

PAPER • OPEN ACCESS

A systematic review of retrofitting tools for residential buildings

To cite this article: A Gonzalez-Caceres *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **294** 012035

View the [article online](#) for updates and enhancements.



IOP | ebooks™

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the collection - download the first chapter of every title for free.

A systematic review of retrofitting tools for residential buildings

A Gonzalez-Caceres^{1,2,4}, M Rabani¹ and P A Wegertseder Martínez³

¹ Department of Civil Engineering and Energy Technology, Oslo Metropolitan University, Norway

² Department of Civil Engineering, Technical University of Denmark, Denmark

³ Departamento de Diseño y Teoría de la Arquitectura, Universidad del Bío-Bío, Chile

⁴ Corresponding author's e-mail address: alexgc@oslomet.no

Abstract. Retrofitting of existing buildings offers significant opportunities to reduce global energy use and greenhouse gas emissions. Therefore, it is considered as one of the main approaches to achieve sustainability in the built environment at a relatively low cost. Although there is a wide range of retrofitting technologies available, methods to identify the most cost-effective measures for each project remain a major technical challenge. Numerous projects have been developed worldwide to face this challenge with different approaches; however, many of the tools meet only local objectives, which is why they are unknown in the international arena, showing a limited transfer of knowledge. This review organizes the results under three categories: renovation assessment, financial assessment, and transfer of knowledge. The tools focusing on promoting the renovation of buildings differ in the type of user, for example, the owners, politicians, or investors. The tools dealing with financial assessment suggest different methods to evaluate and calculate the cost savings, construction costs, and return forecasts through retrofit interventions. Other tools comply with the policies that seek to register, evaluate, and characterize the existing buildings. This review provides researchers, construction professionals, and politicians with a better understanding of the advances made to effectively design building retrofitting measures and promote energy conservation as well as the assessment of the building stock for the development of policies. The review shows that many tools have the potential of joining their capabilities, which can create many opportunities for innovation in the retrofitting area.

1. Introduction

It is well known that the building sector has a great share of responsibility on global energy use, which is expected to grow in the next decades [1]. It has been even reported that the energy use of buildings is exceeding the other major sectors like industry and transportation [2]. Therefore, building renovation is the key point to reduce the global energy use and CO₂ emissions [3], and to improve the indoor environment quality as well [4]. Due to this, the retrofit of existing buildings represents one of the major challenges for the transition to a low carbon society [5]. In this context, governments around the world have taken strong measures towards the retrofit of existing buildings in terms of improving the energy performance [6], in different ways. This might be explained as the retrofitting involves substantial funding and a complex decision-making process, requiring a wide range of stakeholders such as landlords, tenants, property managers, developers and local council to involve in this process [7]. Moreover, there are many barriers that may prevent renovation [8]. For instance, energy efficiency strategies are mostly not applied due to the uncertainty about the amount of investment required and the efficiency of the potential energy saving strategies [4]. The clearest attempt to address this issue has



been performed by the European Union where a certification system has been put in place for existing buildings. The certification was designed to provide building owners and tenants with information about the energy performance of their buildings, heating and air-conditioning systems, as well as about the effective ways to improve these through building renovation works [9]. The certificate might also provide the expected saving and the cost involved if the measures are implemented. However, the results from that evaluation shows that the tool needs several improvements in order to be used effectively as a trigger for renovation purposes [9, 10].

According to the result from IBROAD survey, applied in three European countries [11], homeowners' motivations to invest in energy renovation are centered around comfort and energy use/cost. The most common aspiration for homeowners is to upgrade their home to a more comfortable level. This report also adds that the most required information from homeowners is the estimated costs of each renovation step, expected benefits in terms of reduced heating/bills and technical information to help them to avoid mistakes. When it comes to performing the renovation project, most of the homeowners will hire a contractor to do the job. However, a significant share of the interviewees claims that some tasks of the renovation are performed by themselves without proper knowledge. Building Performance Institute of Europe (BPIE) survey [6] identified that there are many barriers related to knowledge and technical expertise within energy consultants, certifiers, and architects, highlighting that they also have different levels of knowledge and participate differently in a renovation process. Energy consultants are closer to auditing, although they are oftentimes too expensive to be hired for retrofitting of a single residential house. In general, most consultants use tools that are more sophisticated than the ones that a regular architect would use. It is relevant to note that architects are not usually interested in the energy performance of buildings and they do not have the competence to develop successful measures to improve the energy performance of buildings. Therefore, special requirements on information and communication are needed [12]. In general, architects tend to look for a general understanding of the problem to explore acceptable solutions and are prone to propose the design solutions on the basis of experiential knowledge [13], similar is the case among actors during the construction process. For a reliable data basis and the comparability of the collected data, consultants have to be aware of what the sensible points are, through home inspection [12].

The scale of information needed by policy makers and investors is much greater, since they must evaluate it at national, communal, or district level. In general, the studies on this area deal with identifying building typologies considering age, state of conservation, and energy use. This allows to find areas with a high energy saving potential or with high vulnerabilities. Some of the policies include evaluating properties through the Energy Performance Certificate (EPC), other ones provide financial incentives for building owners as well as support for low income neighborhoods. Other examples of policies include comparative billing to increase the 'observability' of household energy use, hiring energy service companies to manage the 'complexity' and cognitive burden of renovation decisions, and open house schemes to support social communication on energy efficiency.

To summarize, although the building construction sector and stakeholders acknowledge the need for integrated solutions for maintenance and renovation, there is still lack of specialized knowledge on how and when to successfully maintain, manage, adapt, transform, and redesign [14]. Moreover, most crucial decisions happen in the first stages of the design process; thus, designers need tools that will assist them in creating better and more sustainable refurbishment projects [15].

2. Review of tools for building retrofitting

There have been limited attempts to systematically review the available analytical tools for improving energy efficiency in the buildings sector, where the most of the existing reviews of tools and methods have a broader scope than energy efficiency in buildings [16]. It is worth noting a report from Lawrence Berkeley National Laboratory (LBNL) [17] in 2014, reviewed sixteen existing tools available for retrofitting purposes, targeting small and medium size office and retail buildings for California-specific conditions. It concluded that an easy-to-use and readily accessible retrofit assessment tool is needed to help small and medium building owners to make wise decisions by providing information about energy savings and economic benefits from the investment in energy efficiency retrofits.

The goal of present work is to review the currently available retrofit tools, targeting residential buildings, for homeowners, energy consultants, and policymakers. Researchers have investigated retrofit tools both in the public domain and in the private sector to better understand the diverse approaches that are currently in use to evaluate retrofit options, specifically, calculation methods, retrofit measures, financial assessment, and policy development.

In order to map the existing range of tools and to facilitate building energy efficiency improvements, this paper presents an overview and categorization of the current tools. In addition, a decision tree is offered, illustrating the types of policy tools and project development in the field of energy efficiency in buildings.

3. Methodology

To prepare the review, two main tasks were fulfilled: tool selection and categorization. For the selection, fifty tools were studied and eighteen tools were chosen and described. It has been either identified as relevant due to their contribution to help in the renovation tasks as well as in designing a different model of evaluation, providing detailed support to key users, and delivering information in an interactive and influential way. The categorizations were organized into three groups: renovation assessment, financial assessment, and transfer of knowledge. Each tool was resume, delivering an introduction of the tool, its features, and the novelty.

Renovation assessment: In this category, tools were selected due to their capacity to assist in the evaluation of measures for renovation, by delivering technical recommendations, energy reduction, design guidelines, comparison of scenarios, etc.

Financial assessment: Tools in this category were dedicated to assist in the economical phase of the renovations process. Not only the tools that calculate the savings or find the cost optimal measures, but also those that provide costs and tailor approach to evaluate implementation costs or help investors to find investment opportunities were included in this group.

Transfer of knowledge: Renovation is not only about defining profitability or accurate renovation measures. It can also include the transfer of knowledge, either to promote the benefit of renovation or to help stakeholder to produce better guidelines, policies or evaluation program.

4. Results

Renovation assessment requires multiple tasks. Therefore, to find a tool that can accomplish all tasks may not be the most appropriate solution. Due to this, in the study several tools are presented that can contribute during the renovation assessment. The selection explores different approaches to support the renovation decisions instead of finding the most complete tool. The targeted audience including energy consultant, certifier or architect are relevant for the classification, as well as energy performance and life cycle cost assessment. This section presents detailed information about the scope, features, and targeted user of each tool, summarizing how the tool can serve during a renovation process. In total, the study examines eighteen selected tools under three categories including renovation assessment, financial assessment, and transfer of knowledge.

4.1. Renovation assessment

INSPIRE: It is a software developed within the framework of the international Eracobuild project INSPIRE. The INSPIRE Tool focuses on residential buildings and simple office buildings without cooling needs [18]. It was designed following the principles of ISO 13790 and considering energy performance of building envelope, outdoor climate, target indoor temperature, and internal heat gains.

- **Features:** The tool allows to investigate trade-offs and synergies between different retrofitting measures and to identify strategies aiming at reducing primary energy (PE) use and greenhouse gas (GHG) emissions while being cost-effective. The tool includes a database of empirical techno-economic characteristics in different categories.
- **Novelty:** The novelty of the tool is to assess relations between GHG emissions and PE use vs. the life cycle costs. Typically, this kind of tools includes only the calculation of GHG emissions and PE use. The tool includes a wide variety of options to be evaluated in terms of GHG emissions and PE use reduction. The strength of the tool is a possibility to compare different

renovation packages with reference cases and to build up a renovation strategy with different steps. This enables users with little detail knowledge to use the tool and to generate (preliminary) results in the first stage of development.

A56opt-tool: The tool aims to support decision making in terms of building renovation allowing to compare and evaluate different packages of renovation measures through the process explained in figure 1.

- **Features:** It is a tool for cost effective analysis of the energy-related renovation of the existing residential buildings and low-tech. office buildings (without HVAC systems). The Excel sheet uses simulation data that comes from other tools related to each renovation scenario under analysis, such as: area of intervention, energy performance (energy needs or use), costs (investment, maintenance, and energy) and environmental impact (global warming potential (GWP) and/or embodied energy) [18]. The main results of different renovation packages are presented in graphs of emissions and primary energy use in relation to the life cycle costs for each renovation package [19].
- **Novelty:** A56opt-tool allows performing optimization analysis, providing renovation packages, and comparing and evaluating them. It also helps to identify the cost optimal and the cost-effective solution using secondary information and simulation data coming from other tools related to each renovation scenario under analysis.

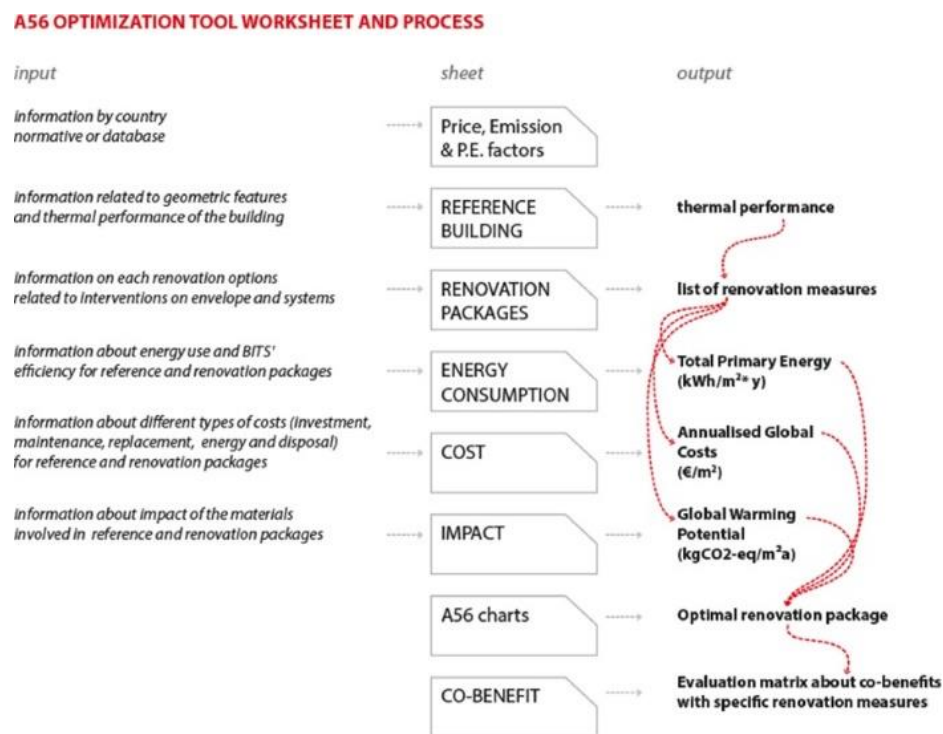


Figure 1. A56opt-tool worksheet and procedure [19]

EHeD: A user-friendly software, named EHeD, has been developed to predict the airtightness of Chilean homes.

- **Features:** The software is aimed at non-expert users in the sustainability area, to evaluate the expected behavior of the home, with different scenarios and options which allow orientating the design stage. The software allows to predict the performance of homes under the building regulation, targeting designers, builders or owners to make decisions when making changes to improve airtightness. The calculation model is obtained by analysing the airtightness of homes in Chile, supported by laboratory and onsite measurements of the home's components [20]. Figure 2 indicates the input and result interfaces of the EHeD tool.

- **Novelty:** The software can be used to retrofit existing dwelling based on the expected improvement on airtightness, which reduces the energy need for heating.

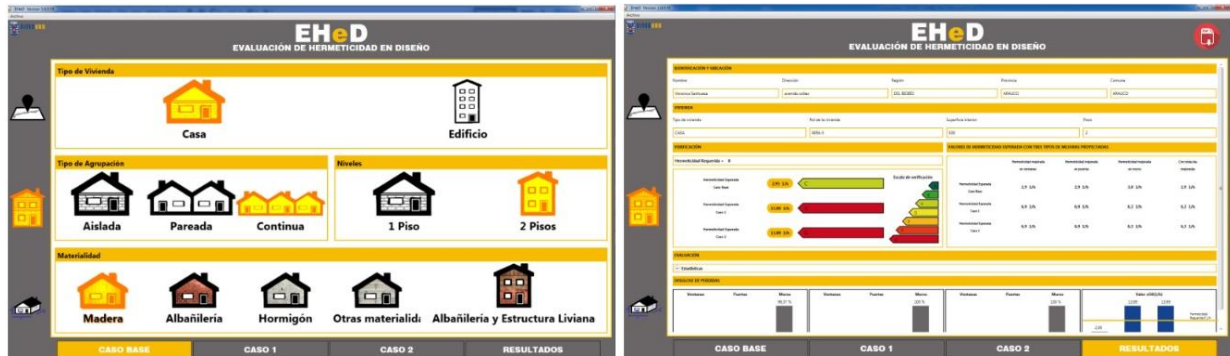


Figure 2. Screenshots of EHeD input (left) and result (right) interfaces that can be used for quick description and comparison of multiple retrofit scenarios [20]

RenoFase tool: A free decision making tool for architects and building professionals to assist them in designing an energy efficient building retrofit solution and identifying the potential hygrothermal problems.

- **Features:** The tool is functional in relatively small refurbishment projects. It has two modules; the main module that collects all the general information and dimensions of the building and the specific information for each building component. The second module is used for analysing the presence of potential damage in facade. Each performance indicator is illustrated by a short descriptive text on how to realize the type of damage as well as the photos of common examples are shown (see figure 3) [21].
- **Novelty:** The tool incorporates all required knowledge for identifying hygrothermal problems before the renovation and the architect or building engineer does not necessarily need to have all specific competence in this regard. Additionally, the tool is accompanied with detailed photographs of common building performance problems that facilitates the identification of potential moisture problems.

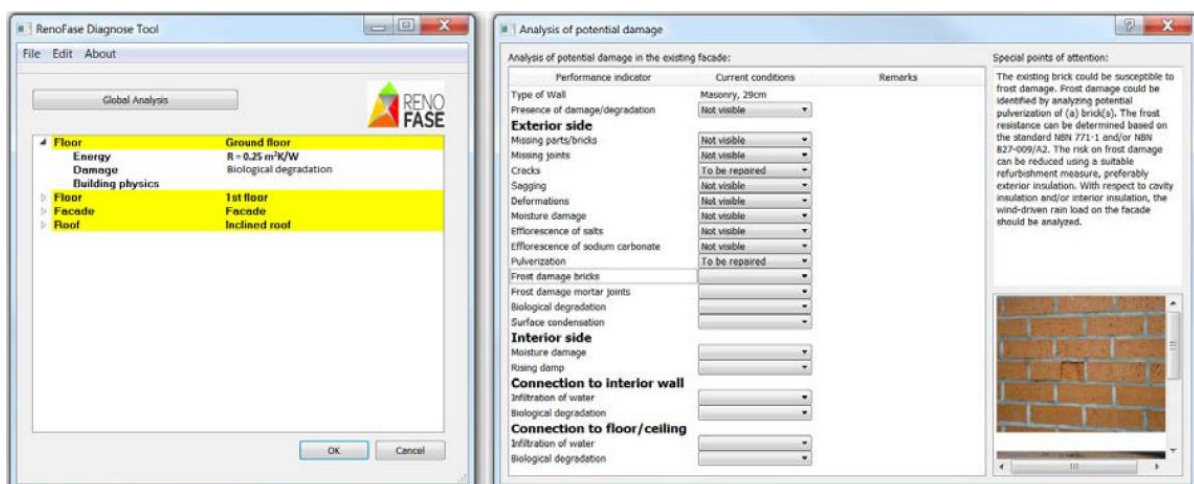


Figure 3. Screenshots of the main module (left) and module for the analysis of potential damage (right) in RenoFase tool [21]

EZ Retrofit: A user-friendly (do-it-yourself) tool designed for whole-building evaluating the opportunities for energy and water efficiency savings, using owner priorities. It is especially well suited for small to medium size properties.

- **Features:** The tool identifies specific retrofits that can generate savings by considering up to 10 different systems and utility including measures like HVAC, domestic hot water, lighting, and duct sealing. The tool provides users two complementary pathways to determine the potential building upgrades. Figure 4 illustrates the measures category description for EZ and AP levels as well as an example of the comparison of the most common measure types between the EZ Retrofit (using EZ) and third party audits with features common in level II audits [22].
- **Novelty:** The tool results prepare the user to more easily engage with qualified contractors to implement user choice of the suggested upgrades. Furthermore, the user can enter the contractor’s costs and the specifications, and re-evaluate the cost effectiveness of the proposed upgrades.

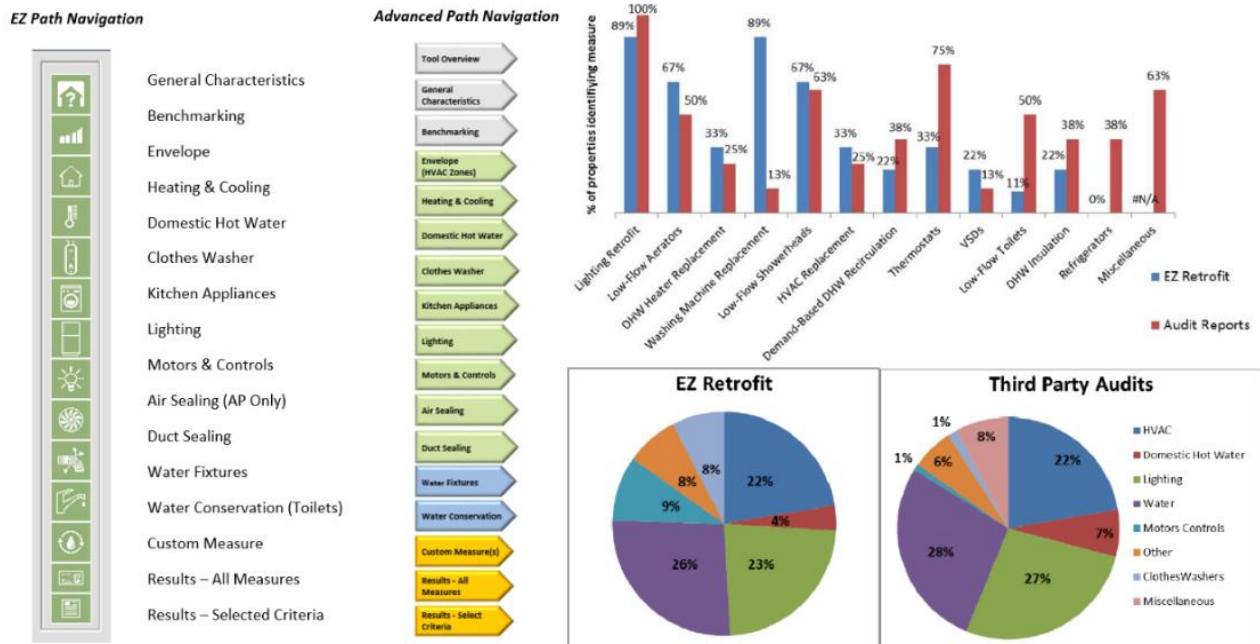


Figure 4. Measure category descriptions of EZ and AP in EZ Retrofit (left), an example of frequency of common identified measure types (right-up), and the cumulative projected cost savings by measure category for the eight properties (right-down) [22].

Table 1 summarizes the features of five above mentioned retrofitting tools related to renovation assessment group.

Table 1. Directory of studied tools for renovation assessment

	Type of building	Target audience	Goal	Method	Integrated variables
INSPIRE	Residential and simple office without cooling needs [18]	Energy manager, architects and engineers, users with little detail knowledge	To identify cost optimal and cost effective strategies aiming at reducing primary energy (PE) use and greenhouse gas (GHG) emissions	It compares different renovation packages with reference cases and to build up a renovation strategy with different steps	<ul style="list-style-type: none"> - Energy performance of envelope - Outdoor climate - Target indoor temperature - Internal heat gains - Database of empirical techno-economic characteristics
A56opt-tool	Residential and low-tech office (without HVAC systems)	Energy manager, architects and engineers	To support decision making in terms of building renovation by evaluating different packages of renovation measures	To compare and evaluate different packages of renovation measures through the process.	Simulation data from other tools related to each renovation scenario (area of intervention, energy performance, costs and environmental impact ((GWP) and/or embodied energy) [18].
EHeD	Residential	Energy manager, architects, engineers and owners	To evaluate different packages of renovation measures predicting energy performance of homes	Analysing the airtightness and onsite measurements of the home's components [20].	<ul style="list-style-type: none"> - National building regulation - Airtightness of homes in Chile supported by laboratory
EZ Retrofit	Small to medium size housing	Energy manager, architects, engineers and multifamily property owner	To establish best retrofitting strategies by examining opportunities for energy and water efficiency savings in building	A four-step workflow including benchmarking, building/system information, analyse results and refine results to prioritize strategies [22]. The analysis is based on characteristic of most commonly multifamily housing (EZ) or on buildings with complex HVAC systems (AP).	<ul style="list-style-type: none"> - Database of 10 different HVAC systems with cost and equipment efficiency information
RenoFase tool	Small refurbishment projects	Architects and building professionals	To assist in designing an energy efficient building retrofit solution by identifying potential hygrothermal and moisture problems at facade	With the general and specific information of the building, it analyses the presence of potential damage in facade [21].	<ul style="list-style-type: none"> - Common examples of damaged in façade - Dimensions of the building - Specific information for each building component

4.2. Financial assessment

The Total Concept: It is a method for improving energy performance in existing non-residential buildings with the aim of assuring maximum energy savings in a profitable way by applying a comprehensive approach, accurate investment and return forecasts, and close follow-up. [23]

- **Features:** The tool provides a method based on an action plan comprising a package of measures that fulfils the property owner's profitability requirements. To present the cost-efficiency in a simple-to-understand way, internal rate of return model is used. When forming the action package, both the single cost-efficient measures ("low hanging fruits") and the costlier measures are considered. From an economic point of view, the single cost-efficient measures are related to the costlier measures. This way of working has shown that total energy savings up to 50% are possible. The profitability calculations are done with the Total Concept tool, the TotalTool, where the outcomes are illustrated in a simple-to-understand way by using an internal rate of return diagram (see figure 5).
- **Novelty:** The method is based on the same economic conditions, calculating the global cost of a package of measures as the cost-optimal methodology, but the results of the calculations are presented in a different way. It aims at presenting how to implement further measures while still meeting the profitability expectations set by the building owner.

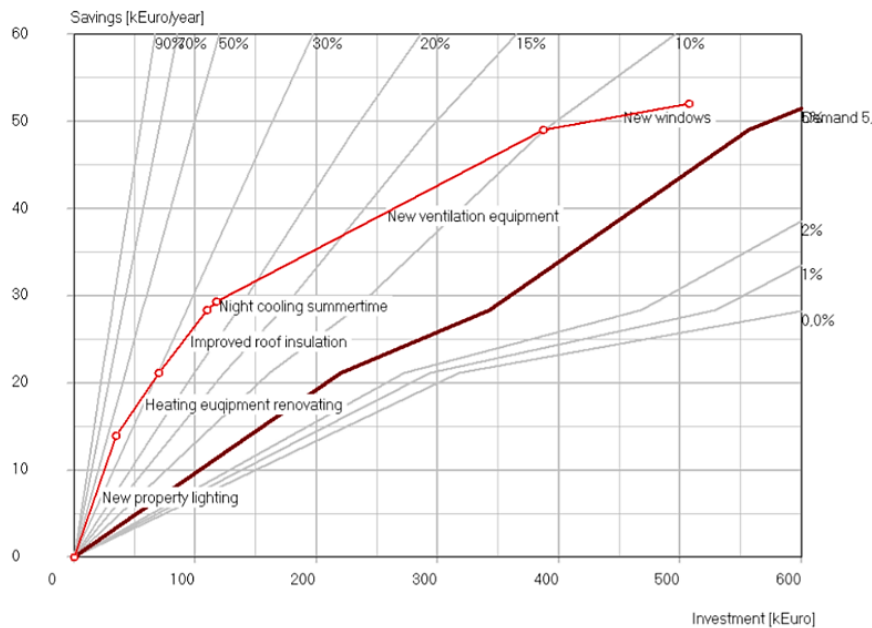


Figure 5. Screen capture of the internal rate of return diagram in TotalTool [23]

ECC: European Construction Costs (ECC) is an online platform dedicated to make construction cost data in Europe more accessible to project developers, investors, quantity surveyors, architects and other important stakeholders in the construction industry.

- **Features:** The database provides detailed data of a wide range of European construction costs. It works as an online cost calculator, developed to improve the quality, reliability and effectiveness of construction cost management.
- **Novelty:** EEC is an online European cost database that opens many opportunities not only for construction companies and building projects, but also for economical assessment. Through an official cost data base, economical assessment for renovation can be designed using standardized methods, and policies can benefit from transparent sources of costs. This feature has not been exploited by EEC, but could be used for these purposes.

ENERPAT: Energy Planning Assessment Tool has been developed by the research group ARC Engineering and Architecture La Salle, within the framework of the ENERSI project funded by the

"State Research, Development and Innovation Program Oriented to the Challenges of Society " (RTC-2014-2676-3), carried out in the period 2014-2017.

- **Features:** It is an application that enables professionals in the building sector (architects, urban planners, builders, technicians and municipal managers) to assess the state of the residential building stock and define rehabilitation strategies to improve the energy efficiency of the buildings. The application integrates the data obtained from the EPCs provided by the Catalan Institute of Energy (ICAEN), the cadastre and the census sections, together with geographic information. The rehabilitation measures are based on the ICAEN simulation tool and the "Long-term strategy for energy rehabilitation in the building sector in Spain" (ERESEE 2014). Figure 6 indicates the tool interfaces for retrofitting assessment [24].
- **Novelty:** The online tool allows to visualize EPC label of buildings in selected cities, estimate the improvement that can be obtained if renovation takes place in a certain percentage of building by each category, and count the measures for each group. This includes cost, energy savings, and return of the investment.

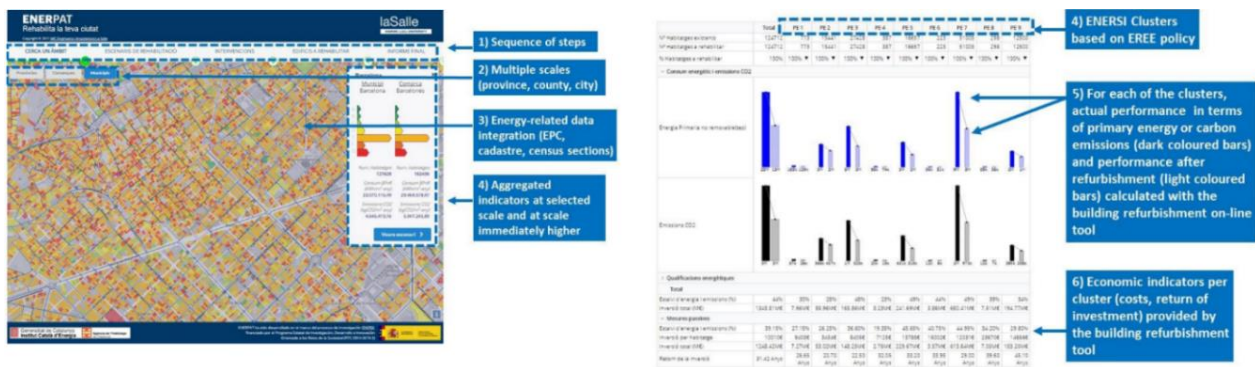


Figure 6. Two steps in ENERPAT: Step 1 (left) includes finding an area of interest, a map showing the integrated building data, and a table showing the number of EPCs, non-renewable primary energy use, and carbon dioxide emission. Step 2 (right) includes assessing the impact and costs of the refurbishment scenarios for the buildings [24].

EPIQR Software: A European methodology and software developed for building audits of apartments and techno economic assessment of refurbishment actions in order to improve the energy performance and indoor environmental quality.

- **Features:** During the building audit, the user specifies the elements/types for a given building and determines their stage of deterioration by selecting a deterioration code "a, b, c, or d" (figure 7) that well fits the observed state of each element/type. Before making the selection, the user can review the corresponding text with a detailed description and several photos that illustrate the four possible deterioration stages. A total of about 500 photos and sketches support the user to select the appropriate deterioration code. The software contains a description of usual deterioration and corresponding refurbishment work including costs for each building element, potential upgrading work as well as related national standards and guidelines [25].
- **Novelty:** The software includes a decision process of whether and how maintenance and refurbishment should be done. EPIQR uses a systematic diagnosis formalism to determine the current state of deterioration of each element and its impact on energy use and indoor environment quality. It also calculates the global refurbishment cost and the energy requirement of the new situation. A cost analysis is possible using the EPIQR cost database with more than 900 detailed refurbishments.

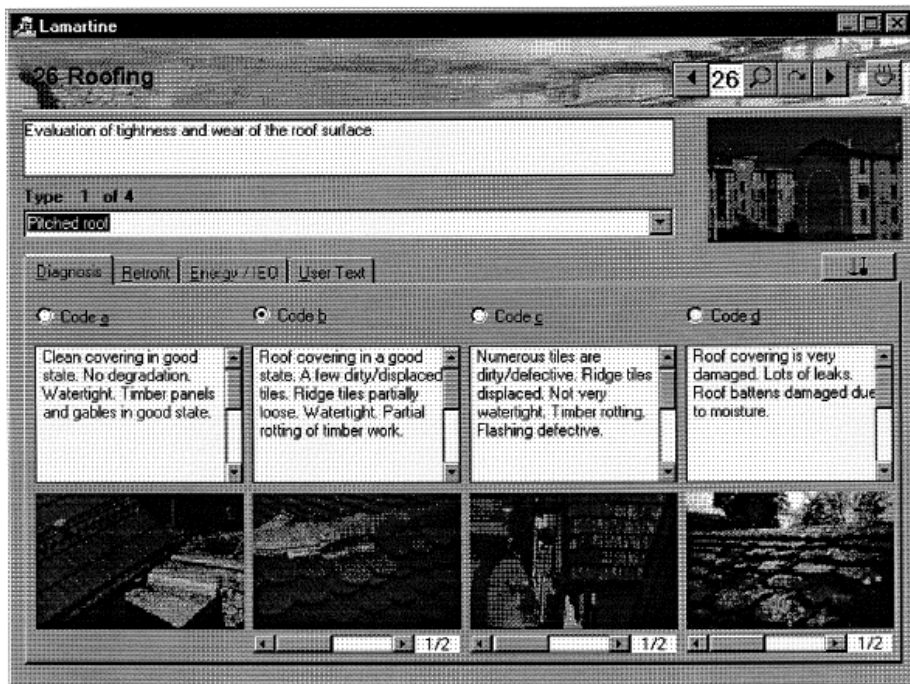


Figure 7. Screen capture of the deterioration codes in EPIQR software [25]

Table 2 explains the features of four retrofitting tools focusing on the financial objective.

Table 2. Directory of studied tools for financial assessment

	Type of building	Target audience	Goal	Method	Integrated variables
The Total Concept	non-residential buildings	Energy manager, architects and engineers	To assist the calculation of profitable renovation measures assuring maximum energy savings [23].	It is based on the same economic conditions, calculating the global cost of a package of measures as the cost-optimal methodology, using an internal rate of return model.	<ul style="list-style-type: none"> - Costs of measures - Total Concept tool - TotalTool - Package of measures
ECC (European Construction Costs)	non-residential buildings	Auditor, project developers, investors and architects	To improve the quality, reliability and effectiveness of construction cost management in Europe.	An online cost calculator provide detailed data of a wide range of European construction costs	Database of European construction costs
ENERPAT	Residential	Auditor, architects, urban planners and engineers	To assess the state of the residential building stock and define strategies to improve the energy efficiency of the buildings	It shows georeferenced EPC label of buildings to compare housing energy efficiency with similar properties, indicating the rehabilitation measures (based on ICAEN simulation tool), the needed investment and subsidies to carry out the reform.	<ul style="list-style-type: none"> - Data obtained from the EPCs (of Catalan Institute of Energy) - Cadastre and census - Geographic information
EPIQR Software	Residential, Offices and Educational	Auditor, architects and engineers	To assist techno-economically refurbishment actions in order to improve the energy performance and IAQ during building audits	By determining the stage of deterioration from varied options of levels, the tool shows corresponding refurbishment work including costs and related national standards [25].	<ul style="list-style-type: none"> - Database of possible deterioration stages with corresponding improvements. - EPIQR cost database - national standards and guidelines

4.3. Transfer of knowledge

EnergySavingCheck 3.0: It is an integrated energy advising tool for homeowners and tenants. It is user-friendly and provides valuable information on the household's energy and water use. It was first introduced by Caritasverband Frankfurt e.V, Germany for the EU-funded project ACHIEVE and it is based on the calculation tool of the Cariteam Energiesparservice.

- **Features:** The software is based on an Excel sheet. It requires significant information as inputs, such as data on energy and water use and costs (from bills), electricity using devices (lightning, cooking, washing, entertainment, cooling, heating etc.), state of the building (heating system, insulation, windows, the position of flat, etc.). After the estimation of current energy and water use, the end user can calculate the energy and water savings and take appropriate steps for reducing energy and water use. Furthermore, the relevant carbon dioxide footprint can be calculated.
- **Novelty:** It can be used in the residential sector, but it mostly targets and advises energy poor households who cannot afford their energy/electricity bill and/or keep their flat/house adequately comfortable at reasonable cost.

eeMeasure: It is a web based software developed for the European commission, which enables social housing organizations and municipalities to quickly evaluate their energy policies.

- **Features:** It allows for a harmonized way of recording and calculating energy savings of projects funded by the Information and Communications Technology Policy Support Program (ICT PSP), through a consistent methodology. The software tool is designed to facilitate the evaluation of all kinds of energy saving effects produced by a variety of ICT-based solutions, including behavioral changes and improved public awareness. The aim of ICT PSP projects is to demonstrate the energy efficiency benefits ICT that can be brought to building owners and their inhabitants.
- **Novelty:** It helps policy makers to produce a better quantitative analysis on the energy saving potentials of ICT based solutions in residential and non-residential buildings.

The HERON-DST: An innovative, friendly to the end user, software developed by KEPA in the frame of the HERON project (H2020, Grant Agreement. No. 649690). It aids policy makers and market stakeholders in their energy efficiency policy making for buildings and transport.

- **Feature:** The HERON-DST stands for Decision Support Tool, it provides a user-friendly software that facilitates the selection of the optimum combination of technologies and practices minimizing the negative impact of end-users behavior in the implementation of energy efficiency scenarios to be used by policy makers [26].
- **Novelty:** The HERON-DST allows to calculate the impact factors of behavioral barriers on the inputs drivers or alternatively on final users, as shown in Figure 8.

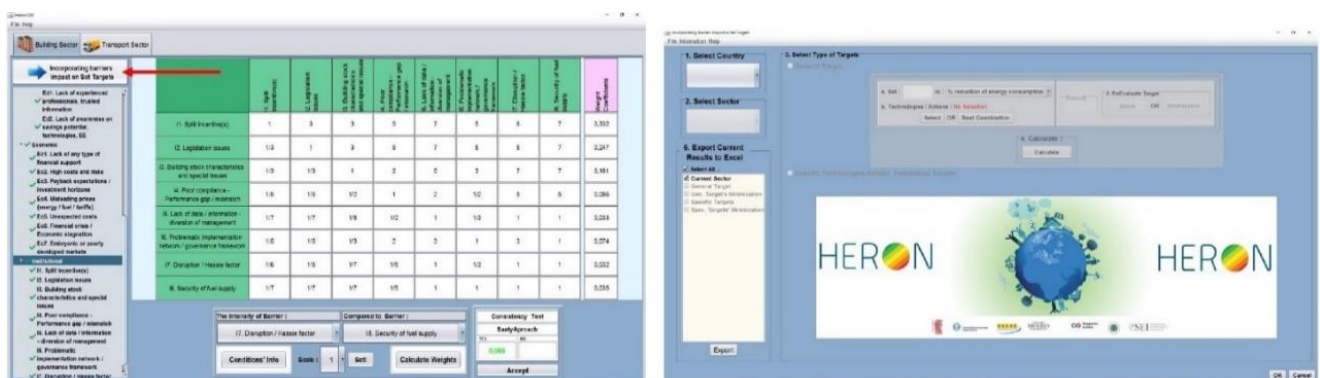


Figure 8. Screenshots of the calculation of the weight coefficient for different barriers (left) and incorporation of the barriers impact in the assumed targets (right) [26]

TABULA: It was developed based on the common DATAMINE data structure and the experiences of typological classification. The objective of the project was to create a harmonized model for European

building typologies, in particular, residential buildings. The set of typologies represents different construction periods and building sizes. The results of the building typologies are compiled and presented in the TABULA web tool (Figure 9) [27].

- **Feature:** On that basis, each participating country developed a national “building typology”, that is a set of modelled reference buildings (named “building types” in the project), each of them with its specific energy related properties. The building types were used by each country to display energy uses and to assess potential energy savings achievable through retrofitting actions dealing with the building envelope, space heating, and domestic hot water systems. In the project, two levels of retrofit actions were defined: “standard” through the implementation of measures commonly applied within the country and “advanced” through measures that reflect the use of the best available technologies [28].
- **Novelty:** The online tool provides data to analyse the existing building stock by typology, construction year, materiality etc. The project has been used for policy making and research projects related to existing building renovation.

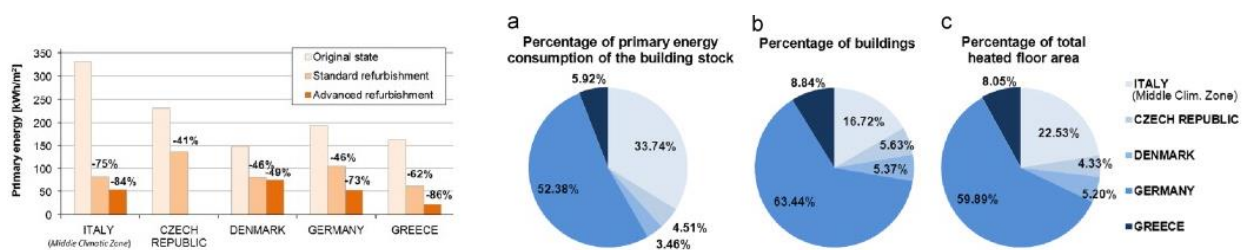


Figure 9. Outcomes of TABULA: Annual energy saving potentialities of the analysed residential buildings stock (left), Comparison figures of some analysed countries (right) [27]

ENERFUND: It is a European project aiming to develop and promote a tool for stakeholders to make intelligent decisions on energy renovation strategies. The tool targets local authorities, financial institutions, and ESCOs, as an evaluation tool before examining more in-depth the feasibility or usefulness of deep energy renovation of commercial and other buildings.

- **Feature:** The website tool rates and scores deep renovation opportunities – like a credit score used by banks to rate clients. The tool is based on a set of parameters such as EPCs, number of certified installers, governmental schemes running, etc. By providing a rating for deep renovation opportunities, energy services or product companies can identify customer segments based on their needs. Furthermore, environmental department heads can assess and compare buildings when prioritizing deep renovation and deciding on fund allocation and financial institutions that can provide targeted loans for building retrofits.
- **Novelty:** An interactive map of Europe where the user can visualize the energy ratings of buildings and narrow them down by applying filters, where the data can be easily analysed. The interface consists of multiple layers, which use a range of different mapping technologies, through the large amount of data and visual capabilities. The app can also be used by several stakeholders. Figure 10 shows a screenshot of the tool workspace environment.

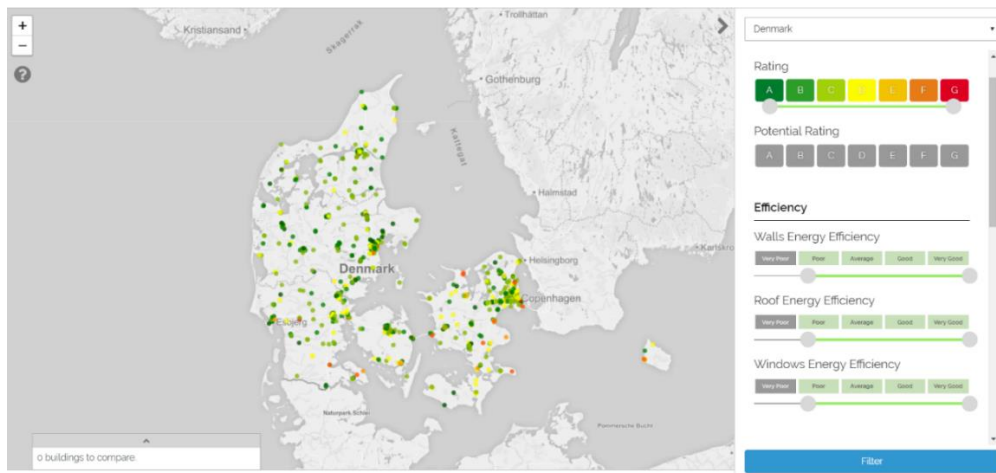


Figure 10. Screenshot of the ENERFUND workspace environment [29]

Em Build Navigator: It is a project financed under the Horizon2020 Programme which developed a comprehensive online guidance tool providing practitioners in Europe with practical instructions on how to design and implement a renovation strategy for buildings. The EmBuild Navigator is structured around three main pillars: Plan, Invest, Benefits, which all are aimed to provide local municipalities with the right toolbox to construct a successful strategy for the renovation of public buildings.

- **Features:** The value of its strategy consists not only in the renovation strategy itself but also in the process behind its development. EmBuild partners provides a set of best-practice examples and recommendations on how to plan and direct interventions on public buildings and private housing and attract investment. The Navigator also provides local authorities with a reference to address the benefits of renovation measures to target groups, as well as to strengthen motivational aspects in building renovation programs and illustrate that renovation is not only a matter of energy savings.
- **Novelty:** With the use of EmBuild material, municipalities can use a comprehensive approach to plan, invest, and implement wider benefits in their decision making process and in the necessary reporting and evaluation schemes for deep renovation measures. The tool will raise the knowledge and awareness amongst local stakeholders on the wider benefits of renovation, such as comfort, air quality, and local jobs.

EDGE: It is an online building design software, a certification system, and a global green standard for more than 140 countries. The platform is intended for anyone who is interested in the design of a green building, whether an architect, engineer, developer or building owner [30].

- **Features:** EDGE is intended to meet the demand for a quick, easy, and affordable online application that can be used to plan and assess the design of resource efficiency to scale up green building growth. The complexity of the underlying methodology lies beneath the application's interface so that industry professionals can easily determine resource efficiency and the associated cost savings without the necessity of hiring energy specialists or purchasing additional modelling software. EDGE incorporates available embodied energy data of construction materials from around the world. The major point of reference for the data, which is also referred to as materials life cycle analysis, is the Inventory of Carbon and Energy (ICE) developed by the University of Bath.
- **Novelty:** EDGE utilizes thermal calculations to determine the building's overall energy demand, including requirements for heating, ventilation and air-conditioning, as well as domestic hot water, lighting demands and plug loads. EDGE also estimates water use and the embodied energy of materials used in constructing the building, to create a comprehensive analysis of projected resource usage. Figure 11 shows the screenshots of inputs and outputs for energy use, water use, and embodied energies in the tool.



Figure 11. Three screenshots of inputs and outputs for energy use (left), water use (middle), and embodied energy (right) in the EDGE tool [30]

Easykenak: This tool has been developed by a group of Greek energy auditors according to Greek standards and regulations for energy efficiency of buildings. The application is targeted on the energy efficiency professionals who are certified by the Greek Ministry of Environment as energy auditors.

- **Feature:** Easykenak is a web-based application which minimizes the time required for the EPC. The online tool sets four simple steps to produce an EPC, which saves time and tailors the needs of the certifiers work. The tool includes a feature to quickly draw the building. In addition, it includes an algorithm that helps the auditor to calculate the surface areas of the envelope (opaque and transparent) as well as the U-values. Once all the data has been submitted, it is processed and it is then possible to calculate the energy efficiency of the building.
- **Novelty:** It is a private initiative to improve and facilitate the process for certifiers to calculate and obtain an EPC under the Greek regulation.

EnergimerkeKalkulator: It is a Norwegian website tool used to generate EPC based on a self-assessment method. The tool enables the building owners to produce their own certificate without spending money on a certifier.

- **Features:** There are two options for the evaluation of existing buildings, where the first allows the homeowner (non-expert) to generate their own certificate. This option requires little technical information about the building, such as age of the construction, floor area, and energy sources. In addition, many aspects are standardized, such as the building shape, windows and doors area, floor to ceiling height, etc. The second option requires information that is more detailed. Furthermore, a high level of knowledge is not needed, however this option is more time consuming than the first one, especially in the description of the envelope, where customized U-values can be added.
- **Novelty:** This system intends to encourage the owners to be more involved and to stimulate their interest in energy efficiency [31].

Table 3 describes the features of the nine aforementioned retrofitting tools that use different methods in assessing various building retrofit interventions

Table 3. Directory of studied tools for transfer of knowledge

	Type of building	Target audience	Goal	Method	Integrated variables
EnergySavingCheck 3.0	Residential	Home owner and policy maker	To assess in refurbishment for water use reduction	After entering certain data of the building (energy and water use, state and morphology) and using the tool of the Cariteam Energiesparservice, it is calculated the energy and water savings, the appropriate steps for it and the relevant carbon dioxide footprint	<ul style="list-style-type: none"> - Data on energy and water use and costs (from bills) - Electricity using devices - State of the building (heating system, insulation, windows, the position of flat, etc.).
eeMeasure	Residential and non-residential	Policy makers	To evaluate of all kinds of energy saving and them benefits	For residential calculation, proposes a matrix of consumption analysis and also analyses the questionnaires of the survey. For non-residential is uses eeMeasure software	<ul style="list-style-type: none"> - Energy consumption - Room air temperature - Relative humidity - Cost of energy - Return of investment - Public funding
The HERON-DST	Residential and non-residential	Policy makers and market stakeholders	To assess in the selection of the optimum combination of technologies and minimize the impact of end-users' behavior in the implementation of energy efficiency	Based on a Hierarchical Analytical process, it is analysed comparatively the barriers created by the behavior of the end users towards the Energetic Efficiency goals. This qualitative data is quantified in numerical entries for the final modelling.	Inputs drivers or alternatively on final users: i) socio-cultural-educative, ii) economical iii) institutional.
TABULA	Residential	Policy-maker and researchers	to create a harmonized model and classification for European residential building typologies	Different countries developed a set of modelled reference buildings and their respective potential energy savings achievable through retrofitting actions.	Construction periods and building sizes specific energy properties of types of building envelope domestic hot water systems

ENERFUND	Commercial and others	Authorities, financial institutions and stakeholders	To evaluate the best decisions on energy renovation strategies by rates and scores of deep retrofiting opportunities	By providing a rating for deep renovation opportunities, energy services or product companies can identify customer segments based on their need, fund allocation and financial institutions.	<ul style="list-style-type: none"> - Energy Performance Certificate - Number of certified installers, governmental schemes running
Em Build Navigator	Public buildings and private housing	Municipalities	To evaluate schemes for deep and successful strategies for renovation	It provides a set of best-practice examples and recommendations on how to plan and direct interventions on buildings and attract investment.	<ul style="list-style-type: none"> - National renovation templates (comfort, air quality) - Target groups
EDGE	Residential and Commercial	professionals in the building sector [30].	To determine the most economical options for an ecological design within the context of the local climate and certificated it.	It calculates the savings in energy needs and the reduction of the impact of building emissions, comparing them with those of a baseline. It also informs about the additional costs needed and the return time.	<ul style="list-style-type: none"> - Available embodied energy data of construction materials - Thermal calculations for energy needs (heating, ventilation and air-conditioning, DHW and lighting) - materials life cycle analysis
Easykenak	Residential and Non-Residential	Certifiers as energy auditors	To minimize the time required for the Energy Performance Certificate	Four simple steps: quickly draw the building, calculate construction and thermal properties of envelope, data processing and energy efficiency calculation. It is possible to re-calculate with EE measures suggested.	<ul style="list-style-type: none"> - Greek standards and regulations for energy efficiency of buildings - Surface areas of the envelope (opaque and transparent) - U-values
EnergimerkeKalkulator	Residential	Home owners and Certifiers	Energy Performance Certificate	Self-assessment method, with two possibilities of analysis. The user can choose a simple analysis with less information, or a complexly one which need information of envelope and HVAC systems.	<ul style="list-style-type: none"> - Technical information about the building (age, floor area and energy sources). - Detailed description of the envelope

5. Discussion and Conclusions

An extensive review of eighteen tools used for renovation purposes was performed and presented in a comparative way, specifying its characteristics such as main goal, target audience, methodology, novelty, among other. The tools were grouped into three categories: renovation assessment, financial assessment, and transfer of knowledge. From the review it is possible to state that the development and innovation in retrofitting tools are of interest to a wide range of stakeholders including researcher, organizations, countries, and international alliances. It is clear that the renovation of existing buildings is a priority issue, where different sectors have space to promote new ideas and contribute in the development of solutions, from the public to commercial sector.

All the tools analysed for renovation assessment deliver as a result the best option for improvement for a given case, however the evaluation varies depending on the variables considered. It is observed that only some include the cost and time of return as a variable to define the best improvement energy efficiency strategy for, while others include more specific physical construction conditions such as airtightness or potential hygrothermal and moisture problems.

In relation to the tools that provide financial assessment it is observed that all of them function as an online platform, but they differ in interface they use. The methodology used to collect the information for the database used for calculations, varies between cadastres of real cases or simulations with specialized software.

The complexity of the use of the tool for transfer of knowledge varies if it is intended for owners or for audience with greater knowledge of the subject. Therefore, the inputs are more detailed in some cases, indicating more precise results. It is observed that when the tools are for owners or municipalities, the results highlight motivational aspects in building renovation programs and illustrations that make the population aware of energy efficiency.

In general, it notices a wide spectrum of tasks and approaches that these tools have implemented, including fuel poverty, water savings, airtightness improvements, policy evaluation etc., as well as the wide group of target users including homeowners, municipalities, investors and policy makers. Although many of the tools are no longer available, their contribution may be used for developing new tools based on their scheme, upgrading their capabilities with the current technology. At the same time, it is expected that the database of tools can continually updated, especially with regard to costs and existing financial grant.

One of the main barriers to the rehabilitation of buildings, the uncertainty about amount of investment required and the efficiency of the potential energy saving strategies. But part of this gap could be covered, if these tools deliver standardized methods with transparent sources of improvement costs, benefiting policies development.

Equally important is the fact that, no tool can do it all, and online tools are becoming more popular and accessible for the users. Hence, the promotion of these software is another key factor to trigger their applications in the renovations of the existing building stock. The review suggests that there is no common agreement on the scope, indicators, and calculation methods for the evaluation of retrofitting measures. Differences in the approach towards retrofitting are dependent on the scope of the development agency and on the country framework of climate change mitigation. The results of this review are a basis for the development of a new tool targeting renovations in residential buildings, where the presented tools may be used as the part of a methodology to assess renovation measures under the EU Energy Performance Building Directive (EPBD).

References

- [1] Pacheco-Torgal F 2017 *Cost-Effective Energy Efficient Building Retrofitting*: Elsevier) pp 1-20
- [2] Pérez-Lombard L, Ortiz J and Pout C 2008 A review on buildings energy consumption information *Energy and buildings* **40** 394-8
- [3] Ürge-Vorsatz D, Danny Harvey L, Mirasgedis S and Levine M D 2007 Mitigating CO2 emissions from energy use in the world's buildings *Building Research & Information* **35** 379-98
- [4] Basarir B, Diri B S and Diri C 2012 Energy efficient retrofit methods at the building envelopes of the school buildings *Mimar Sinan Fine Arts University* 12
- [5] Christensen T H, Gram-Hanssen K, de Best-Waldhober M and Adjei A 2014 Energy retrofits of Danish homes: is the Energy Performance Certificate useful? *Building Research & Information* **42** 489-500
- [6] El-Darwish I and Gomaa M 2017 Retrofitting strategy for building envelopes to achieve energy efficiency *Alexandria Engineering Journal* **56** 579-89
- [7] Alam M, Zou P X W, Sanjayan J, Stewart R, Sahin O, Bertone E and Wilson J 2016 Guidelines for Building Energy Efficiency Retrofitting. In: *Sustainability in Public Works Conference*, (Melbourne, Australia p 13
- [8] C. Wilson, L. Crane and Chryssochoidis G 2015 Why do homeowners renovate energy efficiently? Contrasting perspectives and implications for policy *Energy Research & Social Science* **7** 12-22
- [9] European Commission 2016 Commission Staff Working Document: Evaluation of Directive 2010/31/EU on the energy performance of buildings. Accompanying the document Proposal for a Directive of the European Parliament and of the Council amending Directive 2010/31/EU on the energy performance of buildings. (Brussels: European Union: European Commission) p 109
- [10] Geissler S and Altmann N 2015 How to improve the energy efficiency of existing buildings - The role of recommendations in the Energy Performance Certificate. ([online] p 10
- [11] Volt J, Fabbri M and Groote M d 2018 Understanding Potential User Needs. A survey analysis of the markets for Individual Building Renovation Roadmaps in Bulgaria, Poland and Portugal. p 106
- [12] Bittner B and Lechner R 2004 A policy framework for Energy Performance Assessment for existing dwellings. EPA-ED) p 41
- [13] Cross N 2006 *Designerly ways of knowing*: Springer)
- [14] Itard L 2008 *Towards a Sustainable Northern European Housing Stock: Figures, Facts, and Future* vol 22: Ios Press)
- [15] Konstantinou T and Knaack U 2011 Refurbishment of residential buildings: a design approach to energy-efficiency upgrades *Procedia engineering* **21** 666-75
- [16] PETRICHENKO K, ADEN N and TSAKIRIS A 2016 Tools for Energy Efficiency in Buildings. (Washington D.C.: C2E2, Copenhagen and WRI) p 40
- [17] Lee S H, Hong T and Piette M A 2014 Review of existing energy retrofit tools. Lawrence Berkeley National Laboratory) p 38
- [18] Almeida M G d and Ferreira M A P S 2017 Tools and procedures to support decision making for cost-effective energy and carbon emissions optimization in building renovation (Annex 56). Universidade do Minho) pp 1-80
- [19] Dalla Mora T, Peron F, Romagnoni P, Almeida M and Ferreira M 2018 Tools and procedures to support decision making for cost-effective energy and carbon emissions optimization in building renovation *Energy and Buildings* **167** 200-15
- [20] González Cáceres A, Recart C, Espinoza R and Bobadilla A 2016 Simple Tool to Evaluate Airtightness in Chilean Homes *Sustainability* **8** 1000

- [21] Steskens P, Vanhellefont Y, Roels S and Van Den Bossche N 2015 A Decision Making Tool for the Energy Efficient Refurbishment of Residential Buildings *Energy Procedia* **78** 997-1002
- [22] Braman J, Schaaf R, Shah R, Bozorgi A and Pando M 2016 EZ Retrofit: Multifamily Building Energy-Efficiency Evaluation Process Just Got Easy! In: *2016 ACEEE Summer Study on Energy Efficiency in Buildings*, (Pacific Grove, California pp 1-13
- [23] Wahlström Å, Maripuu M-L and Abel E 2015 Total Concept – for better decision making about energy efficiency investments in non-residential buildings. In: *ECEEE 2015 SUMMER STUDY – FIRST FUEL NOW*, (Presqu'île de Giens, France pp 1239-48
- [24] Madrazo L, Sicilia A, Massetti M, Plazas F and Ortet E 2018 Enhancing energy performance certificates with energy related data to support decision making for building retrofitting *Thermal Science* **22** 957-69
- [25] Bluysen P M 2000 EPIQR and IEQ: indoor environment quality in European apartment buildings *Energy and Buildings* **31** 103–10
- [26] National & Kapodistrian University of Athens-Energy Policy and Development Centre 2016 A decision support tool (DST) reflecting end-users behaviour in energy efficiency modelling. In: *WP 3*, (HERON: Energy Policy & Development Centre – National & Kapodistrian University of Athens) p 187
- [27] Ballarini I, Corgnati S P and Corrado V 2014 Use of reference buildings to assess the energy saving potentials of the residential building stock: The experience of TABULA project *Energy policy* **68** 273-84
- [28] Loga T and Diefenbach N 2010 *Use of Building Typologies for Energy Performance Assessment of National Building Stocks: Existent Experiences in European Countries and Common Approach*: IWU)
- [29] <https://app.enerfund.eu/>.
- [30] International Finance Corporation (IFC) 2018 EDGE Methodology Report - Version 1.0. p 11
- [31] Isachsen O, Rode W and Grini G 2011 Implementation of the EPBD in Norway Status November 2010. In: *Country Reports on EPBD Implementation, Concerted Action EPBD*, p 10