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# THE RINNO SOLUTION: A HOLISTIC ASSESSMENT FRAMEWORK FOR SUPPORTING BUILDING RENOVATION PROJECTS

Vasileios Sougkakis[1], Ioannis Mamounakis[1], Petros Iliadis[1], Andreas Seitaridis[1], Evdoxia E. Lithoxoidou[1], Omar Doukari[2], Enrico Scoditti[3], Nikolaos Nikolopoulos[1] and Mohamad Kassem[4]
[1]Centre for Research and Technology Hellas, Thessaloniki, Greece
[2]Northumbria University, Newcastle, United Kingdom
[3]RINA Consulting SpA, Genoa, Italy
[4]Newcastle University, Newcastle, United Kingdom

## Abstract

As part of the RINNO project which aims at increasing the building renovation rates in the EU, a framework solution has been developed for the selection of the best renovation scenario for a building. The RINNO solution enables users to take informed decisions through the holistic assessment of alternative scenarios and facilitates the selection of the optimum one according to their preferences. The various software tools developed comprising this framework are discussed in this work along with their integration strategy. An example is also presented where the use of the RINNO solution determines the scenario with the optimum performance.

## Introduction

It is estimated that 90% of the buildings in the EU were built before 1990 and that 75% of buildings have poor energy performance as they were built without any provisions on energy efficiency (Filippidou and Jimenez Navarro, 2019). Furthermore, between 85%-95% of the buildings today will still be in use by 2050 (EC, 2020). As such, increasing the energy efficiency of the building stock is considered critical for the EU to meet the target of zero net emissions as set out in the European Green Deal. To do so, significant increase in the annual rate of renovation is required. Currently, the rate of energy retrofit in buildings is approximately 1% at the EU level, whilst deep energy renovation represents approximately 0.2% of the buildings on an annual basis. (EC, 2020). Despite the obvious benefits of retrofitting, the levels of renovation are low and not sufficient for meeting the EU climate targets; for this reason, the European Commission set out the Renovation Wave strategy aiming at doubling the 2020 rates of renovation by 2030.

Low uptake of building renovation may be attributed to a number of barriers faced by the construction industry and relevant stakeholders (building managers, owners, occupants, construction companies etc). These barriers are commonly classified as (D'Oca et al., 2018, Palm and Reidl, 2018) i) **technical**, including lack of standardized and integrated solutions, shortage of available workers with adequate skills, end-users without the technical expertise to evaluate the effectiveness and savings of deep retrofit, discrepancies between expected and actual energy savings which leads to lack of trust towards renovation, time consuming processes, safety risks etc., ii) **financial**, involving high investment costs, long payback periods, short-sighted analysis that does not consider the benefits throughout the lifecycle of the building, unwillingness of building owners to fund the renovation, lack of financing to medium and low income owners, and iii) **social**, including the time-consuming and complex decision making processes, increased disturbance of the building occupants and limited understanding of the end-users regarding the benefits of renovation, both energy and non-energy related. Additionally, regulatory and legislative barriers have also been identified, including complex administrative processes especially regarding public procurement, split incentives between owners and tenants, regulations often focusing on simple renovation rather than supporting deep renovation (EmBuild, 2017). In order to tackle many of these barriers and contribute to an increase in the rates of building retrofit, the EU funded RINNO project (H2020) proposes a holistic approach for the design stage in which the user is at the centre of the decision making process (RINNO, 2022). This approach involves the multi-criteria assessment of potential renovation scenarios and the selection of the optimum one considering the user's preferences with the use of a Decision Support System (DSS). A set of tools have been developed for the assessment of the building performance in terms of i) energy consumption and production, ii) environmental impact, iii) lifecycle costs and financial performance and iv) user disruption, collectively referred to as the RINNO Simulation and Assessment toolbox. The analysis conducted with these tools is then fed to the RINNO Optimiser and Planner. This includes a DSS software tool to select the best renovation scenario and a scheduling optimiser software to derive the optimum work sequence based on the user preferences.

Such multifaceted analysis presents significant benefits to the end-users and the renovation industry, namely i) communicating effectively the benefits of the renovation regarding both energy and non-energy aspects of the building performance to the occupants and designers in order to make an informed decision and increase trust and confidence on the design process, ii) assessing the retrofit measures considering a lifecycle costing approach, not just the initial investment cost, iii) communicating the renovation process to the occupants and estimating the user disruption levels and total project duration thereby increasing the occupant's acceptance of the renovation (Vainio, 2011), iv) simplifying the decision making process through a DSS that uses suitable algorithms taking also into account the user's preferences.

In the following sections, a brief description of the tools developed, their main functionalities and their interconnections and information exchanges in order to deliver a valuable toolkit for the holistic assessment of building renovation are presented.

## Materials and Methods

The RINNO solution comprises several software tools developed by the project partners. These tools are presented below.

### INTEMA.building

The analysis of a building's energy performance is conducted with the use of INTEMA.building, an in-house whole Building Energy Simulation software developed within the framework of the RINNO project. The tool has been developed using the Modelica language in the Dymola environment, capitalizing on extensive Modelica open-source libraries, which are validated and well-established (Buildings (Wetter et al.,2014), BuildingSystems (Nytsch-Geusen et al.,, 2016), IDEAS (Jorissen et al., 2018) and AixLib (Fuchs et al.,2015, Müller et al.,2016)) whilst additional component libraries were also developed in-house and validated where necessary. INTEMA.building receives the necessary information from the user, generates the building model, and runs the energy simulation, considering also necessary input data from external databases (on-line or off-line) as in the case of the weather data repository.

At the front-end of the tool's web platform, the user determines the inputs through the simplified and easy-to-use Graphical User Interface. Figure 1 presents the main steps of the tool's operation. The whole building energy simulation process starts with the user selecting the location of the building and assigning the relevant associated weather data. Next, the geometry of the building and the properties of the building envelope components are entered and the relevant thermal zones are assigned allowing to determine the loads in each zone. Finally, the relevant HVAC and RES systems are determined to finalise the model and conduct the simulation. The appropriate structure of the Modelica model and the relevant libraries required are automatically generated at the back-end. This automation results in significant time savings in the modelling process and enables the use of the software by sustainability experts/ engineers without requiring specialised programming skills.

The software performs dynamic simulations and estimates the heating and cooling loads and internal temperatures of the building considering the interactions between the various passive and active systems with the external environment, taking also into account multiple energy networks (electricity, heating and cooling etc.), and storage systems (sensible storage tanks, PCM). It has the capacity to perform simulations with high temporal resolution by considering time-adjustable time steps, whilst it allows multi-zone simulation. INTEMA.building has gone through rigorous testing and verification of the results against i) the applicable Standard EN 15265 for building energy calculations as well ii) other well-established dynamic energy software (TRNSYS 18). Details of this verification process, as well as a more detailed description of the tool capabilities and the results from the analysis of a building are provided by Bellos et al. (2022). In order to evaluate a building renovation project within the context of RINNO, INTEMA.building calculates the following indicators:

- Decrease in Energy Consumption (%)
- Savings in Energy consumption for heating (%)
- Savings in Energy consumption for cooling (%)
- Savings in Energy consumption for DHW (%)
- Increase in RES-based electricity production (kWh)
- Increase in RES-based heating production (kWh)


*Figure 1: INTEMA.building operating flow*

### VERIFY

VERIFY is a web-based platform for performing environmental and costing analysis computations. VERIFY adapts the Lifecycle Assessment (LCA) and Lifecycle Costing Analysis (LCC) methodology, applied to building renovation scenarios. This software tool provides a quantitative evaluation of the building's environmental impact and gains throughout its lifecycle approach following the methodology defined under ISO 14040 /44 whilst the cost analysis (impact and/or possible cost savings) follows the ISO 15686-5. The analysis considers the main stages in the lifecycle of a building, namely i) manufacturing and transportation of components (cradle to gate approach), ii) construction stage, iii) operation and maintenance stage and iv) end-of-life, taking into account the production, exchange and disposal of all type of energy flow streams, through an automated process.

VERIFY is accompanied by a user-friendly graphical interface which guides the platform user through the building modelling procedure steps. The analysis includes the modelling of the building to be analysed for both its current and planned/renovated state. The user sets up the model of the building through the development of: 1) an electrical plan (i.e. electrical and RES systems), 2) a thermal plan (building envelope components, HVAC systems and solar RES thermal systems) and 3) optionally an investment plan (financial parameters of the project). The crucial computational data are retrieved through a private database, whilst it is also able to communicate with external databases to acquire relevant information on products. Furthermore, VERIFY can communicate with the external energy software INTEMA.building tool, via a custom API, for retrieving synthetic time series data, thus representing the use phase of the building performance (Figure 2). In addition to the evaluation at the design stage, the software may also be used as an assessment tool for real-time evaluation of impacts; VERIFY can connect to external monitoring sensors, installed in the building area, retrieve the extracted measurements and calculate environmental and relevant cost indicators dynamically (hour interval). Communication to external software tools is achieved through custom API, while datasets exchange is established through communication protocols (e.g. Kafka, MQTT), following the widely used SAREF model ontology. A detailed description of the functionalities of VERIFY and its use in the assessment of building renovation scenarios is provided by Seitaridis et al., (2022).

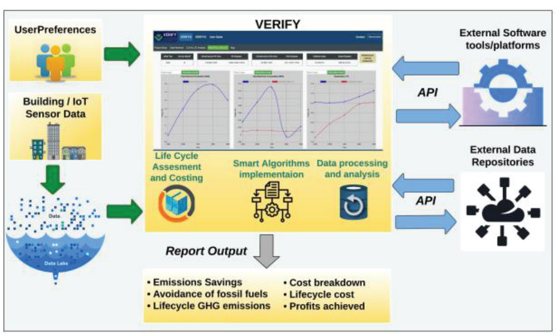


*Figure 2: VERIFY operating flow*

Within the framework of the RINNO evaluation process, VERIFY is used to calculate a series of environmental impact and cost and financial indicators, namely:

- Yearly Primary energy savings – PES (kWh)
- Yearly Lifecycle Life Cycle Global Warming Potential savings (CO2-eq)
- Yearly embodied energy (kWh)
- Yearly water footprint ($m^3$)
- Yearly Energy Self-Supply by RES (%)
- Return on Investment (%)
- Payback period (years)
- Yearly Lifecycle Cost Savings (€)
- Initial investment (CAPEX) (€)
- Annual O&M costs (€/year)

**Techno-Economic Assessment (TEA) tool**

The TEA tool aims at conducting an assessment of the disruption levels caused by renovation activities in order to: i) enable the user (such as project manager and owner) to select the renovation scenario with the least possible disruption out of several alternative scenarios, and ii) to explain the renovation process to the occupants and communicate the expected disturbance that they will likely experience, thus gaining their trust and increasing their acceptance towards the renovation initiative. In addition, the TEA tool evaluates at the preliminary design stage the renovation project duration, cost, and waste generated, as they are all parameters related to disruption.

The TEA process is BIM-based and consists in importing the BIM model of a building and defining the renovation scenario to be assessed. The TEA tool maps the renovation scenario to corresponding activities (based on a renovation ontology), as well as relevant equipment along with their details, such as unit prices, durations and number of workers needed for these activities (through related database). Building elements and material quantities are generated by the BIM model and associated with the renovation activities, which allows users to generate the renovation schedule corresponding to the scenario selected. The methodology includes the main renovation activities (involving the most common general renovation actions) and sub-activities and takes into consideration: 1) specific constraints (spatial and activity-based) and 2) rules for determining a recommended sequence of works, i.e. works that may be conducted in parallel to others, incompatible or even considered as prerequisite jobs for the completion of other works. The analysis outcomes include estimations of the disruption levels, the waste generated and the associated cost and duration of the selected renovation project. Four types of disruption have been considered, namely disruption of i) utilities, ii) traffic, iii) physical space (when occupants need to leave the building) and iv) internal environment (noise, dust, odour and daily light reduction). Based om the results of a survey conducted among the partners of the RINNO project, the disruption levels of each renovation activity and sub-activity for each type of disruption were determined and expressed from a scale of 0 to 4 (Doukari et al., 2023). With the use of the aforementioned TEA tool methodology and database developed, the user (i.e. renovation manager, architect, consultant) may calculate a series of indicators regarding the occupant's disturbance and waste management during the renovation process, namely:

- Average Daily Utilities Disruption (0-4)
- Average Project Utilities Disruption (0-4)
- Average Daily Traffic Disruption (0-4)
- Average Project Traffic Disruption (0-4)
- Average Daily Physical Space Disruption (0-4)
- Average Project Physical Space Disruption (0-4)
- Average Daily Int. Environment Disruption (0-4)
- Average Project Int. Environment Disruption (0-4)

- Average Daily Project Waste (dm$^3$)
- Overall Project Waste (dm$^3$)
- Project duration (days)

The aforementioned tools are used to conduct the detailed multi-criteria evaluation of several alternative renovation scenarios and comprise the RINNO simulation and Assessment toolbox. The set of KPIs generated by each tool is fed to the Renovation Scenario DSS tool to select the optimum renovation scenario according to the user's preferences. Finally, the optimised workflow is generated for the selected scenario with the use of the Job Scheduling Optimiser (JSO). These optimisation tools (DSS and JSO) comprise the RINNO Optimiser and Planner. A brief description of these tools is provided in the following paragraphs.

**Renovation Scenario DSS**

The Renovation Scenario DSS aims at supporting the user in the selection of the best renovation scenario that complies with their needs and preferences on the basis of a Multi-Criteria Decision Making (MCDM) approach. Decision Support Systems (DSS) are becoming particularly useful and increasingly applied for decision-making at various managerial levels due to mainly the following issues related to contemporary decision problems (Podvesovskii et al., 2021, Laguna Salvado, et al., 2022): i) the complex structure of problems encountered, ii) the need to assess a great number of alternative options, iii) the incompleteness and uncertainty of information iv) the uniqueness of tasks, v) the choice often involves multiple and contradictory objectives that need to be achieved, vi) the user is sometimes inexperienced or does not fully understand the totality of the objectives. To do so, the tool has the following features commonly shared between DSS tools (Rashidi et al., 2018): i) it may be used at different management levels, ii) it offers interoperability and can be integrated to other tools (i.e. the Renovation Simulation and Assessment toolbox), iii) it is flexible and versatile and iv) it is user friendly as a Graphical User Interface was developed to facilitate the analysis.

The RINNO decision making problem is a highly structured process with a well-established context, clearly assigned criteria, specific alternative scenarios to be assessed as well as highly predictable outcomes of each scenario (i.e. results obtained from the analysis tools). In order to conduct the selection process, the tool receives inputs from the user (i.e. renovation manager, building owner) and the internal database where the results of the previous analysis have been stored. At first, the Renovation Manager selects the scenarios to be assessed. The tool then retrieves the data stored in the database and delivers the results to the user considering all indicators grouped into four categories: A) Energy, B) Environmental, C) Cost and Financial and D) User Disruption. User preferences are taken into account as the Renovation Manager may remove specific indicators and apply certain weights to each category (thereby defining the relevant importance of each category in the selection process). Based on these inputs, the weighted score of each category is determined, and finally the overall score of each scenario is computed. The scenario with the highest score among the alternatives examined is considered the best option.

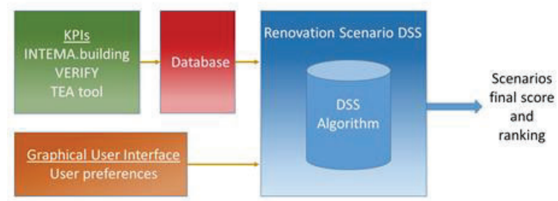


*Figure 3:Renovation Scenario DSS workflow*

**Job Scheduling Optimiser (JSO)**

The purpose of the JSO software tool is to generate the optimal sequence of the jobs included in the renovation scenario, previously selected by the DSS. The preferred sequence of jobs is the one that i) minimizes the total duration of the renovation project, ii) achieves minimum tenants' disruption, while iii) respecting a set of constraints that was set by the renovation manager, such as the availability of workers, the available monetary budget and the precedence of the jobs.

The process followed by the JSO to produce the optimal schedule can be described by a three top-level step approach: At first, the JSO receives a set of initial setup data regarding the renovation jobs (duration, persons employed, related disruption, job's precedence) from the TEA tool and input data regarding the user preferences and constraints (availability of workers, available funding on a weekly/monthly basis) from the tool's Graphical User Interface. Secondly, the complexity of the input data (i.e. renovation scenario) is assessed and the most suitable algorithm among the four developed algorithms is selected by the user, namely i) Integer Linear Programming techniques (exact method), ii) Priority Rules (heuristic method), iii) Genetic Algorithms (meta-heuristic method) or iv) a hybrid method combining Priority Rules and Integer Linear Programming which exploits the low execution times of the former and the optimal scheduling of the latter method. The best-fit algorithm selection depends on the number and size of the input jobs and the availability of the input data. Finally, the optimal sequence of jobs is produced. In more detail, the output states the specific date that a job will start its processing and which of the following days it will be processed until it is completed. Moreover, general statistics for the whole project, such as the total duration, cost and level of disruption, are included in the output. The output of the tool may be stored into its database and be available to the Renovation Manager for proceeding with the renovation or in the case of the RINNO project forwarded to an external source, i.e. additional planning tools applied during the construction stage. The process followed is presented in Figure 4.

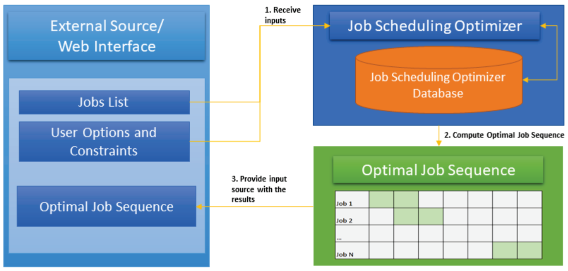

*Figure 4: Job Scheduling Optimiser operating flow*

### Tools Integration

The software tools developed may be used individually to assess the various performance aspects of a renovation. However, in order for a user to be able to conduct the holistic analysis of a building and benefit from the RINNO approach of informed decision-making, the assessment and communication of all tools is required. The integration of the tools follows the structure in Figure 5. It can be seen that there are various interconnections taking place to perform, namely:

- **INTEMA.building to VERIFY**. Having conducted the energy analysis of a scenario, the INTEMA tool gathers: 1) the details of scenarios description 2) the energy timeseries data, and 3) the energy key performance indicators computed. The outcomes are packed into a single JSON file, before they are sent to the VERIFY platform and parsed.
- **VERIFY to TEA tool.** VERIFY is responsible for distributing the crucial information gathered. A subset of the data (description of scenarios) is sent to TEA tool, assisting the user disruption and waste management computations.

The above steps conclude the flow of information between the tools of the RINNO Simulation and Assessment Toolbox for the analysis of the alternative scenarios. Next, the information is fed to the RINNO Optimiser and Planner for the selection of the optimum scenario and optimum workflow. For this, the following interconnections are required.

- **VERIFY to Renovation Scenario DSS**. VERIFY gathers i) the energy related indicators collected from the INTEMA.building along with the calculated ii) environmental and iii) costing indicators and parses and forwards them to the Renovation Scenario DSS in JSON format.
- **TEA tool to Renovation Scenario DSS.** The DSS tool is responsible for acquiring and parsing the TEA tool analysis outcomes (user disruption and waste management indicators) packed in a JSON file. Following this and the previous step, the Renovation Scenario DSS has gathered all inputs required for the selection of the scenario with the optimum performance. Furthermore, the DSS also gathers a set of specifications for the renovation jobs. These are fed to the JSO for conducting the workflow optimisation.
- **Renovation Scenario DSS and the Job Scheduling Optimiser.** The DSS tool performs its own analysis and forwards the final outcome to the JSO tool, under a single JSON file. This includes the ID of the selected scenario, the relevant description and the renovation jobs specifications which are used by the JSO for the optimisation of the workflow.

The JSON format selected is a widely accepted universal standard for web applications; it is also flexible allowing the update of information throughout the step process from the followed where each tool may add/amend information before communicating it to the next one (Tyson, 2022).

## Simulation

In this section, an example of the RINNO solution applied on the assessment of potential renovation scenarios of an energy inefficient building is presented. The building is a multi-residential block of flats located in Athens and is one of the four demo buildings of the RINNO project. The building comprises eight flats spanning in four floors (two flats in each floor) and has a total floor area of approximately 700 m$^2$ including the common areas. The building also has an unheated basement throughout the whole floor plan. The building construction is concrete frame with brick infill walls with no insulation, whilst the windows are either old single or double glazed windows with aluminium or wooden frame (depending on the flat). Each flat has their own heating/cooling system; most flats

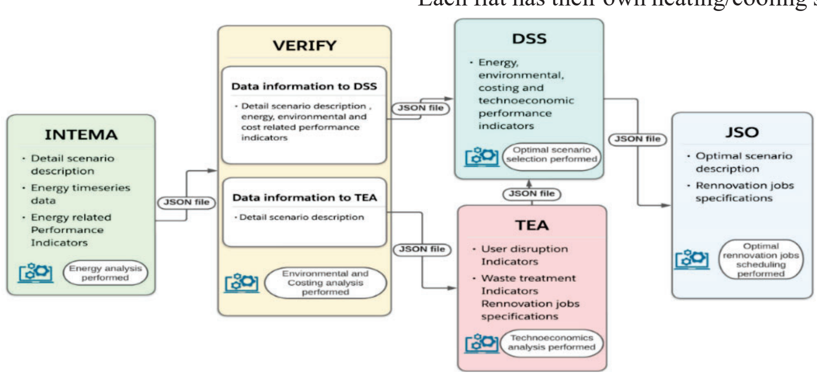

*Figure 5: Interconnections of the RINNO tools for seamless flow of information*

have old AC units, one flat has a heating oil boiler and one has a natural gas boiler. A view of the building is provided in Figure 6.

*Figure 6: External view of the examined building*

Within the context of the RINNO project, several potential renovation scenarios aiming at improving the building's energy performance and improving the thermal comfort and well-being of the occupants were examined. For reasons of space economy, the comparison of two scenarios is presented in this work. Scenario 1 aimed at insulating the building envelope (walls and roof) replacing the inefficient windows with new energy efficient ones, replacing all existing heating and cooling systems with highly efficient Air Source Heat Pumps (AC units) and installing PV system on the roof and part of the building's façade. Scenario 3 considers additional measures to those of Scenario 1; the ceiling of the unheated basement is also insulated for further reducing the heat losses through the envelope, installing mechanical ventilation systems with heat recovery (MVHR) in the flats to reduce ventilation losses and installing solar collectors on the roof for the production of thermal energy through RES. Details of the two scenarios examined are presented in Table 1.

*Table 1:Summary of potential renovation scenarios examined*

| | Scenario 1 | Scenario 3 |
|---|---|---|
| External Wall insulation | EPS 12 cm // U-value 0.25 W/m²K | PUR 8 cm // U-value 0.29 W/m²K |
| Roof insulation | EPS 20 cm//U-value 0.20 W/m²K | EPS 20 cm//U-value 0.20 W/m²K |
| Basement Ceiling insulation | - | EPS 3 cm//U-value 0.83 W/m²K |
| Windows replacement | Triple glazed + thermochromic | Triple glazed + thermochromic |
| Heating/ Cooling system | Decentralized Air Source Heat Pumps | Decentralized Air Source Heat Pumps |
| Ventilation system | - | Decentralized MVHR |
| RES electricity | PV panels on the roof (19kW)// Façade BIPV panels (0.7 kW) | PV panels on the roof (20kW) // Façade BIPV panels (0.7 kW) |
| RES thermal | - | Solar thermal collectors (16 m²) with storage tanks |
| Other | - | Replacement of existing lights with LED ones |

The analysis of the scenarios was conducted with the use of the tools of the RINNO simulation and assessment toolbox and the calculated values for the indicators are presented in Table 2. Based on these results the best scenario according to the preferences of the renovation manager was found to be Scenario 3 with a score of 92.5 against 75.5 for scenario 1 (Figure 7).

*Table 2:Results of the analysis*

| **Indicator** | **Sc. 1** | **Sc. 3** |
|---|---|---|
| **Environmental indicators** | | |
| Yearly Lifecycle Life Cycle Global Warming Potential savings ($KgCO_2$/year) | 50,032 | 71,696 |
| Yearly embodied energy (kWh/year) | 38,941 | 46,448 |
| Average daily project waste ($dm^3$) | 81.3 | 79.4 |
| Overall project waste ($dm^3$) | 41,700 | 44,948 |
| Yearly Energy Self-Supply by RES (%) | 34 | 42 |
| **Energy Indicators** | | |
| Yearly Primary energy savings – PES (kWh/year) | 258,896 | 369,699 |
| Decrease in Energy Consumption (%) | 56.80 | 84.60 |
| Savings in Primary Energy consumption for heating (%) | 90.50 | 96.30 |
| Savings in Primary Energy consumption for cooling (%) | 76.60 | 93.60 |
| Savings in Primary Energy consumption for DHW (%) | 0 | 79.80 |
| Increase in RES based electricity production (kWh) | 24,755 | 22,918 |
| Increase in RES based heating production (kWh) | 0 | 4,048 |
| **Cost and Financial indicators** | | |
| Return on Investment (%) | 228 | 292 |
| Payback period (years) | 7.83 | 6.58 |
| Yearly Lifecycle Cost Savings (€/year) | 18,555 | 27,102 |
| Initial Investment (CAPEX) (€) | 118,709 | 145,002 |
| Annual O&M Costs (€/year) | 11,322 | 3,940 |
| **User disruption indicators** | | |
| Average Utilities Daily Disruption | 0.003 | 0.014 |
| Average Utilities Project Disruption | 0.003 | 0.014 |
| Average Traffic Daily Disruption | 0.029 | 0.0265 |
| Average Traffic Project Disruption | 0.029 | 0.0265 |
| Average Physical space Daily Disruption | 0.161 | 0.181 |
| Average Physical space Project Disruption | 0.161 | 0.181 |
| Average Internal Environment Daily Disruption | 1.829 | 1.814 |
| Average Internal Environment Project Disruption | 1.829 | 1.814 |
| Project duration (days) | 513 | 566 |

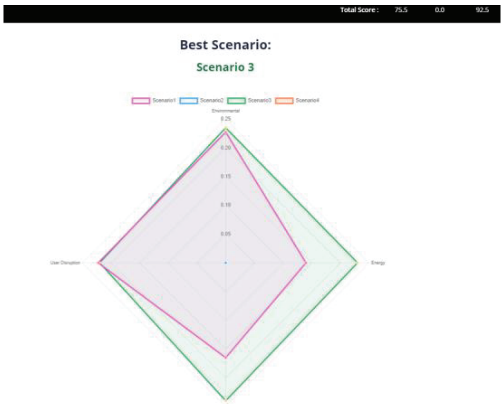


*Figure 7: Scenario selection by the DSS*

Furthermore, the work planning of the selected scenario was optimised with the use of the JSO, using the Genetic Algorithm, which was considered as the most suitable method since the complexity of the problem discourages the direct or indirect (within Hybrid method) use of the Integer Linear Programming algorithm (due to long execution time) and Priority Rules is a weaker method. The basic renovation actions of scenario 3 were considered and a simulation was conducted considering as a variable the number of available workers and two cases were examined; in the first case only four workers were available to undertake the renovation whist in the second case ten workers were available. The latter allowed more jobs to be done simultaneously and reduced the overall time from 343 days to 132 days (Figure 8).

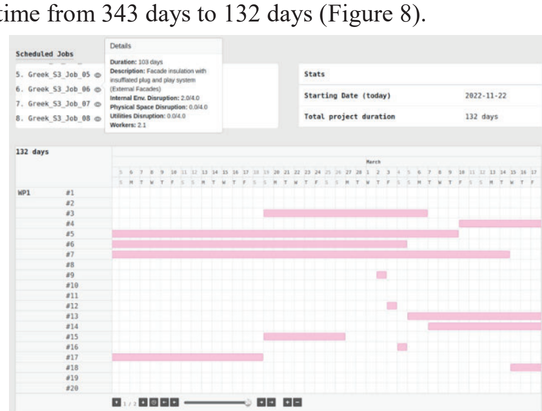


*Figure 8: Optimised work schedule for Scenario 3 when ten workers are available to carry out the work*

## Discussion

In the case examined, Scenario 3 performed better (i.e. achieving the highest score between the alternatives) in the ‘Energy’ and ‘Cost and Financial’ categories and marginally better in the ‘Environmental’ category. Scenario 1 was found to have marginally better performance in the ‘User Disruption’ category. It should be noted that in this case all categories were selected to have equal weights, although the user does have the option to consider certain categories as more important than others and apply different weights. Furthermore, all indicators were considered in the analysis. In a different situation, the user could opt to remove certain indicators from the selection process.

The examined case highlights the benefits of the holistic nature of the assessment as opposed to a decision based only on a few indicators. Palm and Reindl (2018) suggested that often potential investments in renovation projects are dismissed due to the initial cost of a project. Such approach could lead to the selection of Scenario 1 in this example which has the lowest capital cost, ignoring the fact that through a lifecycle perspective Scenario 3 has higher yearly cost savings compared to the baseline (€27,102/year compared to €18,555/year for Scenario 1) and lower payback period (6.58 years against 7.83 years for scenario 1) due to the lower operation and maintenance costs. Scenario 3 also leads to increased primary energy savings and global warming potential savings throughout its lifecycle. It should be noted that these are achieved without significant increase in the expected disturbance of the user.

It is therefore demonstrated that the RINNO approach towards the design and planning of renovation has the potential to lead to an increase in deep energy renovations recommending those alternatives with the greater impact overall. In addition, the Job Scheduling Optimiser allows for optimising the sequence of works and therefore reducing further the duration of the project making it more attractive to the occupants and tackling any potential hesitations through increased transparency of the renovation process.

## Conclusions

The development of a set of tools designed for the multi-criteria assessment of building renovation at the design stage as part of the H2020 RINNO project has been presented in this work. When used collectively, they offer the potential of a holistic assessment of the building’s performance and enable the user (renovation manager, building owner, occupant etc.) to make an informed decision based on their requirements. For this reason, the integration strategy of the various software was also presented.

Such approach has the potential to tackle many of the barriers faced by the renovation industry and lead to the uptake of renovation rates. The case study presented, highlighted the potential to promote measures with greater benefits to the user and the environment throughout the building’s lifecycle. Finally, the optimisation of the renovation workflow makes the whole process more attractive to the building occupants and has the potential to further change the negative attitudes towards renovation.

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