Renovation Passport towards a Near Zero Energy Building

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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 (Long Term Strategy for Building Renovation), PNEC (National Integrated Plan for Energy and Climate 2021-2030) and RNC 2050 (Carbon Neutrality Road Map 2050).

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

1. Introduction

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, as well as addressing the question of the building sector accounting for, by 2014 and according to IPCC[1], "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)" and "23% of global energy-related CO_2 emissions, with one-third of those from direct fossil fuel consumption", when including them [1].

In turn, this is aligned with European Union (EU) guidelines to achieve carbon neutral buildings by 2050 (as per the European Green Deal [2] and European Climate Law [3]). The main contribution this work intends to deliver is to achieve this goal in Portugal, by proposing a framework, for a national scheme implementation, the Renovation Passport towards a carbon neutral and near zero energy building (NZEB), built from the already existing national scheme on building energy efficiency improvement, the Energy Performance Certificate (EPC) system.

The EPC classifies the building, as is, according to its energy performance and suggests measures to improve said performance, ultimately, to achieve the highest classification possible. However, since energy efficiency, *per se* is not enough to achieve the 2050 goal of carbon neutrality, the Renovation Passport scheme proposes to go further by developing a plan to guide the building owner/user to take the necessary steps towards transforming their building into a carbon neutral NZEB whose energy consumption comes from 'green'[2] energy, becoming a self-sufficient and non-GHG[3]-emitting building.

The Renovation Passport is introduced as a voluntary scheme to be implemented by building owners/users, by fulfilling a set of milestones by certain dates, to ultimately achieve carbon neutrality by 2050, as well as a guide that recommends what actions to take and the kind of maintenance needed to ensure a correct functioning of the building and its systems. Furthermore, it is proposed the Renovation Passport, as a national scheme to be implemented, could offer tax compensations to buildings which reach the milestones and tax aggravations, to those which do not.

The building renovation rate in the EU is currently "0.4 to 1.2%" [2], would need to "double to reach the EU's energy efficiency and climate objectives" [2]. So, as well as addressing EU carbon neutrality commitments, this work would also be aligned with the

[1] Intergovernmental Panel on Climate Change.

[2] Green energy is commonly referred to as energy converted/transformed from renewable and/or non-fossil sources.

[3] GHG - Greenhouse Gas.

Portuguese strategies PNEC, which aims to "promote the building stock's energy renovation and the NZEB" (adapted from [4]), 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. ELPRE also defines the execution of the national goals on energy and climate as inseparable from building renovation (adapted from [5]). And finally, RNC 2050, which aims to identify the pathways for decarbonisation and carbon neutrality by 2050 (adapted from [6]), an effort of which the built environment is part of.

On a final note, it is also this work's intention to be consistent with the Sustainable Development Goals SDG, namely, SDG 7, "access to affordable, reliable, sustainable and modern energy for all" [7], SDG 11, "inclusive, safe, resilient and sustainable" "cities and communities" [8] and, lastly, SDG 13, "urgent action to combat climate change and its impacts" [9].

2. Literature Review

2.1. Climate Change Mitigation

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, that have been happening for 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" and this "has led to atmospheric concentrations of carbon dioxide, methane and nitrous oxide that are unprecedented in at least the last 800,000 years" and their effects are considered the "dominant cause of the observed warming since the mid-20th century" [10].

It is as a solution to the problem of climate change, from among many, that energy use in buildings comes into the picture, particularly, the need to renovate the already existing building estate, where, according to IPCC, the "the largest energy savings potential is in heating and cooling demand", by means of improving building energy efficiency and renewable energy sources (RES) use [1]. Furthermore, "energy savings from shifts to high-performance lighting, appliances, and water heating equipment account for a further 24% of the total reduction" [1]. This reinforces the need to address building energy rehabilitation, 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" [1].

2.2. Near Zero Energy Building

2.2.1 Definition

A near zero energy building, as per the European Directive 2010/31/EU, is a building which "has a very high energy performance" and where "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" [11]. This definition is essentially the same as the one described in the Portuguese Decree-Law 118/2018, article 16, which adds 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 [12].

Nonetheless, there are a myriad of other possible (near) zero energy buildings definitions[4]. NZEBs can be characterised according to their grid connection [14] (autonumous ZEB, net ZEB, +ZEB), to their "energy demand and installed renewable typology" [14, 15], as well as to their considered "boundary and metric" [16] methods (net zero site energy building, net zero source energy building, net zero energy costs building, net zero energy emissions building and off-site ZEB).

2.2.2 Best Practices

The best practice to follow when planning for a NZEB is to first reduce its energy demand and only then, implement on-site renewable energy conversion technologies (RECT) to provide for the new energy demand. This strategy is supported by Torcellini *et al.*, saying that firstly, energy efficiency should be encouraged and then move on to RES "available on-site or within the footprint" (over off-site ones), claiming "it is almost always easier to save energy than to produce energy" [16], 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" [17], 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".

2.2.3 Energy Performance

Calculating the building's energy balance is a way to evaluate its energy performance and it is 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" [18].

To calculate the energy balance of the system, which is the building in case, the boundary needs to

[4] For more detail, please refer to [13].

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 [19]. On figure 1 the connections between the building and the grid, as well as imports and exports, are illustrated.

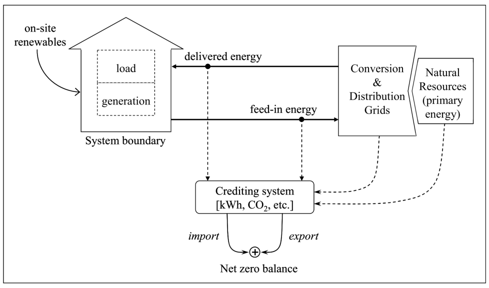

Figure 1: "Connection between buildings and energy grids", as illustrated in Sartori *et al.* [20].

Other factors also need to be defined to properly calculate the energy balance and, according to 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 [17], thus expressing the values in $\frac{kWh}{m^2.y}$. These are the same units recommended by Portuguese law [12].

Different equations can express the energy balance. Equation 1, which reads the sum of the monthly global primary energy minus the primary energy from renewable sources minus the certified purchased green primary energy (and equation 2, which reads that global primary energy is the sum of primary energy used for space heating, for obtaining hot water, for space cooling and associated with electricity use) [17] is equal to zero, can be used for net zero energy buildings and equation 3, which reads the amount of exported energy should be greater than or equal to the amount of imported energy [20], for plus or net zero energy buildings, respectively.

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

$$EP_G = EP_H + EP_W + EP_C + EP_{EL} \qquad (2)$$

$$|\text{export}| - |\text{import}| \geq 0 \qquad (3)$$

On figure 2, a visualisation of how the energy balance changes for a building that is being transformed into a NZEB, which first, has its energy demand reduced and then, has its energy demand met by on-site RECT.

[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." [19]

[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)" and year, season and month [21].

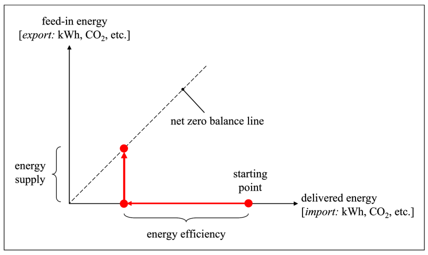

Figure 2: "Graph representing the net zero balance of a Net ZEB", as illustrated in Sartori *et al.* [20].

2.3. Defining a Pathway for Energy Conservation Measures Identification

In this section two methods for identifying the measures to implement first, from a set of several energy performance improvement measures, based on their cost-effectiveness, are presented. The first is based on the cost of conserved energy (CCE), which is described by equation 4, from Meier *et al.* [22], which reads the CCE is the investment cost of the improvement measure divided by the energy savings associated with that measure's implementation, times an annualisation term[7]. The CCE can also be understood as the cost to save a unit of energy and can be expressed in $\frac{€}{kWh}$. The first measures to be implemented should be the ones with lower CCE. However, for the same set of improvement measure, the CCE for each measure depends on the order the set of measures is implemented.

$$\text{Cost of Conserved Energy (CCE)} = \\ = \left(\frac{I}{\Delta E}\right)\frac{d}{[1-(1+d)^{-n}]} \qquad (4)$$

The second is similar, presented by Hirst [23] and organises measures per cumulative energy savings, in $\frac{kWh}{m^2}$ and per cumulative implementation cost, in $\frac{€}{m^2}$, as seen on figure 3. The measures to implement first are those that fit the initial part of the graph, with significant energy savings for almost no investment cost.

2.4. Energy Performance Certificate - EPC - in Portugal

The current national scheme in building energy performance assessment and improvement is the EPC scheme/system (in Portuguese, Sistema de Certificação Energética de Edifícios), managed by ADENE[8]. The EPC, issued by a qualified expert[9] (QE), gives information to the building owner/user about the building's energy class, energy consumption and possible improvement measures, among oth-

[7]The "capital recovery formula", as per Meier *et al.* [22].

[8]ADENE is the Portuguese Energy Agency.

[9]Adapted from the Portuguese, "perito qualificado", certified and trained by ADENE [24].

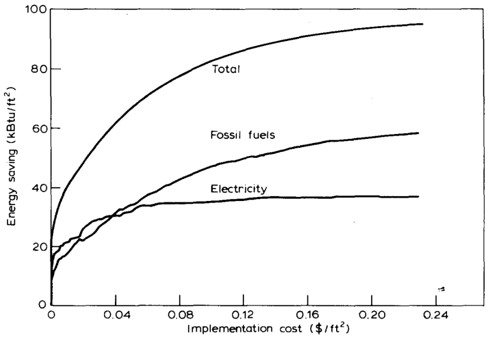

Figure 3: "Plot of the cumulative estimated energy saving per unit floor area as a function of the cumulative implementation cost per unit floor area" as illustrated by Hirst [23].

ers[10] [25]. On table 1 the building characteristics subject to energy audit can be seen. The energy class

Table 1: Building characteristics subject to energy audit.

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

and performance indicators are defined by law (Portuguese Decree-Law nº118/2013 [12] and dispatch, Despacho (extrato) n.º 15793-J/2013 [26]). 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 a residential building, the energy class is determined, through the "energy class ratio" (adapted from "rácio de classe energética", where each interval of R_{Nt} values corresponds to a certain energy class, as defined on Portuguese dispatch n.º 15793-J/2013 [26]), given by equation 5, which reads the energy class ratio corresponds to the value of the nominal yearly needs of primary energy (expressed in $\frac{kWh}{m^2 \cdot Year}$) over the regulated limit value for the nominal yearly needs of primary energy (expressed in $\frac{kWh}{m^2 \cdot Year}$) for the building.

$$R_{Nt} = \frac{N_{tc}}{N_t} \tag{5}$$

[10] For more detail, please refer to [13].

3. Methodological Framework

3.1. Purpose, Context and Structuring a Renovation Passport

As presented before, the Renovation Passport is proposed as a new framework, for a national scheme implementation, to achieve carbon neutral NZEBs and to grow from the already implemented scheme of building energy certification, the EPC. In this approach, a Renovation Passport, to reside in a digital platform, intends to be an 'identity card' of the building and, at the same time, a guide, for its user, owner and/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.

At first, the Renovation Passport will be suggested as a framework for voluntary implementation, offering building owners/users which comply with the legislation requirements, to be created for the Renovation Passport, 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.

Besides clearly ensuring QE jobs and upgrading 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 practices on building use 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.

In order to encompass all these requirements necessary to transform the building into a carbon neutral NZEB, it is necessary for the Renovation Passport to have several components, as follows:

1. Milestones (see section 3.2).
2. Physical and Technical Characteristics of the Building (see section 3.3).
3. Energy Performance Improvement & Near Zero Energy Building (see section 3.4).
4. Inspection & Audit (see section 3.5).
5. Maintenance & Construction (see section 3.6).
6. Building Owner/Users Roles (see section 3.7).

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 can be seen on figure 4.

Figure 4: Components of the Renovation Passport, with their respective input databases, and connections between them.

3.2. Milestones

In order to reach a carbon neutral NZEB, the Renovation Passport introduces the Milestones, which are the objectives of energy performance, the building has to fulfil by a certain time. These follow NZEB best practices (as discussed on section 2) of first reducing energy consumption and then deploying RECT as well as ELPRE's strategy, which is comprised of four packages, where the first addresses passive and envelope measures, to reduce the need of climatisation and energy poverty[11] risk, as well as increase comfort levels, the second promotes energy efficiency, the third relates to decarbonisation and RECT installation and finally, the fourth addresses gradual comfort level[12] improvement [5].

In line with ELPRE's strategy, the Renovation Passport proposes three key Milestones, as detailed on table 2. Milestone 1, for 2030, is based on PNEC's

Table 2: Renovation Passport Milestones.

Milestone	Date	Energy	Carbon Neutrality[13]
Milestone 1	2030	Energy performance improvement	at least -35%[14]
Milestone 2	2040	50 to 75 % of consumed primary energy provided by RECT	at least -73%[15]
Milestone 3	2050	100% of consumed primary energy provided by RECT - NZEB	Carbon neutrality (-97%[16])

recommendation to improve the building's energy efficiency (and electrification of technical systems) and to use building rehabilitation to reduce resource intensity, as well as the recommended and proposed value of 35% of $CO_{2_{eq}}$ emissions reduction, in comparison with 2005 values [31]. Milestone 2, for 2040, starts to focus on RECT deployment and the proposed value of 73% of $CO_{2_{eq}}$ emissions reduction, in comparison with 2005 values, is taken from RNC 2050 [6]. Finally, Milestone 3, for 2050, proposes that 100% from energy is supplied from RECT, therefore, making the building a NZEB and the value for carbon neutrality of at least 97 % of $CO_{2_{eq}}$ emissions reduction, in comparison with 2005 values, is taken from RNC 2050 [6].

To note that by 2050 the definition of NZEB is that of a building which consumes (approximately) 100% of its energy from RECT and not the current NZEB definition from the Portuguese ministerial ordinance, Portaria 98/2019 [32] which states NZEBs are buildings which must have RECT covering at least 50% of the annual primary energy needs [32], must have its nominal annual value of useful energy needs for heating (N_{ic}) be equal to or less than 75% of the maximum annual value of useful energy needs for heating (N_i) and its nominal annual value of primary energy needs (N_{tc}) must be equal to or less than 50% of maximum annual value of primary energy needs (N_t) [26, 33].

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) and are predicted

[11] Energy poverty happens when there is an inability to provide "adequate warmth, cooling, lighting" and "energy to power appliances" [27], 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" [27]. In 2018, 19.4% of the Portuguese population experienced an "inability" to keep their homes "adequately warm" [28] and it is estimated "that more than 50 million households in the European Union are experiencing energy poverty" [27].

[12] The comfort levels considered are the ones presented in European Norm EN 15251 [29], and renovation works should bring the comfort level up to, at least, category II.

[13] 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" [30].

[14] $CO_{2_{eq}}$ emissions reduction, in comparison with 2005 values, as proposed by PNEC [31], for the residential sector.

[15] $CO_{2_{eq}}$ emissions reduction, in comparison with 2005 values, as proposed by RNC 2050 [6], for residential buildings.

[16] $CO_{2_{eq}}$ emissions reduction, in comparison with 2005 values, as proposed by RNC 2050 [6], for residential buildings.

according to what is established in [34–37].

The Renovation Passport, as a national scheme to be implemented, intends to create new 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. Ideally, early adoption support and benefits would be key to drive the voluntary adoption of the Renovation Passport scheme.

3.3. 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 1, regarding construction, envelope, heating and cooling solutions, ventilation and others. Information in this database should be arranged in the described topics (table 1). It is the QE who is responsible 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.

3.4. Energy Performance Improvement & Near Zero Energy Building

This is the Renovation Passport component dedicated to reaching the carbon neutral NZEB. Separated in three phases, the first two deal with assessing the current energy performance, improving energy efficiency and reducing energy consumption. The third is related to RECT implementation, following NZEB best practices.

3.4.1 Inputs

The necessary inputs for this component are, first, the EPC itself, which is the basis for 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 3.3).
2. Inventory of building energy renovation standard measures.
3. Energy related spending (bills) and consumption profile inventory.
4. Renewable Energy Conversion Technologies Database.

These contain the information the QE needs to evaluate the energy performance condition of the building, what measures exist and may be applied in the building and what type of RECT may be deployed.

3.4.2 Phase 1

Having the information from the inputs, the QE can issue the EPC (after performing an initial *in loco* energy audit, see section 3.5), as it is the starting point for analysing the building energy performance, namely, by obtaining its energy class, and selecting the pool of energy improvement measures to be executed to reach the Renovation Passport objectives and Milestones. When choosing the pool of measures, the QE should rank the improvement measures and the first to be implemented should be those with higher cost-efficiency and lower payback time, calculated through equation 6.

$$\text{Payback Time [Year]} = \\ = \frac{\text{Average investment cost [€]}}{\text{Average financial savings [€/Year]}} \quad (6)$$

3.4.3 Phase 2

Based on the chosen pool of improvement measures, the QE should compute the new value of energy consumption, the new consumption profile and the values of energy and financial savings, through equations 7 (in $\frac{kWh}{Year}$) and 8 (in $\frac{€}{Year}$), respectively, obtained from applying the pool of measures. By knowing the energy savings and knowing the types of energy sources used in the building, the carbon savings may also be calculated, through equation 9 (in $\frac{gCO_{2_{eq}}}{Year}$). Milestone 1 is the main concern until here.

$$\text{Total average energy savings} = \\ = A_{\text{floor}} \cdot \sum (\text{Average energy savings})_{\text{measure}} \quad (7)$$

$$\text{Total average financial savings} = \\ = \sum (\text{Average financial savings})_{\text{measure}} \quad (8)$$

$$\sum (\text{Carbon savings})_{\text{energy source}}{}^{17} = \\ = \sum \Big((\text{Total average energy savings})_{\text{energy source}} \\ \cdot (\text{Specific emissions})^{18}{}_{\text{energy source}} \Big) \quad (9)$$

[17] Electricity and natural gas are currently the most consumed energy sources, in residential buildings, in Portugal [38].

[18] For electricity, this value was 225 $\frac{gCO_{2_{eq}}}{kWh}$ [39], in July 2020, for Portugal and for natural gas, the value is 50 $\frac{gCO_{2_{eq}}}{MJ}$ [40].

3.4.4 Phase 3

With the new consumption value and profile, as well as information about the most suitable and available RECT, the QE must then model the best and most suited RECT to implement in the building, to finally achieve a carbon neutral NZEB. The RECT unit(s) should have enough capacity to provide for the new energy demand and be suited to the energy consumption profile of the building user, in order to maximise the energy consumed directly from the on-site RECT. In the end, the equations 1 and 3 should be verified. Milestone 2 and 3 are the main concern of this phase.

3.4.5 Renovated Carbon Neutral NZEB

Finally, the renovated carbon neutral NZEB is achieved, by following the three phases described and reaching the proposed Milestones.

3.5. Inspection & Audit

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", it "is the primary phase in proposing possibilities to diminish energy expense and carbon footprints" and can be carried out at different depth levels [41]. They state an energy audit has "four main phases"[19], audit preparation, execution, reporting and post-audit activities [41].

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 [41], along with pointing out as many possibilities of energy improvement/renovation as possible.

This way, the building user/owner will have more information to work with and can then choose, with guidance and expertise from the QE, which path of renovation to follow (meaning, the pool of energy performance improvement measures to apply) depending on how much they are willing to invest. At this point the QE should guarantee the chosen pool does not cause "lock-in effects" [42], *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 and 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 owner/user's will and power of investment, outline future possible renovations , in a continuous improvement mindset.

There is also the potential to automate these post initial energy audits, by means of using smart meters, Building Information Modelling (BIM)[20] and Internet of Things (IoT)[21] integration, with the possibility of creating a "digital building twins"[22] model, in order to "facilitate monitoring of activities and comparison of relevant data against the initially agreed planning" [47]. These integration would help to automatise some of the manual tasks executed by the QE, adding accuracy and faster response.

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), and these 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.

3.6. Maintenance & Construction

3.6.1 Maintenance

There are two main types of maintenance, commonly used in machinery related industries, that can be performed, preventive and predictive maintenance. Preventive maintenance is to be "performed at predetermined intervals" [48], thus, being "time based" [48]. Furthermore, a "preventive maintenance programme provides the equipment with an environment in which it can perform its design function efficiently and reliably" [48]. As for predictive maintenance, it relies on "baseline and trend data to predict the root cause of the change in condition" [48]. Moreover, a "predictive maintenance programme utilises effective condition monitoring to predict the need, scope and scheduling of corrective action" [48].

These industry concepts can be adapted to building maintenance. At first, the best approach would be to start performing preventive maintenance based on the recommendations of the manufacturers of the

[19] For more detail, please refer to [13].

[20] 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" [43].

[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" [44]. Smart buildings [45] and smart homes [46] are some of "the most relevant IOT systems application domains" [45].

[22] "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" [47]

installed equipment (with primary concern for great energy consumers[23]) and on a schedule defined by the QE. After the initial Renovation Passport deployment phase, it would be wiser to change the approach towards predictive maintenance since, 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[24]), can be avoided.

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, which should prompt a notification to the building user/owner. After defining the maintenance needs, maintenance must 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 Renovation Passport proposes the features seen on table 3 for its maintenance component, where the guidelines are the ones presented above, the recorded history corresponds to maintenance reports and the notifications and guidebook is the feature that warns the building user/owner when maintenance is required and advises them through the necessary steps to perform it correctly.

Table 3: Maintenance Features.

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

[23]Great consumers are not defined for residential buildings, in Portuguese legislation, namely Decree-Law 118/2013 [12]. However, those devices would probably 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.* [49].

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

3.6.2 Construction

Construction is the Renovation Passport phase where actual rehabilitation takes place. These activities are the ones recommended by the QE, when they designed and selected the improvement measures to be implemented and should be done by certified construction entities which could be hired by the building owner/user. These certified entities 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.

The entities are 'certified' because they fulfil certain requirements, related to performance quality, know-how, safety and sustainability, which, since this scheme is building from the EPC one, it could be managed by ADENE as well and, therefore, could receive a 'seal of approval' from ADENE to foster consumer trust.

3.7. Building Owner/Users Roles

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

Nonetheless, these are not the sole addresses of the Renovation Passport. The QE are both creators of content for the platform (energy audit reports, guidance for maintenance and construction certified entities, as well as the step by step renovation plan) and users, as they read and check inputs other users uploaded (maintenance and construction reports and other building information). Furthermore, those certified entities (to issue reports and read guidelines) and funding[25] authorities, that could be government programmes, private companies, banks and credit agencies, may also access the platform (to read information and verify compliance).

3.8. Renovation Passport Innovations Summary

The Renovation Passport innovations have been presented throughout the sections above. In this section they are presented, on table 4, 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.

[25]A list of (Portuguese) funding programmes, directed at building renovation, the building owner/user could apply to, in order to finance the necessary investment(s) is presented on [13].

Table 4: Renovation Passport Innovations Summary.

No.	Innovation Description
1	Different NZEB definition from the EPC. The NZEB is considered as a "yearly energy neutral building" [14] 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 [32] (see section 3.2).
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 3.2).
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 3.5).
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 3.4.2 and 3.5).
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 3.6).
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 3.7 and 3.6).
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).

4. Digital Platform Organisation Proposal

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 others, in order to create the most intuitive experience for all.

The proposed setting is to have an initial page that presents the Renovation Passport concept and contains links to European and Portuguese programmes and projects relevant for better understanding building rehabilitation. On this initial page, there should also be links to access each of the Renovation Passport components pages. In order to help the platform user understand how each component interacts with each other a graphic, picture like, preferably interactive, data map should exist and be shown, as figure 5, a more detailed overview of the Renovation Passport and its components, tries to convey. The initial page could possibly also be the place where notifications and warnings for the building owner/user and the current status report, made and updated by the QE, could be displayed.

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 importantly, the EPC results (namely, building energy class) 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.

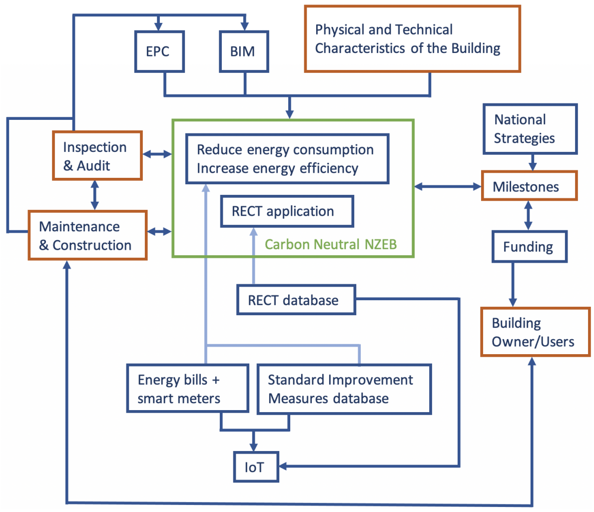

Figure 5: Renovation Passport information flow, where the Renovation Passport components are shown in orange and green.

5. 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 starting from the existing EPC system scheme, taking advantage from its networks and infrastructure, and proposing new features and components, as presented before. The main innovations the Renovation Passport offers are the ones presented on table 4. 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.

Perhaps the most immediate advance to this work would be to address water efficiency and the water-energy nexus[26] which would directly affect the en-

[26] 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

ergy performance of the building. In a urban context, concepts such as Positive Energy Districts[27], smart cities[28], nature based solutions[29] and urban farming[30] may also be incorporated in future and broader versions of the Renovation Passport. Lastly, some concepts of circular economy may also be applied in the context of the Renovation Passport, such as urban mining[31], 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 [56]) and building modularity.

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to "deliver energy for consumption" [50]. Inside the boundaries of a residential building, the most significant water-energy interaction would be in the preparation of domestic hot water.

[27] 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" [51].

[28] 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" [52].

[29] Nature based solutions include "green roofs, green walls, rain gardens, street trees and other urban green infrastructure" [53].

[30] 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" [54].

[31] 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" [55].