AQS	Energia produzida a partir de fontes renováveis para produção de AQS (kWh/ano) (para efeito de verificação do requisito mínimo)	0		0	Classe Energética
Eren,ext	Energia produzida a partir de fontes renováveis para outros usos (kWh/ano)		0.00		C
Ntc	Necessidades nominais anuais globais de energia primária (kWhep/m2.ano)	200.47		156.44	

Figure 5.8: Case study, as is, residence energy class.

Table 5.1: Building, as is, EPC results.

Building Energy Class	Energy Class Ratio R_{Nt}	$CO_{2_{eq}}$ Emissions $\left[\frac{ton}{Year}\right]$
C	1.28	3.32

5.3 Energy Performance Improvement Measures

After determining the building class, according to phase 1 of the 3rd Renovation Passport component, the next step is to choose an adequate pool of energy performance improvement measures. To do so, in this example, information from ADENE was used. ADENE kindly provided information about energy performance improvement measures from their SCE database, with the data mentioned on table 3.2. In total, information on 206 measures was provided. Since the Renovation Passport is following ELPRE's strategy to first address "passive" measures, related to the building envelope and then address systems energy efficiency improvement measures, the measures provided by ADENE were separated in two groups, precisely, 99 measures relative to building envelope (which include roofs, walls, pavement, thermal bridges, door and glazing surfaces) and 107 measures relative to technical systems (which include ventilation, heating, cooling, DHW and other uses systems).

[4] Excel is a spreadsheet software by Microsoft [89].

Each of the group of measures was arranged by payback time (see equation 3.1), from lowest to highest. The ones with lowest payback time should be considered first, as they take less time to payback the initial investment while reducing energy consumption. After arranging the measures from lowest to highest payback time, a threshold should be chosen for maximum payback. In this case, the measures considered were those with less than or equal to ten years of payback time.

By applying the maximum 10 year payback time limit, 45 envelope and 84 technical systems measures remained. These were narrowed down to 3 envelope measures, presented on table 5.2 (for future reference, consider their labels as E1, E2 and E3, by the order they appear on this table) and 4 technical systems measures, presented on table 5.3 (for future reference, consider their labels as TS1, TS2, TS3 and TS4, by the order they appear on this table), by filtering the measures by adequacy and applicability to the case study, given the fact the chosen residence is a 5th floor, right side apartment, and many of the measures simply could not be applied in this context, and/or refer to improvement of features the case study building does not contain and/or are mutually exclusive.

Table 5.2: Envelope improvement measures considered.

	E1	E2	E3
Measure definition	Application of thermal insulation in shutter frame boxes[5]	Application of fixed interior solar protections on East side windows[6]	Application of thermal insulation in the exterior façade, with a coating applied over the insulating material[7]
Measure associated with	Opaque envelope - Thermal bridges	Glazing surfaces	Opaque envelope - Walls
Average floor area [m^2]	95.48	54.48	104.70
Average investment cost [€]	133.11	350	3111.31
Average financial savings $\left[\frac{€}{Year}\right]$	102.02	70	492.16
Average energy savings $\left[\frac{kWh_{PE}}{m^2 \cdot Year}\right]$	14.78	17.50	67.42
Payback time [Years]	1.30	5	6.32

Table 5.3: Technical systems improvement measures considered.

	TS1	TS2	TS3	TS4
Measure definition	Replacing and/ or installing a reversible, multi-split, inverter type, energy class A air conditioning system (heat pump) for climatisation[8]	Insulating DHW distribution piping[9]	Replacing and/ or installing certified and labelled shower systems, with high water efficiency (class A or above)	Replacing and/ or installing a high energy efficiency heat pump for DHW preparation[10]
Measure associated with	Space cooling	DHW	DHW	DHW
Average floor area [m^2]	96.52	83.87	96.03	94.02
Average investment cost [€]	3451.97	245.20	256.74	2272.34
Average financial savings $\left[\frac{€}{Year}\right]$	1332.51	43.99	44.92	364.02
Average energy savings $\left[\frac{kWh_{PE}}{m^2 \cdot Year}\right]$	119.76	9.033	5.62	52.72
Payback time [Years]	2.59	5.57	5.72	6.24

Some of the chosen technical systems improvement measures are based on heat pump technology

[5] New U-value = 1.3 $\left[\frac{W}{m^2 \cdot K}\right]$, as presented on [90].

[6] New global solar factor $g_\perp, T = 0.032$, calculated through expression $g_\perp, T = g_\perp, vi \cdot \prod_i \frac{g_\perp, Tvc}{0.85}$ considering simple glass with 4 mm thickness and solar factor $g_\perp, vi = 0.88$, interior protection with light coloured transparent curtains, with solar factor $g_\perp, Tvc = 0.38$ and assuming light coloured plastic rolled blinds are closed with solar factor $g_\perp, Tvc = 0.07$, as defined on Portuguese Dispatch 15793-K/2013 [20].

[7] New U-value = 0.58 $\left[\frac{kWh_{PE}}{m^2 \cdot Year}\right]$, as presented on [91], for hollow brick walls, with 40 mm of thickness, with EPS - Expanded Polystyrene - thermal insulation applied in the exterior façade, with a coating applied over the insulating material.

[8] Since the heat pump technology selected for space cooling is able to reverse the thermal cycle for space heating, this heat pump technical system is the same considered for space heating. To achieve the best energy performance possible with this improvement measure of installing a space cooling and heating, an A+++ (the highest) energy class air conditioning unit was chosen and the model considered for this example was a heat pump air-air split system powered by electricity, from DAIKIN (a manufacturing company in this market), the "Ururu Sarara" model SB-FTXZ25N. For the calculations done on the Itencons excel tool, values for cooling of 9.54 of seasonal energy efficiency ratio (SEER [92]), energy class A+++ and 2.50 kW of nominal power and values for heating of 5.90 of seasonal coefficient of performance (SCOP) [92].), energy class A+++ and 3.6 kW of nominal power were considered, as mentioned on DAIKIN's catalogue [93].

[9] For EPC calculations, the thermal resistance of the DHW distribution piping thermal insulation is considered to be greater than or equal to 0.25 $\frac{m^3 \cdot °C}{W}$.

[10] To achieve a very good energy performance with this improvement measure of installing a DHW preparation heat pump system (replacing the previous gas water heater), an A+ (the highest) energy class unit (with the water reservoir incorporated) was chosen and the model considered for this example was a heat pump air-water system powered by electricity, from DAIKIN (a manufacturing company in this market), the "Altherma DHW - Monobloc" model EKHH2E200AV3 - 200L. This model is compatible with solar thermal and solar photovoltaic panel integration. For the calculations done on the Itencons excel tool, values of 1.82 kW of nominal power and of 3.30 for coefficient of performance (COP [94]) were considered.

which, at the light of the EPC will contribute to the accounted renewable energy converted *in situ* (due to the fact the heat pump efficiency being grater than 1, as the electricity it consumes is less than the energy, for cooling or heating, it delivers), however, these should still be viewed as energy performance improvement measures, as in the Renovation Passport, as mentioned before, the priority is to have energy efficient systems, but also to reach a carbon neutral NZEB, therefore, if a technical system needs replacing or installing, the most energy efficient and RECT powered solution should be implemented.

From the chosen envelope and technical systems improvement measures, a graphic, like the one proposed by Hirst [30] (see figure 2.7) was done, as presented on figures 5.11 and 5.12, respectively. These values are based on the data provided by ADENE and displayed on tables 5.2 and 5.3. It is important to note these values are average values of how much the implementation of a measure can cost and how much could be its corresponding energy and financial savings. By basing their decisions on the pool of improvement measures to apply on a database such as ADENE's, the QE are making a founded choice, but since these values are a little generic, a more thoughtful analysis of cost-benefit and life cycle assessment may also be performed by the QE, to ensure the chosen pool is a good fit for the building in question. As it happens for the EPC system, as will happen on the Renovation Passport, as it draws from the EPC, the more an improvement measure is applied in a rehabilitation context, the more information there will be about its implementation and future Renovation Passports and QE's analysis will benefit from that.

On figures 5.11 and 5.12 the xx axis is the cumulative investment cost, in $\frac{€}{m^2}$ and the yy axis is the cumulative energy savings, in $\frac{kWh_{PE}}{m^2 \cdot Year}$. The line in blue corresponds to the values taken from ADENE's SCE information. For envelope measures, the cumulative cost of the chosen pool of measures is 37.534 $\frac{€}{m^2}$ and the cumulative energy savings are 99.696 $\frac{kWh_{PE}}{m^2 \cdot Year}$. For technical systems measures, the cumulative cost of the chosen pool of measures is 65.529 $\frac{€}{m^2}$ and the cumulative energy savings are 187.129 $\frac{kWh_{PE}}{m^2 \cdot Year}$. In total, the combined cumulative investment cost is 103.063 $\frac{€}{m^2}$ and the combined energy savings are 286.825 $\frac{kWh_{PE}}{m^2 \cdot Year}$.

Hirst [30] used equation 5.4 in his study to fit the cumulative energy savings (seen on figure 2.7). On the same figures (5.11 and 5.12), the trend line in orange is Hirst's equation 5.4 adapted to the set of envelope and technical systems measures, respectively. On tables 5.4 and 5.5 the coefficients of Hirst's equation adapted to the set of envelope and technical systems measures are presented. These coefficient values were obtained using the excel tool "solver" and following an approach similar to that of [95]. From table 5.4, namely from the R^2 value, it can be concluded thats Hirst's expression fits the envelope measures line quite well and from table 5.5, it can be seen Hirst's expression does not fit as nicely. However, since the pool of measures chosen for each set is too small, the fact that Hirst's equation fits the trend does not mean it will always be the case.

$$E = a + b(1 - e{-}cI^d) \tag{5.4}$$

Where

E are the cumulative energy savings [30].

I is the cumulative implementation cost [30].

a is the value for which the function tends to when I approaches 0 [30].

a + b is the value for which the function tends to when I approaches infinity [30].

$\boldsymbol{b \cdot c \cdot d}$ This product is ”proportional to the cost-effectiveness of measures” [30], *i.e.* cost of conserved energy.

On figures 5.9 and 5.10 a similar graphic, to the one shown above, is presented, but in these, the yy axis contains the cumulative financial savings, in $\frac{€}{m^2 \cdot Year}$. From these graphics, it can be seen that, based on ADENE's values, the total yearly financial savings stemming from envelope measures are 7.054 $\frac{€}{m^2 \cdot Year}$ and stemming from technical system measures are 18.669 $\frac{€}{m^2 \cdot Year}$. The sum of the cumulative financial savings from both sets of improvement measures is 25.723 $\frac{€}{m^2 \cdot Year}$, which through equation 3.1 and the sum of the cumulative investment costs of each set of measures, corresponds to a total payback time of about 4 years.

Table 5.4: Hirst's equation coefficients adapted to the set of envelope measures.

Coefficient	Value
a	12.492
b	2300.568
c	0.0010349
d	0.99899
$b \cdot c \cdot d$	2.378
[11] R^2	0.99932

Table 5.5: Hirst's equation coefficients adapted to the set of technical systems measures.

Coefficient	Value
a	11
b	3000
c	0.0009911
d	0.996
$b \cdot c \cdot d$	2.961
R^2	0.932

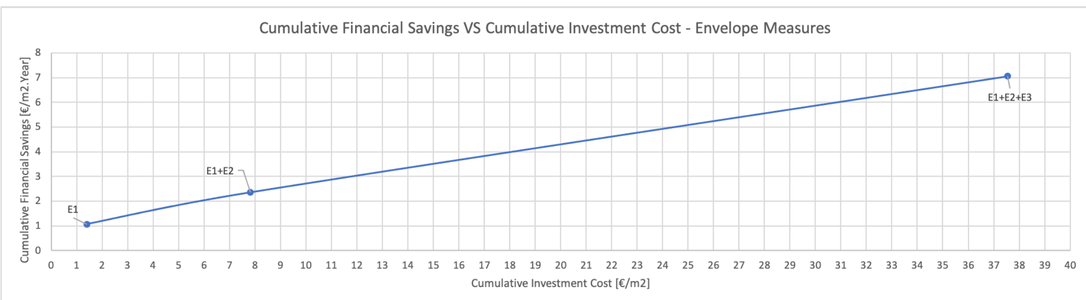


Figure 5.9: Cumulative financial savings VS cumulative investment cost - envelope measures.

[11] This value times 100 is the percentage of variation about the mean [30].

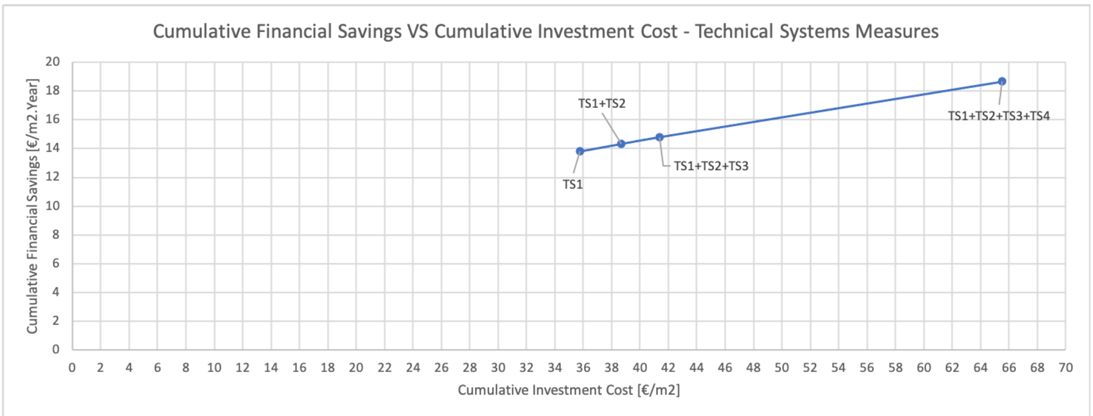


Figure 5.10: Cumulative financial savings VS cumulative investment cost - technical systems measures.

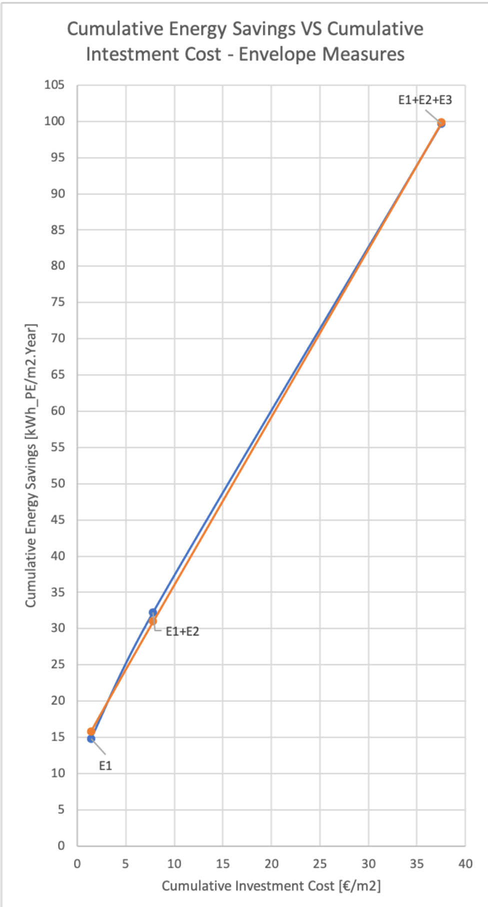


Figure 5.11: Cumulative energy savings VS cumulative investment cost - envelope measures, with Hirst [30] trendline.

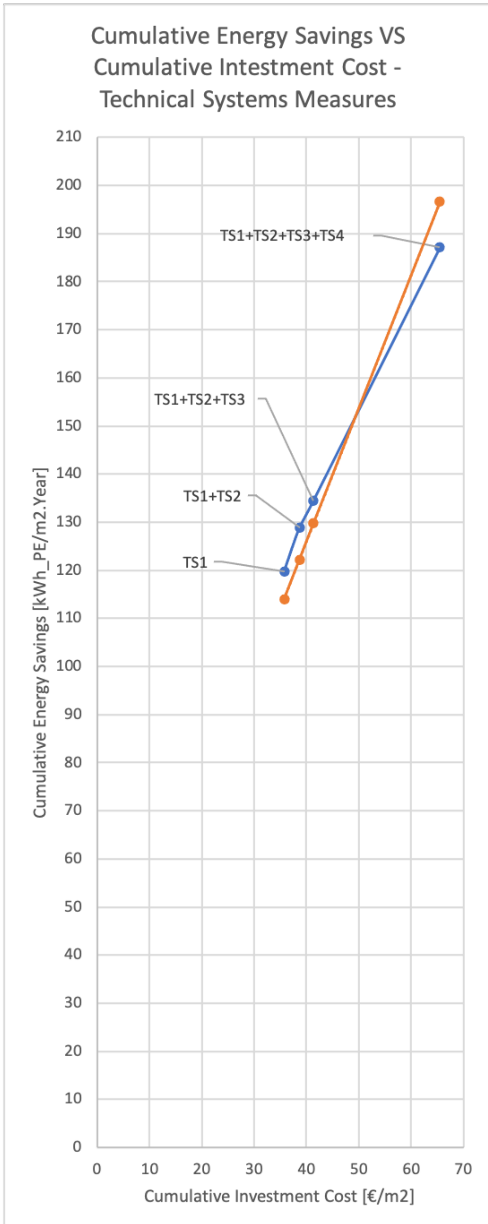


Figure 5.12: Cumulative energy savings VS cumulative investment cost - technical systems measures, with Hirst [30] trendline.

5.4 New Residence Energy Class after Energy Performance Improvement Measures

On figures 5.13 and 5.14 and tables 5.6 and 5.7, the residence's energy class, energy indicators and $CO_{2_{eq}}$ emissions are presented, after the implementation of the envelope measures, and after the implementation of both set of measures, respectively. As referred on table 5.7, an energy class of B is obtained after every improvement measure has been considered. Since the renewable energy consumed influences the energy class ratio, and therefore, the building's energy class, it is expected the energy class will only reach its best after RECT are considered (as verified below). The Itencons excel tool filled with the characteristics of the building after considering the envelope related energy performance improvement measures, is presented on A.2. The Itencons excel tool filled with the characteristics of the building after considering the envelope and technical systems related energy performance improvement measures, is presented on A.3.

Balanço energético

Indicadores energéticos

Sigla	Descrição	Valor		Referência	
Nic	Necessidades nominais anuais de energia útil para aquecimento (kWh/m2.ano)	44.95		45.54	
Nvc	Necessidades nominais anuais de energia útil para arrefecimento (kWh/m2.ano)	15.05		16.61	
Qa	Energia útil para preparação de água quente sanitária (kWh/ano)	2377		2377	**Ntc/Nt**
Wvm	Energia elétrica necessária ao funcionamento dos ventiladores (kWh/ano)		0.00		1.08
Eren	Energia produzida a partir de fontes renováveis para usos regulados (kWh/ano)	0		0	
Eren AQS	Energia produzida a partir de fontes renováveis para produção de AQS (kWh/ano) (para efeito de verificação do requisito mínimo)	0		0	**Classe Energética**
Eren,ext	Energia produzida a partir de fontes renováveis para outros usos (kWh/ano)		0.00		**C**
Ntc	Necessidades nominais anuais globais de energia primária (kWhep/m2.ano)	167.30		154.73	

Figure 5.13: Case study, after envelope energy performance improvement measures implementation, residence energy class.

Table 5.6: Building, after envelope energy performance improvement measures implementation, is EPC results.

Building Energy Class	Energy Class Ratio R_{Nt}	$CO_{2_{eq}}$ Emissions $\left[\frac{ton}{Year}\right]$
C	1.08	2.81

Balanço energético

Indicadores energéticos

Sigla	Descrição	Valor		Referência	
Nic	Necessidades nominais anuais de energia útil para aquecimento (kWh/m2.ano)	44.95		45.54	
Nvc	Necessidades nominais anuais de energia útil para arrefecimento (kWh/m2.ano)	15.05		16.61	
Qa	Energia útil para preparação de água quente sanitária (kWh/ano)	2140		2377	**Ntc/Nt**
Wvm	Energia elétrica necessária ao funcionamento dos ventiladores (kWh/ano)		0.00		0.57
Eren	Energia produzida a partir de fontes renováveis para usos regulados (kWh/ano)	6819		0	
Eren AQS	Energia produzida a partir de fontes renováveis para produção de AQS (kWh/ano) (para efeito de verificação do requisito mínimo)	1426		0	**Classe Energética**
Eren,ext	Energia produzida a partir de fontes renováveis para outros usos (kWh/ano)		0.00		**B**
Ntc	Necessidades nominais anuais globais de energia primária (kWhep/m2.ano)	39.79		70.41	

Figure 5.14: Case study, after envelope and technical systems energy performance improvement measures implementation, residence energy class.

Table 5.7: Building, after envelope and technical systems energy performance improvement measures implementation, EPC results.

Building Energy Class	Energy Class Ratio R_{Nt}	$CO_{2_{eq}}$ Emissions $\left[\frac{ton}{Year}\right]$
B	0.57	0.61

5.5 New Building Energy Class after RECT application

The EPC calculates the building energy class and the $CO_{2_{eq}}$ emissions based on the amount of energy provided by (ideally) *in situ* RECTs, so, from the point of view of the EPC, a carbon neutral NZEB would be one whose energy consumption is the same as the energy delivered by *in situ* RECTs. In a EPC Itencons excel tool filling perspective, a carbon neutral NZEB could be reached by assuming every energy consumption need, for the B class building, which is exclusively electricity, could be suppressed by a certain number of solar photovoltaic panels (to be calculated, see footnote), which deliver the amount of electricity needed[12]. Hence, an energy class of A+ (seen on figure 5.15, as well as other energy indicators), with an energy class ratio of $R_{Nt} = -0.02$ and associated emissions of -0.02 tons of $CO_{2_{eq}}$ per year, as seen on table 5.8, would be obtained. The Itencons excel tool filled with the final characteristics of the building, after considering RECT, is presented on A.4.

Balanço energético

Indicadores energéticos

Sigla	Descrição	Valor		Referência	
Nic	Necessidades nominais anuais de energia útil para aquecimento (kWh/m2.ano)	44.95		45.54	
Nvc	Necessidades nominais anuais de energia útil para arrefecimento (kWh/m2.ano)	15.05		16.61	
Qa	Energia útil para preparação de água quente sanitária (kWh/ano)	2140		2377	Ntc/Nt
Wvm	Energia elétrica necessária ao funcionamento dos ventiladores (kWh/ano)		0.00		-0.02
Eren	Energia produzida a partir de fontes renováveis para usos regulados (kWh/ano)	8574		1040	
Eren AQS	Energia produzida a partir de fontes renováveis para produção de AQS (kWh/ano) (para efeito de verificação do requisito mínimo)	2167		1040	Classe Energética
Eren,ext	Energia produzida a partir de fontes renováveis para outros usos (kWh/ano)		0.00		A+
Ntc	Necessidades nominais anuais globais de energia primária (kWhep/m2.ano)	-1.54		70.41	

Figure 5.15: Case study, after envelope and technical systems energy performance improvement measures as well as RECT implementation, residence energy class.

[12] The total global primary energy needs of the case study, after implementation the proposed improvement measures is of 4223.311 $\frac{kWh_{PE}}{Year}$, in electricity. According to the conversion factor on table 3.6, this corresponds to a final energy need of 1689.324 $\frac{kWh_{FE}}{Year}$. This should be the amount of electricity to be produced by a unit of photovoltaic panels. To know how many solar panels need to be installed to deliver that final energy first, a solar panel model needs to be chosen and second, the area of solar panels needed should be taken from expression $E = A \cdot r \cdot H \cdot PR$, where E is the final energy delivered by the solar panel, A is the solar panel area, r is the solar panel efficiency, H is the annual average solar radiation on tilted panels and PR is the performance ratio or coefficient of losses, as described on [96]. The chosen solar PV panel model was WINAICO's, WSP-MX Series, 325 W Mono Full Black, with the following characteristics per panel, area A = 1.75274 m^2, 352 Watt-peak, solar panel efficiency r = 0.1854, as stated on the PV panel catalogue [97], the coefficient of losses was considered to be PR = 0.75, as per [96] and the annual average solar radiation on tilted panels H = 1800 $\frac{kWh}{m^2 \cdot Year}$, taken from [98] direct normal irradiation. From the previously mentioned expression, the area obtained is A = 3.85, which should be rounded to 4 PV panels to be installed. These 4 PV panels would deliver a total of 1754.773 $\frac{kWh_{FE}}{Year}$, thus surpassing slightly the residence's energy demand.

Table 5.8: Building, after envelope and technical systems energy performance improvement measures as well as RECT implementation, EPC results.

Building Energy Class	Energy Class Ratio R_{Nt}	$CO_{2_{eq}}$ Emissions $\left[\frac{ton}{Year}\right]$
A+	-0.02	-0.02

However, for a real life building RECT implementation, several other factors would have to be taken into consideration for a proper RECT unit modelling and installation. To start, the RECT units to be installed would have to be modelled to suit the daily and seasonal building energy consumption profile, as well as to be capable to deliver energy during consumption peak(s) [99]. The Directorate-General of Energy and Geology, in Portugal (DGEG), has developed an excel tool, SEC.ER [100], to assist in the modelling of solar RECT systems, in the context of the EPC. Moreover, the possibility of including energy storage should be addressed and modelled and the type of control and control system to be used should also be assessed and studied. On figure 5.16 a summary of the factors to consider when modelling the RECT units to be implemented, is presented.

As mentioned before, this exercise intended to showcase the type of analysis the QE goes through when issuing the EPC, choosing the adequate pool of measures, understanding what are their costs, energy and financial savings as well as what parameters to study in order to plan and implement an adequate RECT unit. In the context of the Renovation Passport, the QE would still have plenty of other responsibilities to attend to, such as updating and verifying other entities inputs in the platform, auditing the building, preferably, *in situ*, after each Milestone is reached, verifying the compliance of construction and maintenance works and issuing reports on the global status of the work and of the Renovation Passport goal achievement. All of this, in close communication with the building owner/user.

5.6 Maintenance Recommendations

Some of the manufacturer recommendations, to be considered, for the air conditioning system considered ("Ururu Sarara" model SB-FTXZ25N, from DAIKIN) are the following (as taken from [102]):

- "Do not attempt to install or repair the air conditioner yourself. Improper workmanship may result in water leakage, electric shocks or fire hazards. Please contact your local dealer or qualified personnel for installation and maintenance work".
- "When the air conditioner is malfunctioning (giving off a burning odour, etc.) turn off power to the unit and contact your local dealer. Continued operation under such circumstances may result in a failure, electric shocks or fire hazards".
- "Be sure to install an earth leakage circuit breaker. Failure to install the earth leakage circuit breaker may result in electric shocks or fire".

For the DHW preparation heat pump (the "Altherma DHW - Monobloc" model EKHH2E200AV3 - 200L, from DAIKIN), some of the manufacturer recommendations are the following (as taken from [103]):

- Cleaning the air filter when the unit informs to do so.

	Icon	Technology	Explanation
			type of heating system e.g. a heat pump, and are controlled as a group
Energy system		Heat pump	The utilized heat pumps are located in the buildings and may both be ground source or air source heat pumps
		District heating	Is considered in the sense, that the building(s) heat demand is covered by district heating via typically a heat exchanger in the building
		Other HVAC system	This includes any other ventilation and/or cooling systems
		PV	PV systems located at the building make the building a prosumer, which may put extra stress on the grid when they export electricity to the grid
Source of flexibility		Constructions	The thermal mass of the building (walls, floors, ceilings but also furniture) are utilised for storage of heat
		Thermal storage	Thermal storage are here both DHW tanks, buffer tanks in space heating and cooling systems but also swimming pools or PCM storage
		Battery	Batteries may both be a stationary battery in the building (e.g. in connection with a PV system) or the battery of an electrical vehicle owned by the user of the building
		Fuel switch	Energy flexibility obtained in a building, which has two or more energy systems covering the same demand – e.g. a gas boiler and a heat pump
Control system		Rule based	Traditional control where the energy service systems are controlled by a set of predefined rules. A traditional PI thermostat is a simple rule based controller
		Model based	The controller is based on a model of the energy demand of the building in the form of a white box model (e.g. TRNSYS), a grey box model (typically a low order RC (resistance-capacitance) model) or a black box model (where the model is generated from measurements and the parameters of the model give no direct physical meaning). Model based controllers give the possibility of applying forecasts and can thereby make them more efficient but also more complex
Results based on		Simulations	The results of the example/teaser are based on simulations using typically white box modelling but can also be based on grey and black box models
		Measurements	The obtained results are from measurements in real buildings or from test facilities utilizing hardware-in-the loop where parts of the test are real physical components while the building and weather are simulated

Figure 5.16: Factors to consider when modelling an adequate RECT unit(s) to be installed in the considered building, as illustrated by [101].

- 1 replaceable anode ”or even better protection against corrosion improving the lifetime of the unit”.

Other best practices for air conditioning and heat pump maintenance, as recommended by the U.S. Department of Energy [104, 105] are the following:

- Replace and clean ”clogged, dirty filters”.
- Clean the ”air conditioner’s evaporator coil” and fins.
- Unclogg the ”drain channels”.
- Hiring a professional technician for the following actions:
  - ”Check for correct amount of refrigerant”.

- – ”Test for refrigerant leaks using a leak detector”.
  – ”Verify the correct electric control sequence and make sure that the heating system and cooling system cannot operate simultaneously”.
  – ”Inspect electric terminals, clean and tighten connections, and apply a non-conductive coating if necessary”.
  – ”Oil motors and check belts for tightness and wear”.
  – ”Check the accuracy of the thermostat”.

Finally, for the considered solar panels (WINAICO’s, WSP-MX Series, 325 W Mono Full Black), some of the manufacturer recommendations refer to checking the units, periodically (preferably every three to five years), for faults, namely the following (as taken from [106]):

- ”Deteriorating Cabling”.
- ”Corrosion of wires”.
- ”Birds underneath system or Animal Bites”.
- ”Rare Weather events (Storms, Bush Fires, Hail, Lightning)”.
- ”DC Isolator fire”.
- ”Water egress”.
- ”Defective electrical components”.
- Cleaning dirty solar panels, as it may affect the energy output ”by 5-10%” [107].

5.7 Internet of Things Integration

Installing a smart meter system is an elegant solution to contribute to a more controlled and informed energy consumption. As mentioned before, this system would display the quantity and cost associated to the energy consumption at the building and, if integrated on an IoT system, the smart meters would help to detect sudden changes or abnormalities in energy consumption. This way, needed maintenance would be detected and consequently, its performance could be done sooner, therefore saving energy and money.

As discussed above, a smart meter system has the potential to be read by BIM or even to feed information to a ”digital building twins”[13] system, in order to ”facilitate monitoring of activities and comparison of relevant data against the initially agreed planning” [108]. These integration would help to automatise some of the manual tasks executed by the QE, adding accuracy and faster response.

A system of smart sensors, also IoT integrated, should also be considered to evaluate and optimise the energy output of the RECT units installed. These sensors may help with adjusting the energy output to better fit the needs of the user and optimise the periods when the RECT units are working, to be the ones at which the conditions are the most favourable.

[13]”The digital-twin concept uses tools and technologies to collect and process real data and information from devices, components, parts, machines on an ongoing construction site and structures in use” [108].

Chapter 6

Final Remarks

The Renovation Passport is presented as a new voluntary scheme which could be implemented at a national level, to promote building renovation and rehabilitation that leads to carbon neutral NZEBs by 2050, by starting from the existing EPC system scheme, taking advantage from its networks and infrastructure, and proposing new features and components, such as more integration between the building owner/user with the renovation decisions, more contact from the QE with maintenance and construction entities, as well as presenting the Milestones as goals to be achieved and verified through auditing.

The core idea that motivated this work and that the Renovation Passport brings, in light of building energy performance and efficiency, is to shift the mindset from a fixed energy class to a long term energy performance improvement strategy, with increased progress on comfort levels, energy and financial savings, with phased investment, planned smartly to decrease the chances of lock-in effects, as well as an increase on the market value of the building and adoption of sustainability best practices.

The main innovations (previously listed on table 3.9) the Renovation Passport offers are the proposed NZEB definition; the clear purpose of reaching a carbon neutral NZEB, a goal aligned with current national strategies; the extension of the building's lifetime by means of renovation and improvements applied to the building and its systems; the potential to automate the process of energy auditing and verifying the building's energy performance; having a defined maintenance plan, similar to the system used for automobiles, in Portugal, and the possibility of having the maintenance activities recorded in detail, for future reference; more involvement of the QE in the process of improving the building's conditions and the potential for more communication between the building owner/user and the QE and finally the potential for job creation (new roles) as well as to upgrade the set of the skills of the current QE role. The Renovation Passport also sets a clear goal for rehabilitation and renovation works, the carbon neutral NZEB, thus being aligned with national strategies and going a step further from the current EPC scheme.

It would be interesting to include in the context of the Renovation Passport training and discussion, among the QE community, on new forms to perform the energy audit, namely regarding its automation and considering other types of audit and elements which are not currently subject to audit, in the context of the EPC (such as lighting, for residential buildings). Another innovation which could be achieved making use of the information, namely on energy consumption quantities and patterns, collected on the Renovation Passport scheme would be to recalculate and/or the current 'standard conditions', which are the basis for EPC calculation nowadays, as well as potentiate benchmarking between buildings, specially those with similar characteristics.

In this work, energy improvement for a single building was the main focus, although, there still is a lot of future work to consider for the Renovation Passport. One of the most immediate advances to this work would be to address water efficiency and setting water efficiency goals, which, through the water-energy nexus[1], would directly affect the energy performance of the building. In Portugal, a voluntary scheme, AQUA+ [110], to attribute a 'water class' to the building (much like what is done in the EPC with the energy class), has been recently launched by ADENE.

Nowadays, mindsets that go beyond the carbon neutral NZEB, like Positive Energy Districts[2] (PED) and smart cities[3] are gaining momentum and new opportunities regarding energy, digital transformation and business may be foreseen [8]. These could be incorporated in the Renovation Passport, which could broaden its scope and include neighbourhoods instead of single buildings. Other concepts, such as nature based solutions[4] and urban farming[5], are emerging as ways to promote greener cities and improved air quality, to address resource scarcity and efficiency, food transport and security, shared consumption, self production and local based businesses [8, 115], and again could be incorporated in the Renovation Passport. Besides, these concepts have advantages that result in a better building energy performance, such as reducing summer cooling load and surface temperatures, insulating against cold, minimising heat gains and losses as well as reducing the urban heat island effect[6] [115, 117].

Finally, circular economy concepts may also be applied in the context of the Renovation Passport, such as urban mining[7], as it represents "a significant source of resources, with concentrations of elements often comparable to or exceeding natural stocks" [118] and, therefore, of extreme importance in the light of circular economy and sustainability in cities, the "circular product label" (as an adaptation to the context of building construction and rehabilitation products, of the current label "CERTAGRI" developed by ADENE, for the agri-food industry [119]) and building modularity.

[1] The water-energy nexus studies the relationship between water and energy, namely, by understanding how energy is used to "secure, deliver, treat, and distribute water" and how water is used to "deliver energy for consumption" [109]. Inside the boundaries of a residential building, the most significant water-energy interaction would be in the preparation of domestic hot water.

[2] A "Positive Energy District is seen as an urban neighbourhood with annual net zero energy import and net zero CO_2 emissions working towards a surplus production of renewable energy, integrated in an urban and regional energy system" and "couples built environment, sustainable production and consumption, and mobility to reduce energy use and greenhouse gas emissions and to create added value and incentives for the consumer" [111].

[3] A "smart city is a place where traditional networks and services are made more efficient with the use of digital and telecommunication technologies for the benefit of its inhabitants and business" whose objective is to have "smarter urban transport networks, upgraded water supply and waste disposal facilities and more efficient ways to light and heat buildings" [112].

[4] Nature based solutions include "green roofs, green walls, rain gardens, street trees and other urban green infrastructure" [113].

[5] Urban farming or urban agriculture may be understood as "the growing, processing and distribution of food or livestock within and around urban centres with the goal of generating income" [114].

[6] Heat islands are "urbanised areas that experience higher temperatures than outlying areas. Structures such as buildings, roads, and other infrastructure absorb and re-emit the sun's heat more than natural landscapes such as forests and water bodies. Urban areas, where these structures are highly concentrated and greenery is limited, become "islands" of higher temperatures relative to outlying areas" [116]

[7] Urban mining can be defined as the "activities involved in extracting and processing wastes" "from any kind of anthropogenic stocks, including buildings, infrastructure, industries, products (in and out of use), environmental media receiving anthropogenic emissions" [118].

Bibliography

[1] European Comission. The European Green Deal. *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE EUROPEAN COUNCIL, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS*, (COM(2019) 640 final COMMUNICATION):24, 2019. 1, 2, 21

[2] European Parliament and European Council. DIRECTIVE (EU) 2018/844 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 30 May 2018. *Official Journal of the European Union*, (L 156/75), 2018. 1

[3] IPCC. Summary for Policymakers SPM. *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change,*, page 32, 2018. 1

[4] European Comission - Environment. Resource Efficiency. `https://ec.europa.eu/environment/resource_efficiency`. Accessed: 22-12-2019. 1

[5] European Comission. European Climate Law. `https://ec.europa.eu/clima/policies/eu-climate-action/law_en`. Accessed: 09-03-2020. 1, 21, 31

[6] República Portuguesa. National Energy Climate Plan 2021-2030 (Plano Nacional Integrado Energia e Clima - PNEC). Technical report, 2018. 2

[7] Ministério do Ambiente e Acção Climática. ESTRATÉGIA DE LONGO PRAZO PARA A RENOVAÇÃO DOS EDÍFICIOS (ELPRE) - Consulta Pública. page 75, 2020. xx, 2, 32, 33, 54, 55

[8] Ministério do Ambiente e da Transição Energética; Fundo Ambiental; Agência Portuguesa do Ambiente. Roteiro para a Neutralidade Carbónica 2050 (RNC2050). 2050, 2019. xx, 2, 33, 34, 80

[9] J. Rogelj, D. Shindell, K. Jiang, S. Fifita, P. Forster, V. Ginzburg, C. Handa, H. Kheshgi, S. Kobayashi, E. Kriegler, L. Mundaca, R. Seferian, and M.V. Vilarino. 2018: Mitigation Pathways Compatible With 1.5°C in the Context of Sustainable Development. *Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels*

and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change,, page 82pp, 2018. 2, 3, 6

[10] United Nations. Sustainable Development Goals - 7. https://sustainabledevelopment.un.org/sdg7. Accessed: 09-02-2020. 3, 5

[11] United Nations. Sustainable Development Goals - 11. https://sustainabledevelopment.un.org/sdg11. Accessed: 24-05-2020. 3

[12] United Nations. Sustainable Development Goals - 13. https://sustainabledevelopment.un.org/sdg13. Accessed: 24-05-2020. 3

[13] IPCC. *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. 2014. 6

[14] European Parliament. DIRECTIVE 2010/31/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 May 2010 on the energy performance of buildings. *Official Journal of the European Union*, page 22, 2010. 6

[15] Delia D'Agostino. Assessment of the progress towards the establishment of definitions of Nearly Zero Energy Buildings (nZEBs) in European Member States. *Journal of Building Engineering*, 1:20–32, 2015. xix, 6, 7, 11, 12, 49, 56

[16] H. Lund, A. Marszal, and P. Heiselberg. Zero energy buildings and mismatch compensation factors. *Energy and Buildings*, 43(7):1646–1654, 2011. 7

[17] P Torcellini, S Pless, M Deru, and D. Crawley. Zero Energy Buildings: A Critical Look at the Definition. *ACEEE Summer Study Pacific Grove*, page 15, 2006. xix, 7, 8, 10, 11, 29, 49

[18] Ministério da Economia e do Emprego. Decreto-Lei n.º 118/2013, de 20 de Agosto - Desempenho Energético dos Edifícios). *Diário da República*, I Série(nº 159 - 20 Agosto 2013):4988–5005, 2013. 8, 12, 20, 51, 67

[19] República Portuguesa. Portaria 98/2019, 2019-04-02 - DRE. pages 1816–1818, 2019. 8, 56

[20] Ministério do Ambiente do Ordenamento do Território e Energia - Direcção-Geral de Energia e Geologia. Despacho nº 15793/2013. *Diário da República*, II Série(nº 234 - 3 de Dezembro 2013 - 3º Suplemento), 2013. xvii, xix, 8, 9, 18, 20, 46, 47, 48, 67, 68, 70

[21] Ministério do Ambiente Ordenamento do Território e Energia. Portaria n.º349-B/2013. *Diário da República*, 1ª Série(18):6624–(18) a 6624–(29), 2013. 8, 9, 67, 68

[22] Despacho nº 15793-F. Zonamento Climático. *Diário da República*, 2.ª série(234):26–31, 2013. 8

[23] Giuliano Dall'O', Elisa Bruni, and Luca Sarto. An Italian pilot project for zero energy buildings: Towards a quality-driven approach. *Renewable Energy*, 50:840–846, 2013. 10, 12, 13

[24] Yangang Xing, Neil Hewitt, and Philip Griffiths. Zero carbon buildings refurbishment - A Hierarchical pathway. *Renewable and Sustainable Energy Reviews*, 15(6):3229–3236, 2011. xix, 10

[25] BSi British Standards Institution. Heating systems in buildings — Method for calculation of system energy requirements and system efficiencies — BS EN 15316-1:2007, 2007. 11

[26] BSi British Standards Institution. Energy performance of buildings — Overall energy use , CO2 emissions and definition of energy ratings - BS EN 15603:2008, 2008. 11

[27] Igor Sartori, Assunta Napolitano, Anna Marszal, Shanti Pless, Paul Torcellini, and Karsten Voss. Criteria for Definition of Net Zero Energy Buildings. pages 1–8, 2016. xix, 12, 13, 14, 48

[28] A. J. Marszal, P. Heiselberg, J. S. Bourrelle, E. Musall, K. Voss, I. Sartori, and A. Napolitano. Zero Energy Building - A review of definitions and calculation methodologies. *Energy and Buildings*, 43(4):971–979, 2011. 12

[29] Alan Meier, Arthur H. Rosenfeld, and Janice Wright. Supply curves of conserved energy for California's residential sector. *Energy*, 7(4):347–358, 1982. xix, 14, 15, 16

[30] Eric Hirst. Analysis of hospital energy audits. *Energy Policy*, 10(3):225–232, 1982. xix, xx, 16, 17, 71, 72, 73

[31] Certificar é Valorizar - Certificação Energética de Edifícios. Consumidores. `https://www.sce.pt/certificacao-energetica-de-edificios-3/consumidores/`. Accessed: 11-10-2019. 17

[32] Certificar é Valorizar - Certificação Energética de Edifícios. Profissionais. `https://www.sce.pt/certificacao-energetica-de-edificios-3/profissionais-sce/`. Accessed: 29-02-2020. 17

[33] ADENE. Certificado Energético - Edifício de Habitação. Technical report, ADENE, Lisboa, 2015. 18

[34] Ministério do Ambiente Ordenamento do Território e Energia da Saúde e da Solidariedade Emprego e Segurança Social;. Portaria n.º 349-A/2013 de 29 de novembro. *Diário da República*, 1.ª série(N.º 232):6624–(13) a 6624–(17), 2014. 18

[35] Christopher Gorse, David Johnston, and Martin Pritchard. A Dictionary of Construction, Surveying and Civil Engineering. *A Dictionary of Construction, Surveying and Civil Engineering*, 2012. 19

[36] United Nations Framework Convention on Climate Change. Paris Agreement. Technical report, 2015. 20, 21

[37] European Comission. Committing to climate-neutrality by 2050: Commission proposes European Climate Law and consults on the European Climate Pact. `https://ec.europa.eu/commission/presscorner/detail/en/ip_20_335`. Accessed: 04-03-2020. 21

[38] European Comission. European Climate Pact. `https://ec.europa.eu/clima/policies/eu-climate-action/pact_en`. Accessed: 09-03-2020. 21

[39] European Comission. Horizon 2020. https://ec.europa.eu/programmes/horizon2020/what-horizon-2020. Accessed: 13-03-2020. 21

[40] Cláudia Sousa Monteiro, Rui Fragoso, Marianna Papaglastra, Alexander Deliyannis, Martin Pehnt, Pêter Mellwig, Julia Lempik, and Mandy Werle. The Concept of iBRoad : the Individual Building Renovation Roadmap and Building Logbook. *IBRoad Project*, (September 2018):51, 2018. xix, 21, 22, 23, 24, 39, 49

[41] European Commission - Environment. Level (S): a Guide To Europe ' S New Reporting Framework. pages 1–12. xix, 24, 25, 26

[42] Nicholas Dodd, Mauro Cordella, Marzia Traverso, and Shane Donatello. Level(s) - A common EU framework of core sustainability indicators for office and residential buildings - Part 1 and 2: Introduction to Level(s) and how it works (Draft Beta v1.0). *JRC Technical Reports*, (August):1–68, 2017. 24, 25, 26

[43] Participa. Participa - Consulta - ELPRE - Estratégia de Longo Prazo para a Renovaçãp dos Edifícios. https://participa.pt/pt/consulta/elpre-estrategia-de-longo-prazo-para-a-renovacao-dos-edificios. Accessed: 30-07-2020. 32

[44] EU Energy Poverty Observatory. What is energy poverty? https://www.energypoverty.eu/about/what-energy-poverty. Accessed: 31-07-2020. 32

[45] EU Energy Poverty Observatory. Inability to keep home adequately warm. https://www.energypoverty.eu/indicator?primaryId=1461. Accessed: 31-07-2020. 32

[46] European Committee for Standardization. EN 15251 - Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. (Final Draft), 2006. xix, 32

[47] EUROSTAT: Statistics explained. Glossary:Carbon dioxide equivalent. https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Carbon_dioxide_equivalent. Accessed: 08-11-2020. 33

[48] Government of Portugal. National Energy and Climate Plan 2021-2030: Portugal [in Portuguese]. 2030(Pnec 2030), 2019. 33, 55

[49] Certificar é Valorizar - ADENE. Acesso a instrumentos financeiros & Benefícios Fiscais. https://www.sce.pt/certificacao-energetica-de-edificios-3/investidores/. Accessed: 05-08-2020. 34, 35, 54

[50] Autoridade Trubutária e Aduaneira. Estatuto dos Benefícios Fiscais. Technical report, Lisbon, 2020. 34, 35

[51] Diário da República n.º 206/2009, Série I de 2009-10-23. Decreto-Lei n.º 307/2009 - Regime jurídico da reabilitação urbana. https://dre.pt/web/guest/legislacao-consolidada/-/lc/114291582/201707270100/indice. Accessed: 05-08-2020. 34, 35

[52] Ministério da Agricultura - do Mar - do Ambiente - do Ordenamento do Território. Decreto-Lei n.º 266-B/2012. Technical Report Diário da República, 1.ª série — N.º 252 —, 2012. 35

[53] Itecons - Instituto de Investigação e Desenvolvimento Tecnológico para a Construção, Energia, Ambiente e Sustentabilidade. Ferramentas de cálculo DL 118/2013. http://www.itecons.uc.pt/p3e/index.php. Accessed: 10-08-2020. 37, 67

[54] Amine Allouhi, Ali Boharb, Rahman Saidur, Tarik Kousksou, and Abdelmajid Jamil. *Energy Auditing*, volume 5-5. 2018. 37, 38, 42, 43, 44

[55] Martin Poljanšek. Building Information Modelling (BIM) standardization. Technical report, Joint Research Centre, Ispra, Italy, 2017. xx, 39, 40

[56] Shaimaa Seyam. Types of HVAC Systems. In *HVAC System*, pages 50–66. Mohsen Sheikholeslami Kandelousi, 2018. xx, 43

[57] European Commission. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on an EU Strategy for Heating and Cooling - Part 1/2. Technical report, Brussels, 2016. xx, 43, 44

[58] Diana Ürge-Vorsatz, Nick Eyre, Peter Graham, Danny Harvey, Edgar Hertwich, Yi Jiang, Mili Majumdar, James E Mcmahon, Shuzo Murakami, Kathryn Janda, Omar Masera, Michael Mcneil, Ksenia Petrichenko, Sergio Tirado Herrero, and Eberhard Jochem. Energy End-Use: Buildings. In IIASA - International Institute for Applied Systems Analysis, editor, *Global Energy Assessment - Toward a Sustainable Future*, chapter Chapter 10, page 660. Cambridge University Press, 2012. 43, 44, 51

[59] Observatório da Energia, DGEG, and ADENE. *Energia em Números - Edição 2020*. ADENE, 2020. 45

[60] APREN- Associação de Energias Renováveis. Boletim Electricidade Renovável Julho 2020. Technical report, 2020. 46

[61] Paul Freund, Stefan Bachu, and Murlidhar Gupta. Annex I - Properties of CO2 and carbon-based fuels. In Bert Metz, Ogunlade Davidson, Heleen de Coninck, Manuela Loos, and Leo Meyer, editors, *IPCC Special Report on Carbon dioxide Capture and Storage*, chapter Annex I, pages 383–400. Cambridge University Press, 2005. 46

[62] Michael J. Moran, Howard N. Shapiro, Daisie D. Boettner, and Margaret B. Bailey. *Fundamentals of Engineering Thermodynamics, Seventh Edition*. Don Fowley, seventh ed edition, 2011. 46

[63] DGEG - Direcção-Geral de Energia e Geologia. Conversões energéticas (1990 a 2019). https://www.dgeg.gov.pt/pt/estatistica/energia/balancos-energeticos/balancos-energeticos-nacionais/. Accessed: 15-01-2021. 46

[64] Smart Energy GB. Smart Meters Explained. https://www.smartenergygb.org/en/about-smart-meters. Accessed: 28-12-2020. 49

[65] European Commission. The Internet of Things. https://ec.europa.eu/digital-single-market/en/internet-of-things. Accessed: 28-12-2020. 50

[66] Gianna Reggio, Maurizio Leotta, Maura Cerioli, Romina Spalazzese, and Fahed Alkhabbas. What are IoT systems for real? An experts' survey on software engineering aspects. *Internet of Things*, 12:100313, 2020. 50

[67] Abhishek Singh, Ashish Payal, and Sourabh Bharti. A walkthrough of the emerging IoT paradigm: Visualizing inside functionalities, key features, and open issues. *Journal of Network and Computer Applications*, 143(February):111–151, 2019. 50

[68] Ali GhaffarianHoseini, Tongrui Zhang, Nicola Naismith, Amirhosein GhaffarianHoseini, Dat Tien Doan, Attiq Ur Rehman, Okechukwu Nwadigo, and John Tookey. ND BIM-integrated knowledge-based building management: Inspecting post-construction energy efficiency. *Automation in Construction*, 97(September 2018):13–28, 2019. 50

[69] Michael S. Forsthoffer. Predictive and Preventive Maintenance. In *Forsthoffer's More Best Practices for Rotating Equipment*, pages 501–546. 2017. 50, 51

[70] Portal da Habitação - Instituto da Habitação e da Reabilitação Urbana. 1.º Direito - Programa de Apoio ao Acesso à Habitação. https://www.portaldahabitacao.pt/web/guest/1.\protect{\mathsurround\z@\protect$\relax^{\protect\unhbox\voidb@x\hbox{\protect\afterassignment\edef10{71.13188}\afterassignment\edef12.0pt{0.0ptplus1.0pt}\edef1.5{1.5}\let1.51.5\def\size@update{\baselineskip12.0pt\relax\baselineskip1.5\baselineskip\normalbaselineskip\baselineskip\setbox\strutbox\hbox{\vruleheight.7\baselineskipdepth.3\baselineskipwidth\z@}\let\size@update\relax}\protect\xdef\OT1/phv/m/n/7{\OT1/phv/m/n/10}\OT1/phv/m/n/7\size@update\enc@updateo}}$}-direito. Accessed: 05-08-2020. 54

[71] Portal da Habitação - Instituto da Habitação e da Reabilitação Urbana. Reabilitar para Arrendar - Habitação Acessível (RPA-HA). https://www.portaldahabitacao.pt/web/guest/o-que-e-rpa-ha. Accessed: 05-08-2020. 54

[72] Portal da Habitação - Instituto da Habitação e da Reabilitação Urbana. Fundo Nacional de Reabilitação do Edificado. https://www.portaldahabitacao.pt/fundo-nacional-para-a-reabilitacao-do-edificado. Accessed: 05-08-2020. 55

[73] Portugal 2020. Portugal 2020. https://www.portugal2020.pt. Accessed: 05-08-2020. 55

[74] POSEUR. POSEUR. https://poseur.portugal2020.pt/en/po-seur/about-the-programme/. Accessed: 05-08-2020. 55

[75] Portugal 2020. Programas Operacionais Regionais. https://www.portugal2020.pt/content/programas-operacionais. Accessed: 05-08-2020. 55

[76] APA - Agência Portuguesa do Ambiente. ENCPE. https://encpe.apambiente.pt. Accessed: 05-08-2020. 55

[77] APA - Agência Portuguesa do Ambiente. ENAAC. https://apambiente.pt/index.php?ref=16&subref=81&sub2ref=118&sub3ref=955. Accessed: 05-08-2020. 55

[78] Direcção Geral de Tesouro e Finanças - Ministério das Finanças. Fundo de Reabilitação e Conservação Patrimonial. http://www.dgtf.pt/patrimonio-imobiliario/fundo-de-reabilitacao-e-conservacao-patrimonial. Accessed: 05-08-2020. 55

[79] República Portuguesa XXI Governo Constitucional. Casa Eficiente 2020. https://casaeficiente2020.pt. Accessed: 05-08-2020. 55

[80] República Portuguesa. Casa Eficiente 2020 : Regulamento. page 13, 2018. 55

[81] IFRRU e República Portuguesa - Infraestruturas e Habitação. IFRRU 2020. https://ifrru.ihru.pt. Accessed: 05-08-2020. 55

[82] República Portuguesa. IFRRU 2020 Guia do Beneficiário. Technical report, 2019. 55

[83] PNAEE – Plano Nacional de Ação para a Eficiência Energética. FEE. https://www.pnaee.pt/fee/{#}etapasfee. Accessed: 05-08-2020. 55

[84] European Union. Regulation (EU) 2016/679 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data (General Data Protection Regulation – GDPR). *Official Journal of the European Union*, L 199(4.5.2016):88, 2016. 63

[85] IN+. About IN+. http://in3.dem.ist.utl.pt/about/about-intro/. Accessed: 13-11-2020. 65

[86] Trimble. Sketchup. https://www.sketchup.com. Accessed: 13-11-2020. 65

[87] EnergyPlus. National Renewable Energy Laboratory (NREL), U.S. Department of Energy's (DOE) and Building Technologies Office (BTO). https://energyplus.net. Accessed: 13-11-2020. 65

[88] Instituto da Habitação e da Reabilitação Urbana. Guia Prático da Habitação. Technical report, Ministério da Agricultura, do Mar, do Ambiente e do Ordenamento do Território, Lisbon. 65

[89] Microsoft. Excel. https://www.microsoft.com/en-ww/microsoft-365/excel. Accessed: 13-11-2020. 68

[90] SOTECNISOL Materiais. Características da Caixa Térmica e Acústica. Technical report, SOTECNISOL S.A. 70

[91] Carlos A. Pina dos Santos; Luís Matias. Coeficientes de Transmissão Térmica de Elementos da Envolvente dos Edifícios. Technical report, LNEC - Laboratório Nacional de Engenharia Civil, 2006. 70

[92] DAIKIN. Seasonal Efficiency SEER and SCOP. https://www.daikin.co.uk/en_gb/faq/what-is-seasonal-efficiency--scop-and-seer-.html. Accessed: 15-11-2020. 70

[93] DAIKIN. Ar Condicionado Gama Split - Tabela de Preços 2020 - DAIKIN. Technical report, 2020. 70

[94] DAIKIN. Heating Catalogue - COP definition. https://www.daikin.pt/content/dam/document-library/catalogues/heat/air-to-water-heat-pump-flex-type/edhq-b6v3/Daikin%20Altherma%20technical%20catalogue_ECPEN11-721A_Catalogues_English.pdf. Accessed: 15-11-2020. 70

[95] Leroy E. Laverman. Solver - Excel Tool Example for non-linear curve fitting. Technical report, University of California, Santa Barbara - Chemistry and Biochemistry, Santa Barbara USA. 71

[96] Photovoltaic Software. How to calculate the annual solar energy output of a photovoltaic system? . https://photovoltaic-software.com/principle-ressources/how-calculate-solar-energy-power-pv-systems. Accessed: 15-11-2020. 75

[97] WINAICO. WSP-MX Series. Technical report. 75

[98] SOLARGIS. Solar resource maps of Portugal. https://solargis.com/maps-and-gis-data/download/portugals. Accessed: 15-11-2020. 75

[99] P A Boyd, G B Parker, and D D Hatley. Load Reduction, Demand Response and Energy Efficient Technologies and Strategies. Technical Report November, U.S. Department of Energy, 2008. 76

[100] Direcção-Geral de Energia e Geologia - DGEG. SCE.ER. https://www.dgeg.gov.pt/pt/areas-setoriais/energia/energias-renovaveis-e-sustentabilidade/sce-er/. Accessed: 15-11-2020. 76

[101] IEA - International Energy Agency. *Examples of Energy Flexibility in Buildings*. Number September. 2019. xx, 77

[102] DAIKIN. Daikin Room Air Conditioner Operation Manual. 76

[103] DAIKIN. Monobloc - DHW heat pump. 76

[104] U.S. Department of Energy. Maintaining Your Air Conditioner. https://www.energy.gov/energysaver/maintaining-your-air-conditioner. Accessed: 29-12-2020. 77

[105] U.S. Department of Energy. Operating and Maintaining Your Heat Pump. https://www.energy.gov/energysaver/heat-and-cool/heat-pump-systems/operating-and-maintaining-your-heat-pump. Accessed: 29-12-2020. 77

[106] WINAICO. Cleaning and Maintenance. https://www.winaico.com.au/installation-manual-cleaning-and-maintenance. Accessed: 29-12-2020. 78

[107] WINAICO. Everything You Need to Know About Cleaning Solar Panels. https://www.winaico.com.au/blog/cleaning-solar-panels. Accessed: 29-12-2020. 78

[108] EU Strategy for the Alpine Region. Digital Building Twins. https://www.alpine-region.eu/funding-calls/digital-building-twins-ria. Accessed: 29-12-2020. 78

[109] Christopher A. Scott, Suzanne A. Pierce, Martin J. Pasqualetti, Alice L. Jones, Burrell E. Montz, and Joseph H. Hoover. Policy and institutional dimensions of the water-energy nexus. *Energy Policy*, 39(10):6622–6630, 2011. 80

[110] ADENE. AQUA+. https://www.aquamais.pt/#. Accessed: 11-11-2020. 80

[111] Urban Europe. Positive Energy Districts (PED). https://jpi-urbaneurope.eu/ped/. Accessed: 11-11-2020. 80

[112] European Comission. Smart Cities. https://ec.europa.eu/info/eu-regional-and-urban-development/topics/cities-and-urban-development/city-initiatives/smart-cities_en. Accessed: 11-11-2020. 80

[113] Vera Enzi, Blanche Cameron, Péter Dezsényi, Dusty Gedge, Gunter Mann, and Ulrike Pitha. *Nature-Based Solutions to Climate Change Adaptation in Urban Areas: Linkages between Science, Policy and Practice - Theory and Practice of urban Sustainability Transitions*. Springer, Leipzig, Germany, 2017. 80

[114] James McEldowney. *Urban agriculture in Europe Patterns, challenges and policies*. Number December. 2017. 80

[115] Susanne Thomaier, Kathrin Specht, Dietrich Henckel, Axel Dierich, Rosemarie Siebert, Ulf B. Freisinger, and Magdalena Sawicka. Farming in and on urban buildings: Present practice and specific novelties of zero-acreage farming (ZFarming). *Renewable Agriculture and Food Systems*, 30(1):43–54, 2015. 80

[116] EPA - United States Environmental Protection Agency. Urban Heat Island. https://www.epa.gov/heatislands. Accessed: 11-11-2020. 80

[117] H. F. Castleton, V. Stovin, S. B.M. Beck, and J. B. Davison. Green roofs; Building energy savings and the potential for retrofit. *Energy and Buildings*, 42(10):1582–1591, 2010. 80

[118] Raffaello Cossu and Ian D. Williams. Urban mining: Concepts, terminology, challenges. *Waste Management*, 45:1–3, 2015. 80

[119] ADENE. CERTAGRI - Rótulo de Produto Circular no sector agroalimentar. https://www.adene.pt/certagri-rotulo-de-produto-circular-no-setor-agroalimentar/?fbclid=IwAR3a0aicic-gyoW17_swsEnnv7y8VbKUqmT9OaJSVvol3z0iTwqSKPutUL0. Accessed: 11-11-2020. 80

Appendix A

EPC Calculation Sheets

A.1 Residence Initial Energy Class Calculation

To access the Itencons tool for building energy class calculation, filled with the initial characteristics of the building, please refer to https://www.dropbox.com/s/5z26ekw8v3ufytr/Tese_1_building_as_is.xlsb?dl=0.

A.2 Residence Energy Class Calculation after considering Envelope Measures

To access the Itencons tool for building energy class calculation, filled with the characteristics of the building after considering the envelope related energy performance improvement measures, please refer to https://www.dropbox.com/s/xknyjvz1a9150ml/Tese_2_building_MM_envelope.xlsb?dl=0.

A.3 Residence Energy Class Calculation after considering Envelope and Technical Systems Measures

To access the Itencons tool for building energy class calculation, filled with the characteristics of the building after considering the envelope and technical systems related energy performance improvement measures, please refer to https://www.dropbox.com/s/1yqrziqw3jcqcyt/Tese_3_building_MM_tech_sys.xlsb?dl=0.

A.4 Final Residence Energy Class Calculation

To access the Itencons tool for building energy class calculation, filled with the final characteristics of the building, after considering RECT, please refer to https://www.dropbox.com/s/u3j46be40upop2m/Tese_4_building_MM_RECT.xlsb?dl=0.