Novel methodology and platform for NZEB renovation of residential buildings

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Abstract

Renovation of the existing building stock is a vital part of reaching upcoming energy savings and CO2 emission targets. The European Union (EU) continuously publishes directives and guidance to support the transition of existing buildings to nearly-Zero Energy Buildings. A method for calculation of cost-optimal levels for minimum energy performance was introduced in 2012. Its aim is to compare and select different renovation alternatives, based on energy savings and global costs. It has been successfully applied on a package level; however, its complexity has restricted it from being used for comparing renovation alternatives between single components with the same and different functions. This paper presents a methodology for determination of a simplified value linking economical and efficiency parameters on a component level. The value allows for fast overview of cost-benefit of different renovation alternatives between components and systems. It serves a decision-making aid for compilation of renovation packages, which are further evaluated with the cost-optimal approach. The paper also introduces novel refurbishment assessment platform that can assist decision makers with fast compilation of refurbishment packages incorporating key aspects of the presented methodology. The current functionality of the platform is showcased at the end of the paper by a case study.

# Introduction

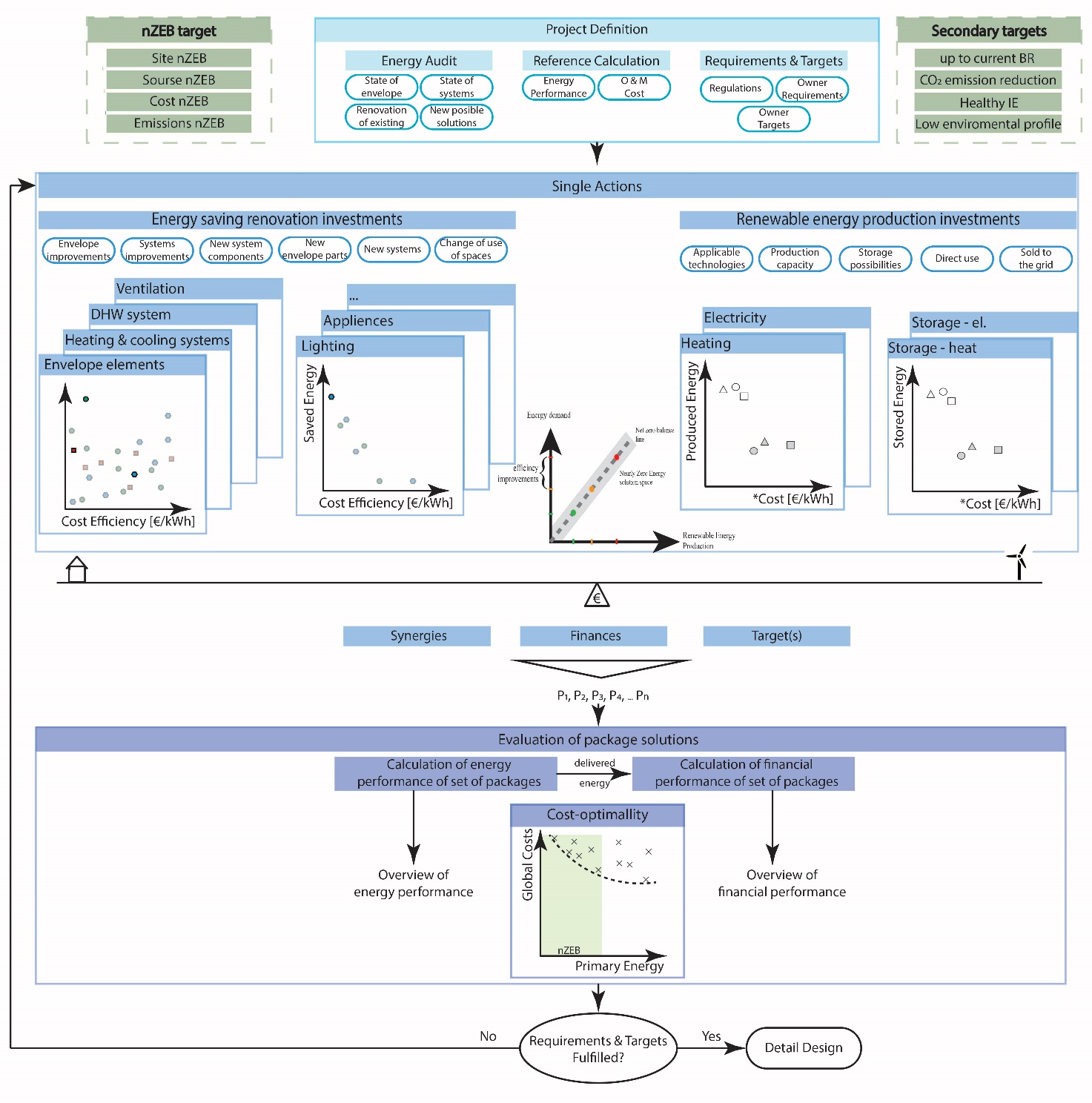
Buildings are a major factor in the transition of clean energy as they account for 36% of the final energy use and 40% of carbon emissions globally [1]. To reduce building related energy use and emissions, the European Union (EU) has implemented number of directives as the recast of Energy Performance of Buildings Directive (EPBD) and Energy Efficiency Directive (EED) to drive the improvement of EU buildings. Those two well-known directives have been amended by DIRECTIVE (EU) 2018/844 [2], requiring Member States to develop and implement long-term renovation strategies for cost-effective transformation of the existing building stock to nearly-Zero Energy Buildings (NZEB). Two of the mentioned obligations under the new *Article 2a* are approaches for cost-effective renovation and, transparent and assessable advisory tools for customers and designers.

In 2012 the EU established a comparative framework for calculation of cost-optimal levels for minimum energy performance requirements for buildings and building elements [3]. The methodology employs energy saving and Life Cycle Cost (LCC) calculations to evaluate efficiency measures, renewable energy sources and packages applied to reference buildings with the aim of identifying cost-optimal levels for minimum energy performance requirements. While the aim of this methodology was to set minimum requirements for cost-optimal levels, literature review in [4] showed that it has been applied for evaluation of single buildings. Even though the framework for the cost-optimal methodology can be applied on a single element, it is mostly applied on a package level. This could be due to the rather tiresome amount of parameters and complexity of LCC calculations when analysing a single element. Moreover, cost calculations and energy savings are typically estimated in different software and combined in spreadsheets like e.g. Excel, requiring great deal of bookkeeping.

The work presented in this paper is twofold. First, a presentation of novel renovation methodology for evaluation of single actions and their compilation in renovation packages. The method proposes simplified economic evaluation for single renovation actions as a pre-step to the well-established cost-optimal method, incorporating LCC. Secondly, a novel refurbishment assessment platform is introduced and showcased by a case study. The platform can collect results from energy saving and economic calculations performed in different software. In spite of its early stage of development, the platform allows for fast and easy compilation and comparison of renovation scenarios, based on data from energy audits, energy and cost analysis for each individual renovation action. The data can be either imported via common JSON file format, or typed in manually, making it independent and flexible.

# Low cost renovation to NZEB

Overview of the complete process, included in the methodology is presented in *Figure 1*. The procedure considers a renovation project with an owner of a specific building(s) and associated renovation targets. The method does not include securing of financing schemes, however, when in place the specifics of such can be accounted for. The methodology is structured as a flowchart with three main sections – 1) project definition, 2) evaluation of the applicable single actions, 3) evaluation of selected renovation packages (scenarios). Detail design of the selected renovation package is beyond the scope of the proposed method. Each section and corresponding tasks and activities within are explained in the following subsections.



*Figure 1 Overview of methodology for obtaining least-cost renovation scenarios for specific building projects.*

## Project definition

The project definition stage of the methodology is where the designer is aquatinted with the general project information as age, type, size, function of the building, etc. At the same time the owner’s primary, secondary targets and motivations for renovation are set.

The method is focused on reaching NZEB, therefore, it is important to establish the specific NZEB definition. This plays an important role in the actions to be included and the focus of the optimization. According to the definition provided in the EPBD, an NZEB is a building with low amount of energy, covered mainly by renewables [5]. In most Member States, maximum limit of primary energy is used as main determining factor for reaching NZEB. The maximum limit value varies in magnitude and the way that it is determined from country to country. In few cases the indicator is determined via non-dimensional parameter, relative to a reference building [6]. Other Member States, apply carbon emissions as indicator, while in third, emissions are used in combination with primary energy [6]. Since the release of the EPBD, various interpretations and calculation methods for NZEB have been illustrated [7]. Some interpretations throughout literature have defined NZEB depending on the considered boundary (e.g. at the building – Site NZEB or at the supplier – source NZEB), the emissions or by the cost of the energy [8]. Due to the evolving nature of the NZEB definition the methodology presented on *Figure 1* is not targeted to a specific NZEB definition or main indicator, rather designed in a way to assess the necessary building parameters in order to fulfil a given NZEB requirement.

The owner may also have secondary targets, besides reaching NZEB. Those can be of varying nature, for example, improvement of indoor comfort, addition of extra living space, low environmental profile, etc. Some of those may also be imposed by the local regulations, which are set by the location of the building. Depending on the country/region, requirements for renovation can be defined on a component or building level or combination of both. If the building is with historic or cultural value one or more elements may be protected and not allowed to be changed.

A reference calculation determining the existing energy demand is necessary in order to estimate the potential energy savings of a component or complete renovation package. This calculation can be performed either with steady-state or dynamic methods. The selection of the method is up to the designer, however, there may be specific regulatory framework and/or the project specific needs.

Reference calculation models provide theoretical estimate of the energy performance of a building, while an energy audit can provide knowledge for the actual energy use under real conditions. If available, the historical energy use of the building can be used to calibrate the reference energy models. Calibrated models can yield more realistic results for potential energy savings from different renovation interventions. While performing the audit, the designer can also assess the state of different building parts and systems, and if those are in need of replacement, renovation to a given extend or readjustment of set-points and operation parameters. Furthermore, ideas and considerations of the possible solutions for each building part can be initiated and discussed with the property manager and/or building users.

To obtain grounds for financial comparison between investigated renovation scenarios and state of the building before renovation, it is necessary to know the running, operation and maintenance cost of the building in its existing state. This information is valuable, yet rather hard to obtain. A good source for such information (if it is not recoded explicitly) is the property manager, as he/she is responsible for the daily operations or the building and performing day-to-day maintenance tasks.

## Evaluation of single actions

It is proposed that after completion of the project definition stage, the applicable single renovation actions are evaluated independently. The goal is to obtain an overview and compare how the different actions, applicable to the specific building, perform both in terms of potential energy savings and costs. The methodology used to evaluate and rank energy efficiency actions is presented and tested in detail in [4] and briefly explained further.

Investments in energy efficiency are evaluated based on a value termed cost‐effectiveness, linking implementation cost, primary energy savings and lifespan of the evaluated actions. The cost‐effectiveness of each action is calculated using the equation (1) and represents the cost of saved kWh primary energy for the different actions. The lifespan of investigated improvements is taken into account by dividing the implementation cost by the expected lifespan of the action in question. The implementation cost at this stage of the method include all cost necessary to implement an action (removal and disposal of old materials, equipment, labor and investment for the new materials or components). In this way, a building owner obtains a direct overview of the required investment to implement a given action at the beginning of the renovation process.

|  |  |
| --- | --- |
|  | (1) |

It is proposed that the cost-effective parameter for investments in renewable energy production and storage is with the same unit as the cost‐effectiveness of investments in energy efficiency measures. This is done with the aim of obtaining grounds for direct comparison of cost‐effectiveness between energy producing systems and energy efficiency improvements. Improvements in energy efficiency and energy production are different by nature and thus cannot be evaluated in the same way and require different approach for estimating their benefits and level of costs.

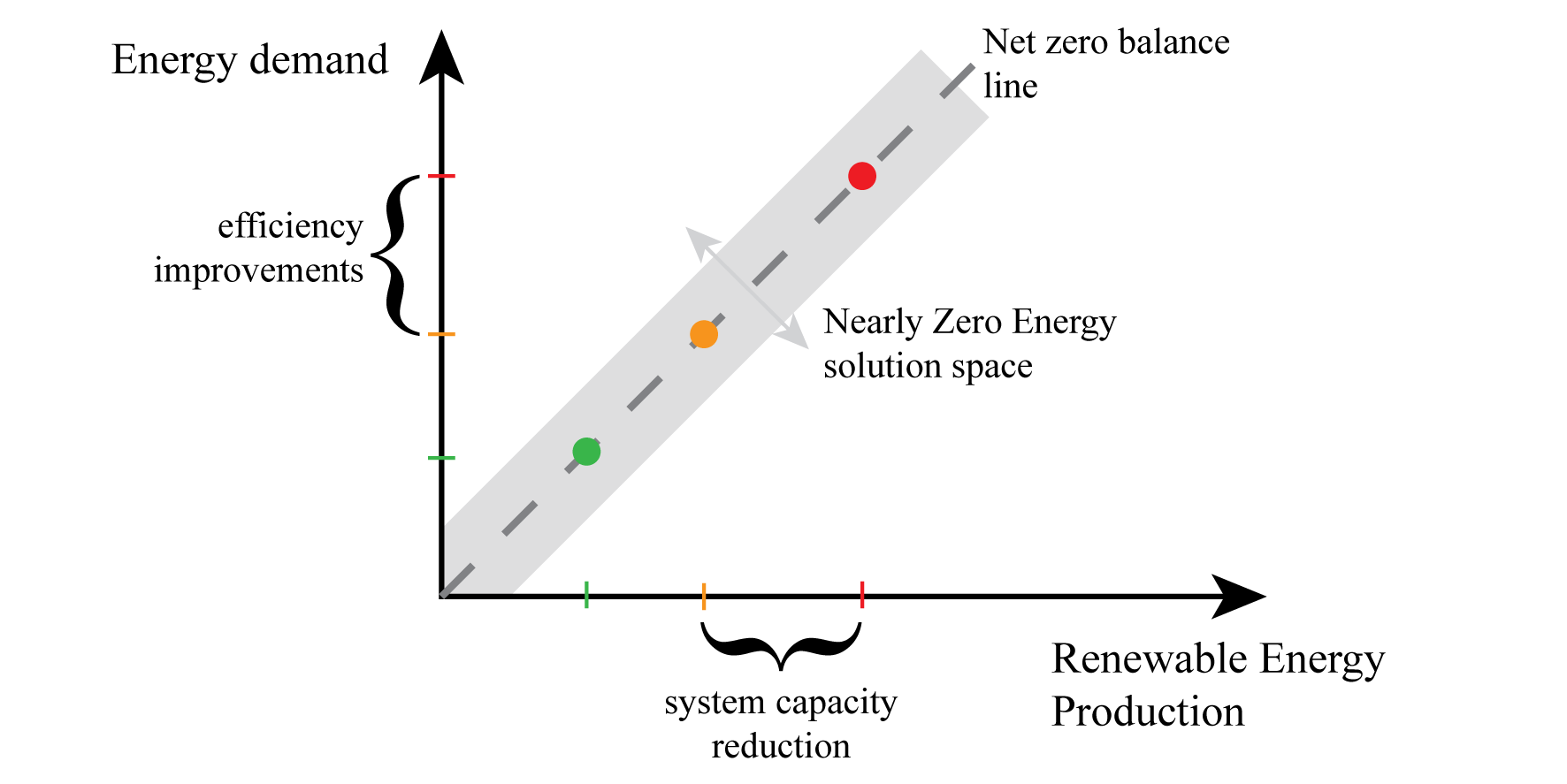
The annual investment is obtained in the same way as for the energy efficiency actions - by dividing the total costs by the expected lifetime of the system. The considered costs for cost-effectiveness of production systems are the investment, installation, operation, maintenance, variable and fuel costs.

The total fuel costs can be estimated based on the energy demand of the building, total amount of fuel needed to cover the demand (estimated with calorific value for the fuel in question), the cost of the fuel and technological specifications of the system.

The investment cost of a system is dependent on its production capacity. In the present methodology, the required capacity is determined during the project definition via the reference calculation. In principle, the capacity of a system, dimensioned according to the existing heating demand would be able to cover the demand of the building prior renovation. It is possible to reduce that when applying energy efficiency measures to the building. However, for cases where the energy producing system is outdated, while other building parts are not, the energy demand of the existing building would be the appropriate for dimensioning of the new system. The idea is that the comparison of all applicable systems is based on the same demand in order to obtain a relative comparison between the options. The correct system parameters, dimensioning and its costs are taken into consideration in the next stage when all efficiency actions are selected.

While the value of cost‐effectiveness considers the total costs throughout the lifetime of the considered systems, it does not take into account the price increase of fuel with time and inflation, as it is done in LCC calculations. This simplification however, provides grounds for comparison between multiple systems, and energy production systems energy efficiency actions. Moreover, the process acquires solid background of all parameters necessary for LCC calculations, performed in the next step of the method on package level.

## Balancing energy efficiency and energy production

Achieving balance of investments in energy efficiency and renewable production in accordance with the budget of the project is sought by using the schematic chart represented in *Figure 2*. Knowing what is the demand of the building prior renovation, the cost‐effectiveness of produced and/or saved energy by each action; one can use the chart to assess the different ways to reach the NZEB standard, while considering their cost.

The chart shows the Net zero balance line, where the energy use and renewable production are equal for a given period. However, as discussed above, Member states have imposed different NZEB standards. In countries where the only requirement is primary energy the limit value is above zero, thereby there would be solutions satisfying NZEB requirements, which are not exactly on the net zero balance line. Higher limit values for energy demand would increase the solution space for NZEB (indicated in grey in *Figure 2*).

*Figure 2 Schematic representation for balancing energy efficiency improvements and renewable energy production, adapted from [9].*

Depending on criteria and targets set in the project definition stage, one can estimate the required amount of efficiency actions and the resulting required renewable energy production, necessity to reach NZEB. In principle if the complete demand is covered by own renewable production, a building may be zero energy for. However, the definition in EPBD and local regulatory requirements set comfort and efficiency requirements as well. This means that if those are covered the NZEB may be reached by simply suppling the demand by renewable production. Otherwise, some actions have to be taken to satisfy comfort and efficiency requirements, besides providing renewable production. Overall, there are many different ways to reach NZEB and their cost can differ considerably. Thereby, this should be checked on the package level by applying the well-established LCC approach, where number of various packages, compliant with the specific project at hand are compared.

This is the pivotal point of the methodology as all information acquired in project definition and single action stages is segregated in making viable package solutions. Besides obtaining NZEB standard, the designer has to take into account synergy of actions, the targets and finances of the project, dependence of actions on the result as well as other unforeseeable factors as rebound effect of the packages, implementation complexity, time, etc.

## Evaluation of renovation packages

The last stage of the method consists of comparing the “balanced” renovation packages using LCC calculations. For consistency and comparability reasons throughout the EU, those are to be done in accordance to the cost‐optimal methodology, introduced in the EPBD [5]. While the method was imposed by the EPBD for regulation of national building standards it has been shown throughout literature that it can be successfully applied to single buildings with various functions (cf. Literature review provided in [4]).

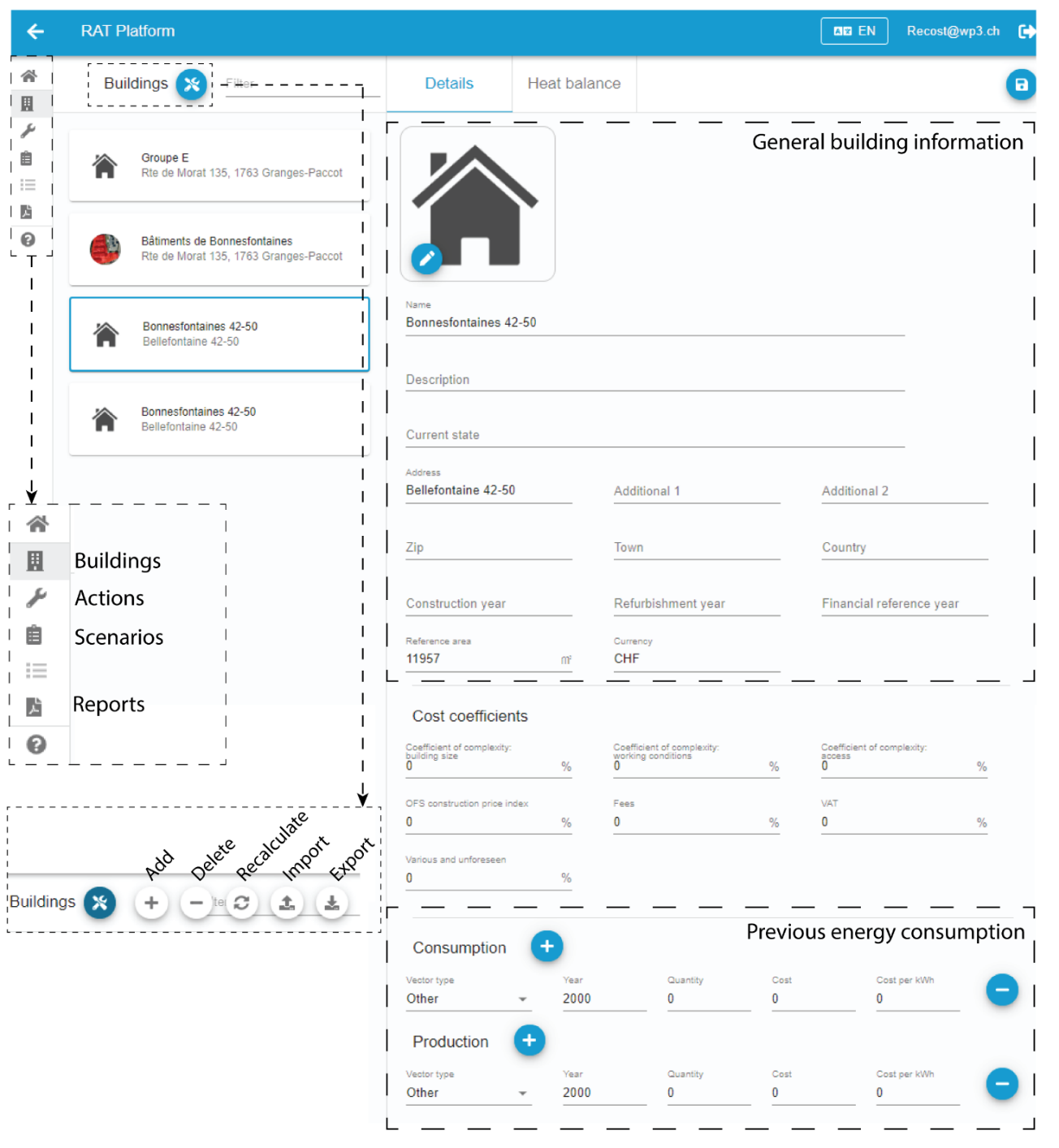
The method consists of obtaining an overview of energy and financial performance of each selected package and plotting the resulting global cost as a function of the energy performance of each package as indicated in the bottom part in *Figure 1*. This visualization allows the designer to compare different packages in terms of global costs and if they satisfy the NZEB demands or not. *Figure 1* provides an example where NZEB requirements are defined by maximum limit for primary energy, however, that can be replaced with the parameter valid for the country or region, if that is not primary energy.

When and if the satisfactory package is found, the last step of the methodology is to check if the selected package fulfils all primary and secondary targets of the project. If that is true, the process can continue with detail design of the selected package. If some of the requirements and targets are not fulfilled, the designer can loop back to either selecting a different package, or creating new set of packages from the single actions, defined in the previous step.

# Refurbishment assessment platform

The refurbishment assessment platform (for simplicity referred to as the platform) is an online tool created to segregate information for a project and empower the building owner or designer in taking decisions. The platform is capable of combining results from different types of software by either directly importing their results via JSON file or manually entering data to the platform. The goal is that the platform and Least-Cost Method (LCM) complement each other in a way that the LCM provides overview of the tasks and calculation methodology for renovation assessment, while the platform provides bookkeeping of all gathered information and external software results. Furthermore, the platform allows for combination and re-calculation of the imported data into key performance indicators, used for decision support and comparison of renovation scenarios. In time of writing of this paper, the platform is still under development. It currently integrates activities from the first two stages of the LCM: project definition and to some extend the evaluation of single actions. The third part of the method – evaluation of packages using LCC calculation is not part of the platform yet. To understand how the platform, in conjunction with the LCM, support designers and building owners its principles and functionality is explained below.

Similarly, to the method, the platform is also disconnected from country specific regulation or NZEB definition. Its user-friendliness allows direct import from the EPIQR+ [10] and ECOSOLUTION [11] calculation tools; however, it is not limited to those, as the user may also enter data manually. The software EPIQR+ is a tool for assessing the state of the building and evaluating the cost and energy performance of different refurbishment scenarios. This is possible after an audit of the building, which is the basis for obtaining most of the information in the project definition stage and the cost necessary for economic evaluation of single actions. The tool ECOSOLUTION complements EPIQR+ with specific energy saving calculations for HVAC and renewable energy producing systems. It also requires energy audit in order to find the specific energy use of a component and/or system and compare it to a new proposed alternative. In that way ECOSOLUTION also covers tasks from project definition and calculation of single actions stages of the LCM. If a designer plans to use the LCM and platform from the beginning of a project, a great deal of double work can be avoided. For example, single audit can serve both tools and cost and energy savings can be shared by both tools via the platform. The project targets and regulatory framework are currently not an explicit part of neither the two tools nor the platform. Therefore, the designer must be conscious of the project targets and regulatory requirements.



*Figure 3 Home screen of the online refurbishment assessment platform.*

*Figure 3* shows a screen print of the first page of the platform, including the functionality behind some of the main buttons. A building can be added manually or imported through a JSON file. Currently the functionality of EPIQR+ and ECOSOLUTION tools allows direct export of JSON files which are compatible with the platform. The user can perform basic operations as import, export of JSON files, add or delete a building data. The “Recalculate” button performs calculations from the cost and savings (energy or CO2) data to indicators of cost- or CO2-effectiveness, similar to those described in the LCM.

When a building is selected, on the right-hand side, a user can enter general information for the building as name, address, description, age etc. Below, there is a possibility to enter cost coefficients related to complexity, fees, VAT, price indexes and unknown costs. At the bottom of the page, one can enter the historical energy consumption, type of fuel and energy produced at the site, if that is available.The ribbon on the left-hand side is the backbone of the platform. The buttons for Actions, Scenarios and Report link respective pages. Actions and Scenarios pages are shown in *Figure 4* and *Figure 5,* respectively*.*

*Figure 4* shows the actions page of the platform. On the right-hand side, the user can see a list with all imported and/or created actions. Each action contains a part with general information, a part with techno-economic parameters and a part with the total energy and CO2 savings, achieved by the action. The general information contains name, description, as well as some categorization and grouping parameters as which building part, element and group the action belongs to. Technology parameters are the investment cost, payback time, share of energy relation of the action, priority, planned date and type of works - maintenance, refurbishment, improvement, etc. If using the EPIQR+ software, values for Global warming potential, primary (embodied) energy and Abiotic Depletion Potential (ADP fossil) are calculated automatically. A main technology parameter that is not yet implemented in the platform is the lifetime of an action. Due to that, when recalculating the effectiveness parameters, the lifetime is not included and the cost- and CO2-effectiveness are simply the cost divided by the achieved savings or CO2 savings.

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Description générée automatiquement

*Figure 4 Actions page in the online refurbishment assessment platform.*

The page where different scenarios can be created, evaluated and compared is shown in *Figure 5*. On the left-hand side, the user can see all scenarios that have been created, as well as a quick overview of the total cost, energy savings and global warming potential (GWP) of each one.

A scenario is constructed by adding a new or selecting existing one and editing its content. When a scenario is selected, on the right-hand side on top of the page, the user can see the three parameters shown in the list of scenarios - cost, energy savings and GWP. Additionally, the cost‐ and GWP‐effectiveness for the whole scenario are shown. In the middle section of the page the user can add the name of the scenario and a comment of own choice.

On the bottom right-hand side of the page, the user can select the actions, which make up the scenario in question. The list of actions, defined in the previous page, is interactive and can be re-arranged depending on the preferences of the user. It is possible to filter and sort the actions according to building type or group, ascending or descending cost or energy savings, cost- and CO2‐effectiveness. This provides great flexibility and excellent bookkeeping when comprising and comparing different scenarios.

It must be noted that the total amount of cost, energy savings and GWP is a result of the addition of the separate values. This should be used only as guiding value, especially when considering energy savings and cost. This is imperative, as addition of energy savings calculated on element level does not provide correct global energy performance of their addition. This is due to synergies and contradictions (interactive effects) between the different actions. In relation to cost, those could also differ when considering global scenario. The global cost may be smaller if a certain cost can be avoided or reduced if several actions are combined (quantity discounts, exclusion of tasks due to nature/location of works). On the contrary, global cost of a scenario may be larger than the addition of separate single actions if complexity, timeframe is extended due to technological sequences of the tasks being applied to the building. Therefore, the selected scenario must be re-evaluated using a global method to obtain more accurate estimate of the predicted performance of the building after renovation.

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*Figure 5 Scenario page in the refurbishment assessment platform.*

The LCM surpasses the platform in many of described activities. The specific methodology for comparing energy producing technologies, balancing the renovation packages as well as the final stage of package evaluation is not yet available in the platform. However, for its ‘young age’ the platform proves to be a great tool for decision support by providing opportunity for comprising, comparing, and reporting on expected performance of renovation scenarios. The platform can be used in the early stages of a renovation process in an iterative way by providing both initial quick overview of possibilities and performance. Moreover, the possibility for manual entry allows the user to apply preferred calculation methods for cost and energy savings and thus use the platform in the latter stages of the renovation process or in cases where greater accuracy is required. The functionality, advantages and drawbacks of the platform are discussed via a case study, described in the next section.

# Case study

The selected case sturdy is a public building complex located in Fribourg, Switzerland, and shown in *Figure 6*. It consist of 10 buildings constructed in 1993 - a round tower and nine rectangular buildings. There are 125 dwellings distributed over five floors with total heated floor area of 13,144 m2. The complex houses studios, single, double room apartments as well as such on two and three levels with total capacity for 370 inhabitants. The housing complex is equipped with unheated parking in the basement and common laundry facilities.

Calculation model using the compliance tool CECB classifies the complex in energy class E, with primary energy demand of 133,4 kWh/m2 year. The buildings are naturally ventilated through windows; the kitchens are equipped with independent extraction hoods, while the bathroom ventilation occurs via centralized chimneys employing stack effect. The heating of the building is done via water based heating system with radiators and floor heating (supplied from radiator return). The heating system consist of a common gas boiler located in the basement and individual substation with heat exchanger for each individual building. Domestic hot water production and supply are done in the same way as for space heating.

*Figure 6 Site plan of the case study building complex.*

The building envelope elements vary in regards to typology. There are two different roof types; seven different external wall types; three different floors and two different window types. Three of the seven wall types constitute about 90% of all building external wall, those are the ones considered in the analysis below. The most represented external wall type is bricks with rigid external insulation and plaster on both sides. It constitutes for 34% of the total external walls and has U-value equal to 0.3 W/m2 K. The other two wall types comprise of brick, insulation and concrete (28% of all external walls, U-value of 0.29), and brick insulation and ventilation gap (27% of all external walls, U-value of 0.28). The biggest share of the floor is this over the unheated parking, constituting of about 95% of all floors part of the thermal envelope. It is with the highest U-value (0.77 W/m2 K) and the only type where no relocation of tenants is necessary; thus, this is the only floor type considered in the analysis. Both roof types have undergone improvements in recent years and are therefore not part of the analysis. In regards to the window, replacement with two different types is investigated. While none of the building envelope elements complies with the current regulation, they are in good condition. Therefore, economic feasibility evaluation is necessary in order to determine the most appropriate actions in order to reach the owner’s target and NZEB standard.

*Table 1* presents the evaluated refurbishment actions selected for the initial test of the platform. The actions are selected to test the capabilities and drawbacks of the platform rather than perform in-depth renovation analysis for the building complex. That is why a precise description of obtaining of each indicator as cost, energy savings, GWP and CO2 savings are not part of this publication. The actions were determined after energy audit, cost and energy analysis of the buildings. Energy saving analysis are done using the ECOSOLUTION and Lesosai tools, while cost analysis were performed using EPIQR+. Due to recent upgrade and integration of EPIQR+ with an LCA database developed for the RECO2ST project, actions analysed with EPIQR+ automatically provide environmental indicators as embodied energy, GWP and ADP.

|  |  |  |
| --- | --- | --- |
| Envelope | Distribution systems | Producing technologies |
| - Insulation of slab over unheated parking  - Insulation of external wall - 2 types  - Replacing windows - 2 types | - Circulation pump for heating  - Circulation pump for DHW  - LED lights for parking, laundry room and hallways | - MVHR  - Renewing existing gas boilers  - Switching to district heating  - DHW boilers (PAC) |

*Table 1 Single refurbishment actions included in the analysis.*

Using the scenario creation page, presented in *Figure 4*, four scenarios were created. Using the sort function, a scenario with the three top ranking actions for the following criteria were compiled: lowest cost, highest energy savings, lowest cost-effectiveness and lowest CO2-effectiveness. The resulting actions for each of the four scenarios, their total cost, energy and CO2 savings are presented in *Table 2*.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Scenario | Lowest cost | Highest energy savings | Cost-effectiveness | CO2-effectiveness |
| Actions | LED Hallway  LED Parking  LED laundry | MVHR  3 layer windows  PAC boiler for DHW | LED Hallway  DHW boilers (PAC)  MVHR | MVHR  Floor insulation  Wall insulation |
| Cost [CHF]  Energy savings [kWh]  CO2 savings [kgCO2] | 11 100  26 129  300 | 2 296 700  2 217 012  510 300 | 324 200  1 770 857  263 100 | 3 533 581  1 755 360  721 440 |

*Table 2 Actions and respective cost, energy and kgCO2 savings.*

Despite the limited number of investigated actions, the results from the different selected optimisation parameters show the capability of the platform of creating various scenarios and obtaining an overall idea of their performance. For example, the cost-effectiveness scenario is 30% less in energy savings but 85% cheaper, compared to the scenario with highest energy savings. This indicates that with greater number of investigated actions the optimization options would be greater variation of the content of scenarios. Further work for the platform should include integration of the lifespan of building parts, and treat renewable energy producing systems as described in the LCM. It would also provide even greater value to the renovation process if LLC calculation on a package level is integrated. However, the presented variability in the scenarios with limited number of renovation actions, the user friendliness and the ease of creating and comparing scenarios are encouraging factors that the platform could be a great tool for decision support for a renovation process.

**Acknowledgements**

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