



RINNO PROJECT

Report

Transforming energy efficiency in
European building stock through
technology-enabled deep energy
renovation

Deliverable D6.2: Pilot Planning and Setup
Work Package 6

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Executive Summary

This report describes the detailed planning of the demonstration activities in the 4 demo sites, located in France, Greece, Poland and Denmark. The planning is based on the results of survey and development of renovation scenarios in WP1, the development of innovative renovation technologies in WP2, the development of IT tools – the Decision Support System (DSS) in WP3 and WP4.

The report finalizes the activities concerning the scheduling for each demo that includes the following, main steps:

- i) Developing the BIM-based simulation scenarios and deciding on the optimal solution for each pilot building
- ii) Developing the innovative technologies
- iii) Analysis of the renovation scenarios
- iv) Agreement with building owners on the renovation scenarios
- v) Appointing advisors
- vi) Budget for implementing the renovation scenarios
- vii) Tender for selection of retrofitting contractor and subcontractors
- viii) Agreement between buildings owners, advisors, and entrepreneurs on the detailed planning
- ix) Scheduling of the renovation scenario
- x) Obtaining required licenses
- xi) Bill of Quantities
- xii) Material/Product orders
- xiii) Site preparation
- xiv) Delivery of material/products
- xv) Training of workers
- xvi) Retrofitting (deployment/installation)
- xvii) Monitoring

Partners participating:

EGC, RINA-C, CERTH, CIRCE, EKOLAB, FOB, UNN, BOUYGUES, K-FLEX, VTT, GREENSTRUCT, HPHI, NAPE, PINK, MOTIVIAN

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Abbreviations List

DHW	Domestic Hot Water
DSS	Decision Support System
EC	European Commission
GA	General Assembly
GA	Grant Agreement
KPI	Key Performance Indicators
LCA	Life Cycle Assessment
LCC	Life Cycle Costs
O&M	Operation & Maintenance
PES	Primary Energy Savings
RPDA	RINNO Planning & Design Assistant

1 Introduction

1.1 Scope and objectives of D6.2

WP6 focuses on the integration of the RINNO development activities in four building renovation sites in France, Greece, Poland and Denmark, the organisation and execution of the large-scale demonstrations.

The objectives of D6.2 are to describe the implementation of the RINNO Suite under real conditions at the four demo sites, later to be able to evaluate the RINNO offered solutions, the process, and to prepare a Replicability Analysis based on the evaluation findings.

The D6.2 is a preliminary report, and it will be delivered in M30 – with a delay of six months. D6.3 is the final report with the results of the implementation and evaluation of the building renovations.

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1.2 Relation to other tasks and deliverables

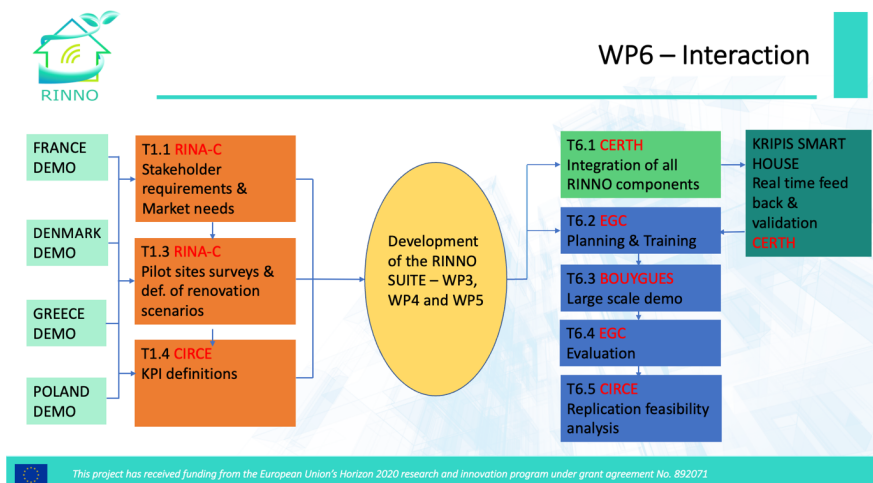


Figure 1 - WP6 interaction

The four demo sites have provided information on stakeholder requirements for T1.1 and pilot sites surveys for T1.3 to enable the definition of renovation scenarios. Furthermore, the demo sites have contributed with monitoring equipment and information on energy use in the buildings. Finally, BIM models have been developed for all four demo sites.

The information from the demo sites has also been used in the development of the RINNO Suite in WP3, WP4 and WP5 and for the analysis of the scenarios.

1.3 Structure of the deliverable

The deliverable aims to give a presentation of the process as experienced from the demo sites.

It is important to note that the innovation and implementation process in the RINNO project is a dynamic and interactive process. Purpose is to test the different elements in the RINNO Suite and eliminate barriers and obstacles in the process to pave the way for replication. But it also means that the process not always is straight and direct, and there has been delays and exchanges of demo sites along the way. This is described in part 4, Deviations from the Grant Agreement.

The illustrated description of the four demo sites in part 2 is a short introduction to the main characteristics of each demo site including who are the main stakeholders and an overview of the renovation scenarios that have been considered and chosen in the buildings.

Part 3 informs on the innovative technologies that are to be implemented at the demo sites. The demo leaders have calculated the amount of RINNO technologies that they will need, based on the chosen renovation scenario (surface, thickness of insulation etc.). Based on this calculation, an estimation of the costs related to the installation of the RINNO technologies has been performed, and the different technologies have been allocated to the demo sites.

As mentioned above, the deviations from the Grant Agreement are described in part 4.

In part 5, a scenario per demo has then been selected for the simulation phase with WP3 tools. This is a deviation from the initial plan to recuperate the delay accumulated during the last months.

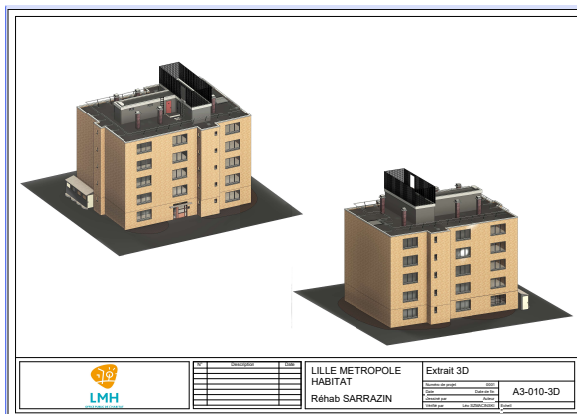
The analysis of the selected scenarios and the selected technologies are performed to support the choices and document the energy savings, the Life Cycle Costs, and the techno-economic analysis (user disruption and waste management) for the demo sites.

Finally, the time plans for each demo site are described in part 6.

2 The four demosites' main characteristics

2.1 The French demosite

The Sarrazin building is constructed in 1976 and has an area of 1.118 m², 29 flats on 4 floors and located in the city center of Lille. The exterior walls are in bricks without insulation, the windows are made of PVC without good thermal performances, rooftop is insulated, and there is a collective gas heating system, but individual hot water production by electric water tankers. There is no ventilation system in the building.



The Sarrazin building from 1979 in Lille, France

2.1.1 Stakeholders

The building owner is Lille Métropole Habitat (wealth management, rental management, etc.). There are 29 tenants. Other stakeholders are the municipality in Lille, ABF (Architect of French Building), maintenance operators, financiers.

2.1.2 Renovation scenarios

The renovation scenarios with the selected implementation of RINNO technologies considered for the French demo (from D1.5):

RINNO technologies	SC1	SC3
Bio-based double layer panels (K-FLEX)		
Bio-based pipes and sheets (K-FLEX)	1	1
Isocell Cellulose Insulation (EKOLAB)		
Thermochromic glass (GREENSTRUCT)		

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RINNO technologies	SC1	SC3
Zappa PV -Roof and -Facade solutions (EKOLAB)		
MicroVent sustainable Ventilation system (EKOLAB)		1
K-BOX bio-based insulating system for parts of energy systems (KFLEX)	1	1
Building integrated photovoltaic panels (GREENSTRUCT)		
De-centralized domestic hot water solution (PINK)		
Total of implemented RINNO technologies	2	3

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A total of four technologies are planned to be integrated in the renovation according to the chosen renovation scenario 3. The renovation will also include renovation of the climate screen incl. insulation exteriors walls, exchange of windows and doors.

Gas boiler will be replaced with heat pumps for heating and domestic hot water production.

The chosen French Scenario 3 aims to improve the building envelope. The envelope is enhanced in order to minimize thermal losses and so to reduce energy needs. See also 5.2.1

2.2 The Greek demosite

The Greek demo site is a multifamily building with 8 apartments, located in Athens and more specifically in the suburb Moschato-Tavros.

The building is a block of 4 floors with 2 flats per floor, each of 75sqm, with a concrete frame structure and hollow brick infill, built in 1970 in the context of a large social housing complex. It was built without any measures to reduce energy consumption, neither for heating nor for cooling. It has a shell with low thermal resistance and low inertia, thus inadequate to guarantee the necessary thermal phase shifting and attenuation during the summer season. The windows are provided with aluminum frames, without thermal break, and single glazing, while the external shutters are sliding blinds or rolling shutters, which do not allow the light to be adjusted according to the sunlight at different times of the day.



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2.2.1 Stakeholders

Building owner, tenants, financial stakeholders (crowdfunding and other financing support).

2.2.2 Renovation scenarios

The renovation scenarios (SC) with the selected implementation of RINNO technologies considered for the Greek demo (from D1.5):

RINNO technologies	SC1	SC3
Bio-based double layer panels (K-FLEX)		1
Bio-based pipes and sheets (K-FLEX)		
Isocell Cellulose Insulation (EKOLAB)		
Thermochromic glass (GREENSTRUCT)	1	1
Zappa PV -Roof and -Facade solutions (EKOLAB)		
MicroVent sustainable Ventilation system (EKOLAB)		
K-BOX bio-based insulating system for parts of energy systems (KFLEX)		
Building integrated photovoltaic panels (GREENSTRUCT)	1	1
De-centralized domestic hot water solution (PINK)		

RINNO technologies	SC1	SC3
Total of implemented RINNO technologies	2	3

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A total of three technologies is planned to be integrated in the renovation according to renovation scenario 3.

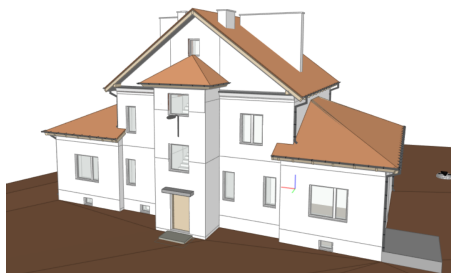
Else the renovation involves insulation, exchange of windows and doors, PV installation – targeting to reach passive house standard.

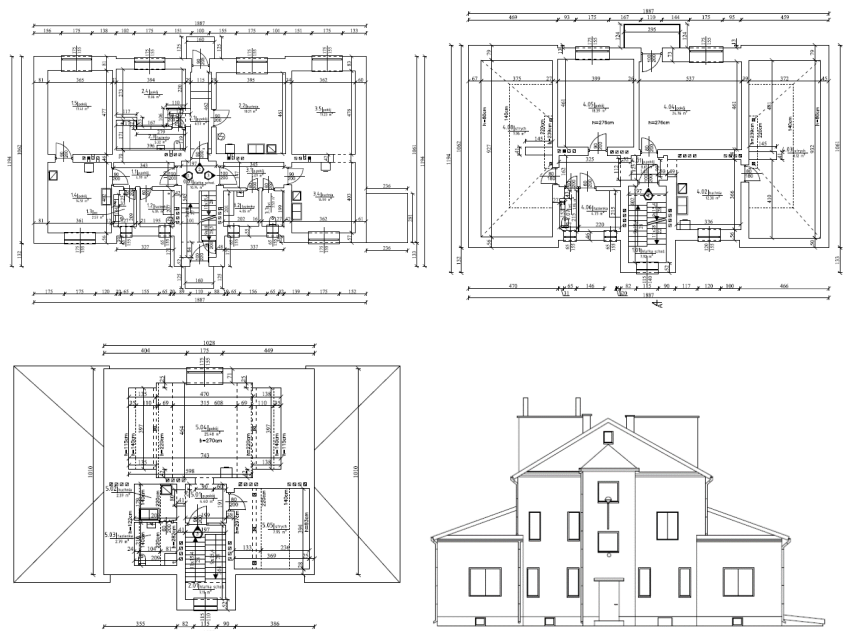
The **Greek scenario 3** aims to improve the building envelope and use highly efficient energy systems. Moreover, it includes an important retrofitting of the existing equipment, and it aims to produce net electricity for the grid (positive building). The envelope is enhanced in order to minimize thermal losses and so to reduce energy needs. See also 5.2.1.

2.3 The Polish demosite

The Polish demo site is located in Rajszew - a suburban village located near Warsaw on the right bank of the Vistula River. This four-story, multi-family building was erected in 1949. It consists of five apartments with a total area of 258 m². It also has a partial basement. The building was never fully renovated. Exterior walls of varying thickness are made of solid brick masonry without insulation, finished with cement-lime plaster. Roof is in wooden construction covered with tile. The building has PVC framed windows. In the apartments and in the staircase the windows were replaced about 20 years ago. The wooden exterior doors need to be replaced.

Each of the five apartments in the building is equipped with its own installation of heating and hot water preparation system. In each case, the heat source is a condensing gas boiler feeding a water system with panel radiators (gas boilers replaced coal and wood boilers and stoves in 2021). The building uses a gravity ventilation system.





2.3.1 Stakeholders

Commune Jablonna, tenants

2.3.2 Renovation scenarios

RINNO technologies	SC4	SC2	SC3
Bio-based double layer panels (K-FLEX)	1	1	1
Bio-based pipes and sheets (K-FLEX)	1	1	1
Isocell Cellulose Insulation (EKOLAB)	1	1	1
Thermochromic glass (GREENSTRUCT)			
Zappa PV -Roof and -Facade solutions (EKOLAB)	1	1	1
MicroVent sustainable Ventilation system (EKOLAB)			
K-BOX bio-based insulating system for parts of energy systems (KFLEX)			
Building integrated photovoltaic panels (GREENSTRUCT)			
De-centralized domestic hot water solution			

(PINK)			
Total of implemented RINNO technologies	4	4	4

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The planned renovation measures in the chosen scenario 2 involve – apart from the RINNO technologies:

- Thermal insulation of external walls
- Insulating ceilings under an unheated attic
- Insulating the ceiling over an unheated basement
- Replacement of windows with new ones along with the installation of window ventilators
- Replacement of external doors
- Installation of a photovoltaic system on the roof of the building and partially on the south façade

The **Polish Scenario 2** aims to improve both the building envelope and also to use of highly efficient energy systems. The envelope is enhanced in order to minimize thermal losses and so to reduce energy needs. See also 5.3.1.

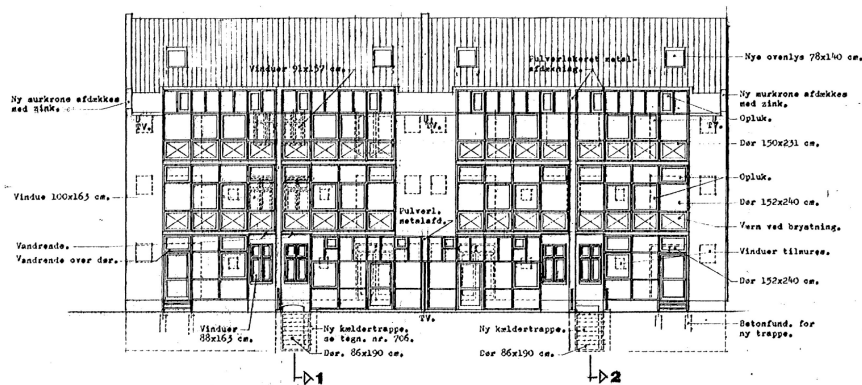
2.4 The Danish demosite

The Danish demo site is from 1913, located in the centre of Slagelse – a middle size city, about a 100 km from Copenhagen. The building is situated very close to the railway station. It was renovated in 1988 – among other things with a new, wooden façade. The façade as well as the windows are in deep need of being renovated. The ventilation system is 35 years old, but still functioning.

The gable to the south is provided with solar collectors that doesn't work and must be exchanged or removed. The gable must be insulated.



The façade construction to the West – build in 1988 – very deteriorated, and the solar collectors on the gable is not functioning.



2.4.1 Stakeholders

Involved stakeholders are the building owner FOB, a social housing company, tenants, consultants – architect and engineer – and Slagelse municipality as local authority.

2.4.2 Renovation scenarios

RINNO technologies	SC1	SC2
Bio-based double layer panels (K-FLEX)		
Bio-based pipes and sheets (K-FLEX)	1	1
Isocell Cellulose Insulation (EKOLAB)		1
Thermochromic glass (GREENSTRUCT)		
Zappa PV -Roof and -Facade solutions (EKOLAB)	1	1
MicroVent sustainable Ventilation system (EKOLAB)	1	1
K-BOX bio-based insulating system for parts of energy systems (KFLEX)	1	1
Building integrated photovoltaic panels (GREENSTRUCT)		
De-centralized domestic hot water solution (PINK)		
Total of implemented RINNO technologies	4	5

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Total renovation of the climate screen is planned - incl. new windows and doors.

The chosen scenario 2 also involves PINK water heater – possibilities for installation are

under investigation.

The Danish **Scenario 2** aims to improve both the building envelope and the use of highly efficient energy systems. The envelope is enhanced to minimize thermal losses and to reduce energy needs. See also 5.4.1.

3 Allocation of the RINNO technologies

3.1 Short presentation of the technologies



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EKOLAB:

- InVentilate – micro ventilation
- ZAPPA – façade elements with PV
- IsoCell – paper based inculation

BOUYGUES:

- Technologies for production – drones will be used in the French demo

K-FLEX:

- K-FLEX Bio-based pipes and sheets
- K-BOX bio-based insulating system for parts of energy systems
- K-FLEX Bio-based double layer panels

GREENSTRUCT:

- Building integrated PV Glass
- Thermochromic glass

PINK:

- De-centralized domestic hot water solution

3.2 Allocation of technologies and budgets

The demo leaders calculated - based on the chosen renovation scenarios – the quantities needed for each of the RINNO Technologies:

Bill of quantities * based on the chosen renovation scenario	Bio-based double layer panels (K-FLEX)		Bio-based pipes and sheets (K-FLEX)		K-BOX bio-based insulation (KFLEX)	Isocell Cellulose Insulation (EKOLAB)		Zappa PV - Roof and - Facade solutions (EKOLAB)	Micro Vent system (EKOLAB)	Building integrated PV glass (GREEN-STRUCT)	Thermo-chromic glass (GREEN-STRUCT)	De-centralized domestic hot water solution (PINK)
	Square meters of needed material (m2)	Thickness (mm)	Linear meters needed (m)	Thickness (cm)	Number of needed units	Square meters of needed material (m2)	Thickness (cm)	Square meters of needed material (m2)	Number of needed units	Square meters of needed material (m2)	Square meters of needed material (m2)	Number of units
Greek demosite	572	80								12,24	34,6	
French demosite			300		30				16			
Polish demosite	58,5	80	25		0	198	25	20				
Danish demosite			100		15	252	10	70	96	12		1-6

Figure 2 - RINNO technologies - quantities

Based on the calculated quantities, the foreseen budget from the Grant Agreement could be allocated to the four demo sites. Anyway, it was necessary to discuss a model for the allocation, as the budget wasn't big enough to cover all the expenses. Four models were developed - with different principles for the allocation:

Model 1:

In model 1, the overall available budget for the technology provider is distributed after the number of m2 in the four demos.

Model 2:

Model 2 gives an equal share of the available budget to the demos, independent of needs and m2.

Model 3:

Model 3 cover the expenses for the demos by 75 %, which is then the same percentage for all demo sites.

Model 4:

Only the Danish demo site is not 100% covered, but it is also the most expensive.

After a discussion and a vote between the demo sites, unexpectedly, model 4 was chosen. But it has been accepted by the Danish Building owner. See the overview below:

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Demos	Total refurbished volume (m3)	Overall cost for installation of RINNO technologies [€]	Overall available budget from RINNO project [€]	Model 1 - Overall available budget from technology provider after m2	Model 2 - Equal share	Model 3 - Not 100% covered expenses - "fair" scenario?	Model 4 - only DK is not 100% covered, but also most expensive
Greek demosite	2294,00 m2	37.689,52 €	26.300,00 €	41.911,69 €	32625,00	28.190,11 €	37.689,52 €

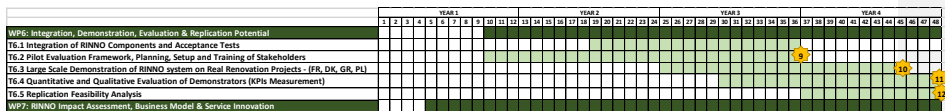
Demos	Total refurbished volume (m3)	Overall cost for installation of RINNO technologies [€]	Overall available budget from RINNO project [€]	Model 1 - Overall available budget from technology provider after m2	Model 2 - Equal share	Model 3 - Not 100% covered expenses - "fair" scenario?	Model 4 - only DK is not 100% covered, but also most expensive
French demosite	4664,00 m2	18.799,23 €	43.000,00 €	37.881,71 €	32625,00	14.061,00 €	18.799,23 €
Polish demosite	922,00 m2	17.580,19 €	50.500,00 €	7.488,62 €	32625,00	13.149,21 €	17.580,19 €
Danish demosite	2243,00 m2	100.406,51 €	118.300,00 €	43.217,98 €	32625,00	75.099,67 €	56.431,06 €
		174.475,45 €	130.500,00 €	130.500,00 €	130.500,00 €	130.500,00 €	130.500,00 €

Figure 3 - Allocation of budget for technologies

4 Deviation from the Grant Agreement

4.1 Updated Schedule

The general schedule for WP6 in the Grant Agreement is as follows:



Large scale demonstration should start M 25, which was in June 2022. We are p.t. about 6 months delayed.

The deadlines for implementation of retrofitting have been revised to regain some of the delay. According to the plan, it is expected that the demonstration projects can be finished by December 2023 / January 2024. The revised plan – worst case scenario - is as follows:

No	list of tasks	Deadline
T1	Finalisation of monitoring equipment installation and data retrieval	Done
T2	Selection of the Renovation Scenario to be executed	Done
T3	Appointing Design Office	Dec.'22
T4	Finishing detailing of project	Mar.'23
T5	Appointing Contractor and sub-contractors	Mar.'23
T6	Bill of Quantities / order of materials	Apr.'23
T7	Optaining required licenses	May.'23
T8	Delivery of Materials/Products	Jun.'23
T9	Preparation of site	Jun.'23
T10	Start works	Jul.'23
T11	Completion of Retrofit	Jan.'24

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4.2 M24 GA meeting – scenario definition alternative route

To speed up the choosing of the best renovation scenario in order to be able to distribute the technologies across cases, and because else it was not possible to implement the renovation within the time frame of RINNO, the following approach, described in this section, was then agreed by all demo leaders and CERTH:

- One scenario per demo was selected to start the simulation phase with WP3 tools (this is a deviation from the initial plan to recuperate the delay accumulated during the last months).
- In a parallel streamline, the Demo leaders calculated the amount of RINNO technologies that they needed, based on the chosen renovation scenario (surface, thickness of insulation etc.).
- Technology providers provided a revision of cost of raw materials to estimate the overall budget for each demo.
- Based on the calculation, an estimation of the costs related to the installation of

- RINNO technologies was performed.
- v) The budget was split between the demo sites according to model 4 (see above).
 - vi) Detailed planning was started for all demo sites.

Final renovation scenarios were defined by all demo leaders with the help of CERTH and RINA in order also to distribute the RINNO solutions in a homogeneous way (see also above – 2.1 to 2.4):

- i) Greek demo: Scenario 3
- ii) Polish demo: Scenario 2
- iii) French demo: Scenario 3
- iv) Danish Demo Scenario 2

4.3 Demonstration of the RINNO technologies

It was envisaged that each RINNO technology would be demonstrated in at least two demo projects. However, this was not always possible. There are three of the RINNO technologies, which are only demonstrated in 1 demo. These are:

- Thermochromic glass (GREENSTRUCT)
- Building integrated photovoltaic glass (GREENSTRUCT)
- De-centralized domestic hot water solution (PINK)

The GREENSTRUCT technologies are only used in Greece, because the solutions are targeted to the climate area of Greece – e.g. closing out (too much) sun light and PV integrated window glasses that also gives shadow.

The use of PINK technology was excluded in Poland, as the demosite had a newly installed hot water system. In France, PINK technology has been challenged due to local regulations, which – among other things - prevent installation of individual solutions for hot water. P.t. it is being investigated, if PINK hot water solution can be implemented in Denmark. To do so, it is necessary to find a Danish software company, which will cooperate with PINK on the implementation in Denmark.

Kommenterede [AA11]: Add a justification based on savings and cost for the implementation. This justification is too short

5 The scenarios for optimizing

In the following, the holistic assessment of alternative renovation scenarios for the four demo sites with the use of the RINNO Planning and Design Assistant are presented. The scenarios are assessed in terms of energy performance, environmental and lifecycle cost performance as well as user disruption and construction waste management and the selection of the optimum scenario is presented according to the preferences of the user.

The process for the selection of the scenarios to be analysed in the demos for the purposes of RINNO is described above in chapter 4 Deviations from the GA. These scenarios were reported in Deliverable D1.5 - RINNO Pilot Analysis and Deployment Plan (Final Version).

The multicriteria analysis involved the following steps: i) the detailed energy analysis of these scenarios with the use of the INTEMA.building tool (T3.3.1) was conducted ii) the LCA and LCC analysis were conducted with the use of the VERIFY tool (T3.3.2). iii) the user disruption and the construction waste produced from each scenario was determined with the use of the TEA tool (T3.3.3). The evaluation of the scenarios at each stage was expressed through suitable indicators. These indicators were then fed to the Decision Support System (DSS) of the RINNO Optimiser and Planner (T3.4) to select the best scenario.

In the following paragraphs the results of this analysis are presented for all four demo sites.

5.1 Selected scenarios for the French demo site

The two scenarios presented in Section 2.1.2 (Scenario 1 and Scenario 3) were analysed by the tools of the RINNO Simulation and Assessment Toolbox (T3.3). The selection of the optimum renovation scenario was conducted from the Renovation Scenario DSS (T3.4). The description of these scenarios and the results of the analysis are presented in the following paragraphs.

5.1.1 Description of the French Demo Renovation Scenarios

5.1.1.1 Scenario 1

French Scenario 1 aims to improve both the building envelope and also to use of highly efficient energy systems. The envelope is enhanced in order to minimize thermal losses and so to reduce energy needs. Below, the retrofitting interventions of the building are listed:

A) Adding Insulation mineral insulation

Goal: Reduce the thermal losses, reduce the U-value, reduce the absorbance of solar irradiation.

External walls: Addition of 20 cm insulation with $k=0.035 \text{ W/mK}$; the new U-value is $0.18 \text{ W/m}^2\text{K}$.

B) Windows and doors replacement

Goal: Reduce the thermal losses, reduce the infiltration rate and manage properly the solar irradiation.

Use of advanced double windows. Window with total U-value=1.4 W/m²K (75% glass and 25% frame) and g-value=0.7. The airtightness of the envelope (infiltration - N50 = 5 ACH) will be reduced from 0.4 air changes per hour to 0.25 air changes per hour (infiltration).

C) Piping insulation (K-FLEX)

Goal: Reduction of the distribution of thermal losses.

Use of Bio-based pipes insulation and K-BOX units to insulate the pipe network and vanes with low thermal conductivity of 0.038 W/mK.

D) Central Mechanical Ventilation system

Goal: Providing the proper fresh air

A new central single flow hygro adjustable ventilation system will be installed in all (29) flats of the building.

E) Electrical air-to-water heat pump

Goal: Cover the heating and DHW needs with an efficient energy system.

Two highly efficient electric heat pumps (PAC 2xHRC70) with 60 kW capacity are used. These heat pumps produce space heating at a temperature level close to 40°C and DHW at a temperature level close to 60°C.

F) Centralized double coil heat storage tank

Goal: Store the hot water from the heat pump in a proper storage device.

Use of an insulated storage tank with two coil heat exchangers with a total volume of 1 m³ for covering the space heating and the DHW needs.

G) Installation of PV panels

Goal: Electricity production from solar irradiation in order to cover all the possible needs and be positive.

Installation of around 40 m² of highly efficient PV panels on the roof. These panels will be located with a slope of around 10° and 75% will be in the southwest direction, while the other 25% to the northeast direction. Every panel has an area of 1.92 m², maximum power of around 400 W and maximum efficiency of 20.8%¹.

H) Installation of motion detector for the lighting in the common spaces

Goal: Reduction of the electricity demand in the common spaces

A typical motion detector is selected which reduces the electricity demand by around 40%. This detector regards the common spaces with an area of around 157 m².

5.1.1.2 Scenario 3

French Scenario 3 aims to improve both the building envelope and also to use of highly efficient energy systems. The envelope is enhanced in order to minimize thermal losses and so to reduce energy needs. Below, the retrofitting interventions of the building are listed:

A) Adding Insulation mineral insulation

Goal: Reduce the thermal losses, reduce the U-value, reduce the absorbance of solar irradiation.

External walls: Addition of 20 cm insulation with $k=0.035 \text{ W/mK}$; the new U-value is $0.18 \text{ W/m}^2\text{K}$.

B) Windows and doors replacement

Goal: Reduce the thermal losses, reduce the infiltration rate and manage properly the solar irradiation.

Use of advanced double windows. Window with total U-value= $1.4 \text{ W/m}^2\text{K}$ (75% glass and 25% frame) and g-value= 0.7 . The airtightness of the envelope (infiltration - N50 = 5 ACH) will be reduced from 0.4 air changes per hour to 0.25 air changes per hour (infiltration).

C) Piping and vanes insulation

Goal: Reduction of the distribution of thermal losses.

Use of Bio-based pipes insulation and K-BOX units to insulate the pipe network and vanes with low thermal conductivity of 0.038 W/mK .

D) Decentralized Mechanical Ventilation with heat recovery (EKOLAB)

Goal: Provide the proper fresh air by reducing the load due to the use of heat recovery.

Addition of the proper mechanical ventilation systems in every apartment.

- 8 apartments will use the Microvent decentralized heat recovery system,
- 21 apartments will use a new central single flow hygro adjustable ventilation system

E) Electrical air-to-water heat pump

Goal: Cover the heating and DHW needs with an efficient energy system.

Two highly efficient electric heat pumps (PAC 2xHRC70) with 60 kW capacity are used. These heat pumps produce space heating at a temperature level close to 40°C and DHW at a temperature level close to 60°C .

F) Centralized double coil heat storage tank

Goal: Store the hot water from the heat pump in a proper storage device.

Use of an insulated storage tank with two coil heat exchangers with a total volume of 1 m^3 for covering the space heating and the DHW needs.

G) Installation of PV panels

Goal: Electricity production from solar irradiation in order to cover all the possible needs and be positive.

Installation of around 40 m^2 of highly efficient PV panels on the roof. These panels will be located with a slope of around 10° and 75% will be in the southwest direction, while the other 25% to the northeast direction. Every panel has an area of 1.92 m^2 , maximum power of around 400 W and maximum efficiency of 20.8% .

H) Installation of motion detector for the lighting in the common spaces

Goal: Reduction of the electricity demand in the common spaces

A typical motion detector is selected which reduces the electricity demand by around 40%. This detector regards the common spaces with an area of around 157 m^2 .

5.1.2 Summary of energy analysis (INTEMA.building tool)

Table 1 below summarizes the results for the French demo for the baseline and the renovation scenarios. Table 2 demonstrates the relevant performance of each scenario against the targets set at the Grant Agreement.

Figure 4 - Summary of energy parameters of the French demo scenarios

Energy parameters (kWh)	Baseline	SC1	SC3
Heating demand	184,795	62,302	44,510
Natural gas demand for heating	190,510	0	0
Electricity demand for heating	0	20,630	14,738
Domestic hot water demand (DHW)	31,086	31,086	31,086
Electricity demand for DHW	55,510	15,942	15,942
Electricity demand for appliances/lighting	26,017	25,786	25,786
PV production	0	5,120	5,120
Total electricity demand	81,527	62,358	56,466
Total electricity demand with PV included*	81,527	57,238	51,346
Primary energy analysis			
Primary energy demand for heating	190,510	53,225	38,024
Primary energy demand for hot water	143,216	41,130	41,130
Primary energy demand for appliances/lighting	67,124	66,527	66,527
Primary energy production from the PV	0	13,208	13,208
Total primary energy demand	400,850	160,883	145,681
Total primary energy demand with PV included*	400,850	147,674	132,473

Figure 5 - Summary of energy analysis of the two renovation scenarios with respect to the proposed targets

Goal	Proposal (kWh/m2)			Scenario 1	Scenario 3
	Baseline	Renovation	Reduction	Reduction	Reduction
Energy consumption	321	104	67%	60% / 63%*	64% / 67%*
Heating consumption	205	65	68%	72%	80%
DHW consumption	117	34	71%	71%	71%

* With the use of electricity from PV.

It can be seen that the Renovation Scenario 3 meets all targets set out in the GA; 80% reduction in heating consumption against 68% set out in the GA, 71% reduction in the DHW consumption which meets the target set out at the GA and 67% reduction in the overall energy consumption (including the electricity produced by the PV) which is equal to the target set out at the GA. On the other hand, Scenario 1 does not meet the overall energy reduction targets (63% reduction achieved against the 67% reduction target). A suggestion

for the present Demo is the trial to increase as possible the electricity production by the PV by adding extra panels or optimizing their configuration on the roof.

5.1.3 Summary of LCA/LCC analysis (VERIFY tool)

Below a summary of the various KPIs exported by VERIFY to conduct a comparison of the two renovation scenarios. Table 3 lists the KPIs that result from the LCA analysis whilst Table 4 includes the results exported from the LCC analysis.

Figure 6 Comparison of the two scenarios according to the list of LCA KPIs

KPI	Scenario 3	Scenario 1	Unit
Yearly Embodied Energy	13,688	13,078	kWh/year
Yearly Lifecycle Global Warming Potential Savings	9,791	9,617	Kg CO ₂ /year
Yearly Primary Energy Savings	223,716	214,173	kWh/year
Yearly Energy Self-Supply by RES	11	11	%

It can be seen that considering Yearly Embodied Energy Scenario 1 has the best performance with 13,078 kWh/year, compared to Scenario 3 with 13,688 kWh/year. Considering the environmental savings Scenario 3 has the best performance in both Yearly Primary Energy savings and CO₂ emissions savings, 223,716 kWh/year and 9,791 kg/year respectively. Regarding the Yearly Energy Self-Supply by RES the two scenarios have the same performance with 11%.

Figure 7 Comparison of the three scenarios according to the list of LCC KPIs

KPI	Scenario 3	Scenario 1	Unit
Return on Investment	-53	-54	%
Yearly Lifecycle Cost Savings	-16,088.13	-16,752.08	€/year
Payback Period	No PBT	No PBT	Years
Initial Investments (CAPEX)	944,854.84	936,814.14	€
Annual O&M Costs	21,037.21	21,689.70	€/year

With regard to the economic performance of the two alternative scenarios it can be seen that neither of the scenarios is an attractive investment without considering any subsidies or other financial support mechanisms. Both scenarios have negative Return on Investment and negative yearly Lifecycle Cost Savings (i.e. the annual O&M savings are not sufficient to cover the very high initial investment cost). As a result it was not possible to determine a payback period for the two scenarios. The CAPEX was determined at €944,854.84 for scenario 3 and €936,814.14 for Scenario 1. Finally, in terms of annual operation and maintenance costs, Scenario 3 has the lowest O&M costs; €21,037.21/year followed by Scenario 1 with €21,689.70/year.

5.1.4 Summary of the TEA tool analysis (user disruption and waste management)

Below a summary of the various KPIs exported by the TEA tool is presented to conduct a comparison of the two renovation scenarios.

Comparison of the two scenarios according to the list of KPIs in user disruption and waste management:

Figure 8 Comparison of the two scenarios according to the list of KPIs in user disruption and waste management

	Scenario 1	Scenario 3	Unit
Average daily project waste	139.6	156.56	dm ³
Overall project waste	69,381.27	96,124.88	dm ³
Average Daily Disruption (UTILITIES)	0.045	0.036	-
Average Project Disruption (UTILITIES)	0.045	0.036	-
Average Daily Disruption (TRAFFIC)	0.030	0.024	-
Average Project Disruption (TRAFFIC)	0.030	0.024	-
Average Daily Disruption (PHYSICAL SPACE)	0.119	0.712	-
Average Project Disruption (PHYSICAL SPACE)	0.119	0.712	-
Average Daily Disruption (INTERNAL ENVIRONMENT)	1.741	1.790	-
Average Project Disruption (INTERNAL ENVIRONMENT)	1.741	1.790	-
Project duration	497	614	days

5.1.5 Selection of optimum scenario through the RINNO Optimiser and Planner

Based on the multicriteria analysis conducted with the use of the i) INTEMA building tool for the energy analysis, ii) the VERIFY platform for the LCA/LCC analysis and iii) the TEA tool for the techno-economic analysis (user disruption and waste management), a set of indicators were produced which provide a holistic overview of the performance of the building under the various renovation scenarios.

These indicators were then fed to the Decision Support System of the RINNO Optimiser and Planner to derive the optimum renovation scenario. Selection of the optimum renovation scenario is then conducted following a Multi-Criteria Decision-Making (MCDM) method which involves ranking and scoring the alternative scenarios; The scenario with the highest

score is the highest performing scenario overall and thus the optimum solution based on the user preferences. A comprehensive description of the methodology is provided in 'Deliverable 3.7: RINNO Renovation Optimiser & Planner (V1)'.

A Summary of indicators used by the DSS in the selection of the optimum renovation scenario is presented in Table 6 below:

Table Summary of indicators used by the DSS in the selection of the optimum renovation scenario

Indicator	Unit	Scenario 1	Scenario 3
Environmental indicators			
Yearly Lifecycle Life Cycle Global Warming Potential savings	KgCO ₂ /year	9,617	9,791
Yearly embodied energy	kWh/year	13,078	13,688
Average daily project waste	dm ³	139.6	156.56
Overall project waste	dm ³	69,381.27	96,124.88
Yearly Energy Self-Supply by RES	%	11	11
Energy Indicators			
Yearly Primary Energy Savings – PES	kWh/year	214,173	223,716
Decrease in Energy Consumption	%	59.90	63.70
Savings in Primary Energy consumption for heating	%	72.10	80.00
Savings in Primary Energy consumption for cooling	%	0.00	0.00
Savings in Primary Energy consumption for DHW	%	71.30	71.30
Increase in RES based electricity production	kWh	5,120	5,120
Increase in RES based heating production	kWh	0.00	0.00
Cost and Financial indicators			
Return on Investment	%	-54	-53
Payback period	Years	No PBT	No PBT
Yearly Lifecycle Cost Savings	€/year	-16,752.08	-16,088.13
Initial Investment (CAPEX)	€	936,814.14	944,854.84
Annual O&M Costs	€/year	21,689.70	21,037.21
User disruption indicators			
Average Daily Disruption (UTILITIES)	Dimensionless	0.045	0.036
Average Project Disruption (UTILITIES)	Dimensionless	0.045	0.036
Average Daily Disruption (TRAFFIC)	Dimensionless	0.030	0.024
Average Project Disruption (TRAFFIC)	Dimensionless	0.030	0.024
Average Daily Disruption (PHYSICAL SPACE)	Dimensionless	0.119	0.712
Average Project Disruption (PHYSICAL SPACE)	Dimensionless	0.119	0.712
Average Daily Disruption (INTERNAL ENVIRONMENT)	Dimensionless	1.741	1.790
Average Project Disruption (INTERNAL ENVIRONMENT)	Dimensionless	1.741	1.790

Indicator	Unit	Scenario 1	Scenario 3
Project duration	days	497	614

The analysis at this stage was conducted considering equal weights in each category, i.e. the relevant weight of each category was considered 25%.

Scenario 1 has the highest score in 2 out of 4 categories, namely the energy and the user disruption categories whilst scenario 3 has the highest score in the environmental and the cost and financial categories. Based on the above analysis, the overall score of the two alternative scenarios is as follows:

- Scenario 1: 70.75
- Scenario 3: 68.26

Based on the results presented, **Scenario 1** was found to be the optimum renovation scenario for the French demo:

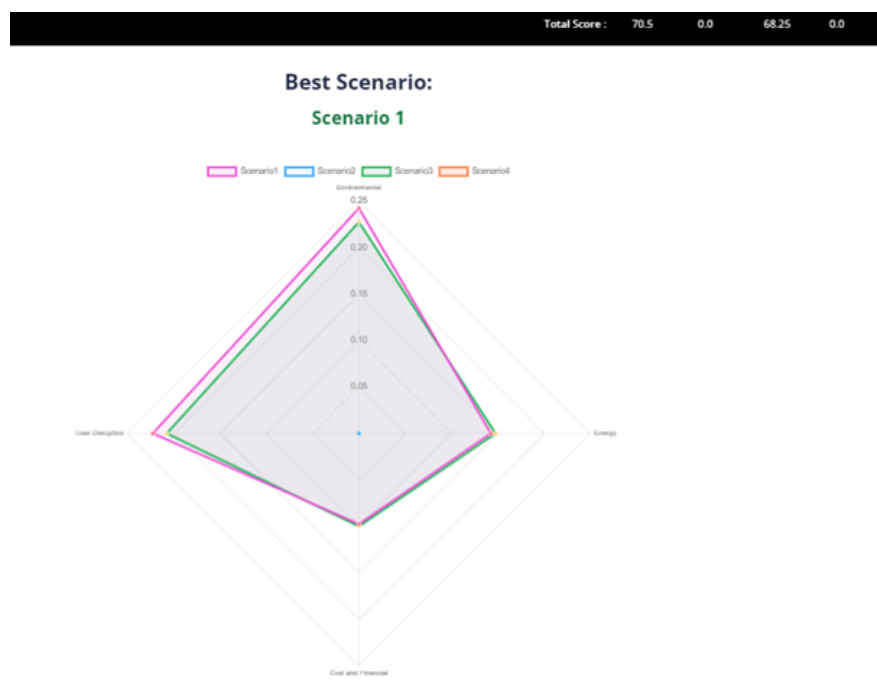


Figure 9 Selection of Optimum renovation scenario for the French demo by the Renovation Scenario DSS

5.1.6 Renovation Scenario to be implemented

The scenario that will be implemented by the French demo leader, LMH, is Scenario 3. It is apparent that there is a deviation between the scenario selected by the DSS following the multi-criteria assessment (Scenario 1) and the one that is going to be implemented (Scenario 3). There are two reasons for this deviation. Firstly, the Scenario 1, although close, does not meet all the performance targets set out at the Grant Agreement regarding the

renovation of the building, whilst scenario 3 meets these targets. The second reason is that Scenario 3 includes an additional RINNO technology (the Microvent ventilation unit) and it was decided by LMH to demonstrate as many RINNO solutions as possible in the demo building.

5.2 Selected scenarios for the Greek demo site

The two scenarios presented in Section 2.2.2 (Scenario 1 and Scenario 3) were analysed by the tools of the RINNO Simulation and Assessment Toolbox (T3.3). In addition, a variation of Scenario 3 which does not include any RINNO technologies was also examined. This was done to increase the number of alternatives assessed. This is additional alternative scenario is referred to as Scenario 4. Therefore, the total number of scenarios assessed for the Greek demo was three.

The selection of the optimum renovation scenario was conducted from the Renovation Scenario DSS (T3.4). The description of these scenarios and the results of the analysis are presented in the following paragraphs.

5.2.1 Description of the Greek Demo Renovation Scenarios

5.2.1.1 Scenario 1

The Greek **scenario 1** is a simplistic one that aims to improve the building's energy performance by incorporating a restricted number of renovation actions. Below, the applied retrofitting techniques of the building are listed:

A) External Insulation

Goal: Reduce the thermal losses, reduce the U-value, reduce the absorbance of solar irradiation.

- **External walls:** Addition of 12 cm EPS insulation with $k=0.034 \text{ W/mK}$; the new U-value is $0.25 \text{ W/m}^2\text{K}$.
- **Roof:** Addition of 20 cm EPS insulation with $k=0.032 \text{ W/mK}$; the new U-value is $0.16 \text{ W/m}^2\text{K}$.
- **Elimination of the thermal bridges.**

B) Windows replacement

Goal: Reduce the thermal losses, reduce the infiltration rate and manage properly the solar irradiation.

- Use of thermochromic windows in the southwest direction for the 2nd and 3rd floors.
 - Use of triple-glazed low-e aluminium/pvc windows in the remaining cases.
- The airtightness of the envelope will be reduced from 2 air changes per hour to 1 air change per hour.

C) Installation of decentralized air to air Heat Pumps

Goal: Cover the heating and cooling loads with relatively low energy demand.

Use of decentralized highly efficient reversible air-to-air heat pumps in all the apartments to cover the heating loads during winter and the cooling loads during summer. These heat pumps present a SEER=5 and a SCOP=3, values provided by the Hellenic Institute of Passive Buildings.

D) Installation of PV panels

Goal: Electricity production from solar irradiation in order to cover all the possible needs and be positive.

- Installation of highly efficient PV panels on the roof with nominal efficiency of 19.9%³. These panels will be located horizontally to put as many panels as possible. Every panel has an area of 2.21 m² and totally 44 panels are installed.
- Installation of vertical BIPV in the southeast direction (GREENSTRUCT). Totally 4 panels were selected to be installed on the 3rd floor. Every panel has dimensions of 2.45 m x 1.25 m, a total area of 3.06 m² and maximum efficiency of 5.8%⁴.

5.2.1.2 Scenario 2

Scenario 2 is not analysed due to technical incompatibility of one of the chosen technical solutions.

5.2.1.3 Scenario 3

The **Greek scenario 3** aims to improve the building envelope and use highly efficient energy systems. Moreover, it includes an important retrofitting of the existing equipment, and it aims to produce net electricity for the grid (positive building). The envelope is enhanced in order to minimize thermal losses and so to reduce energy needs. Below, the retrofitting techniques of the building are listed:

A) External Insulation (K-FLEX)

Goal: Reduce the thermal losses, reduce the U-value, reduce the absorbance of solar irradiation.

- **External walls:** Addition of 8 cm insulation (K-FLEX) with $k=0.027$ W/mK; the new U-value is 0.293 W/m²K.
- **Roof:** Addition of 20 cm insulation (EPS 200 White) with $k=0.033$ W/mK; the new U-value is 0.156 W/m²K.
- **Basement ceiling:** Addition of 3 cm insulation (EPS 100 White) with $k=0.034$ W/mK; the new U-value is 0.831 W/m²K.
- **Cool paint** for reflecting solar irradiation
- **Elimination of the thermal bridges.**

B) Windows replacement (GREENSTRUCT)

Goal: Reduce the thermal losses, reduce the infiltration rate and manage properly the solar irradiation.

- Use of thermochromic windows in the southwest direction for the 2nd and 3rd floors.
- Use of triple-glazed low-e aluminium/pvc windows in the remaining cases.

The airtightness of the envelope will be reduced from 2 air changes per hour to 0.4 air changes per hour.

C) Decentralized Mechanical Ventilation with heat recovery

Goal: Provide the proper fresh air by reducing the load due to the use of heat recovery.

Addition of the proper mechanical ventilation systems in every apartment. The flow rate is about 100 m³/h, which corresponds to 0.4 air changes per hour. The systems include a heat recovery heat exchanger with an effectiveness of 80 % (as per the recommendations from HPHI).

D) Installation of decentralized air to air Heat Pumps

Goal: Cover the heating and cooling loads with relatively low energy demand.

Use of decentralized highly efficient reversible air-to-air heat pumps in all the apartments in order to cover the heating loads during winter and the cooling loads during summer. These heat pumps present a SEER=6.0 and a SCOP=3.31, values provided by the Hellenic Institute of Passive Buildings.

E) Solar thermal collectors coupled to storage tanks

Goal: Provide domestic hot water by exploiting solar irradiation and avoiding electricity demand.

Use of an integrated solar thermal system in every apartment separately. Highly efficient selective solar thermal collectors of 2.0 m² coupled to a storage tank of 120 L, are selected. The collectors are located in the south direction with an inclination angle of 55°. The system includes auxiliary electrical resistance.

F) Installation of PV panels

Goal: Electricity production from solar irradiation.

- Installation of highly efficient PV panels (Polycrystalline silicon) in the roof with a 0° inclination. Totally, the PV area is 82.4 m² which includes 50 modules of 1.65 m² of each module. The maximum efficiency of the panel is 24%.
- Installation of vertical BIPV in the southeast direction (**GREENSTRUCT**). Totally 4 panels were selected to be installed on the 3rd floor. Every panel has dimensions of 2.45 m x 1.25 m, a total area of 3.06 m² and maximum efficiency of 5.8%.

G) Improvement of the lighting installation

Goal: Partial reduction of the electricity demand.

Replacement of the lighting equipment with energy-efficient systems. The nominal specific lighting power becomes equal to 1 W/m² with an operating fraction of 10%, while the appliances operating fraction is 40% and the specific power remains at 4 W/m².

5.2.1.4 Scenario 4

The Greek **scenario 4** aims to improve both the building envelope and to use highly efficient energy systems. The envelope is enhanced to minimize thermal losses and so to reduce energy needs. Below, the retrofitting interventions of the building are listed:

A) External Insulation

Goal: Reduce the thermal losses, reduce the U-value, reduce the absorbance of solar irradiation.

- **External walls:** Addition of 12 cm EPS insulation with $k=0.034$ W/mK; the new U-value is 0.25 W/m²K.
- **Roof:** Addition of 20 cm EPS insulation with $k=0.032$ W/mK; the new U-value is 0.16 W/m²K.
- **Basement ceiling:** Addition of 3 cm EPS insulation with $k=0.032$ W/mK; the new U-value is 0.86 W/m²K.
- **Cool paint** for reflecting solar irradiation.
- **Elimination of the thermal bridges.**

B) Windows replacement

Goal: Reduce the thermal losses, reduce the infiltration rate and manage properly the solar irradiation.

Use of triple-glazed low-e aluminium/pvc windows. The airtightness of the envelope will be reduced from 2 air changes per hour to 0.4 air changes per hour.

C) Decentralized Mechanical Ventilation with heat recovery

Goal: Provide the proper fresh air by reducing the load due to the use of heat recovery.

Addition of the proper mechanical ventilation systems in every apartment. The flow rate is about 100 m³/h, which corresponds to 0.45 air changes per hour. The systems include a heat recovery heat exchanger with an effectiveness of 72 % (a typical system was used as per the recommendations from HPHI).

D) Installation of decentralized air to air Heat Pumps

Goal: Cover the heating and cooling loads with relatively low energy demand.

Use of decentralized highly efficient reversible air-to-air heat pumps in all the apartments in order to cover the heating loads during winter and the cooling loads during summer. These heat pumps present a SEER=5 and a SCOP=3, values provided by the Hellenic Institute of Passive Buildings.

E) Solar thermal collectors coupled to storage tanks

Goal: Provide domestic hot water by exploiting solar irradiation and avoiding electricity demand.

Use of an integrated solar thermal system in every apartment separately. Selective solar thermal collectors of 2.5 m² coupled to a storage tank of 160 L, are selected. The system includes auxiliary electrical resistance.

F) Installation of PV panels

Goal: Electricity production from solar irradiation.

- Installation of highly efficient PV panels in the roof with a 30° inclination towards the south direction (Aleo-Solar panel).
- Installation of highly efficient PV façade panels in the southwest direction (vertical panels – Aleo Solar panels).

G) Improvement of the lighting installation

Goal: Partial reduction of the electricity demand.

Replacement of the lighting equipment with energy-efficient systems. The nominal specific lighting power becomes equal to 3 W/m².

5.2.2 Summary of energy analysis (INTEMA.building tool)

Table 7 below summarizes the results of the Greek demo for the baseline and the renovation scenarios. A summary of the relevant energy performance achieved of each renovation scenario relative to the proposed targets set at the GA is shown in Table 8.

Summary of the simulation results for the Greek demo:

Figure 10 Summary of energy parameters of the Greek demo scenarios

Energy parameters (kWh)	CERTH			
	Baseline	SC1	SC3	SC4
Heating demand	90,890	13,005	5,607	2,967
Natural gas demand for heating	9,584	0	0	0
Oil demand for heating	18,879	0	0	0
Electricity demand for heating	35,026	4,350	1,694	991
Cooling demand	67,573	37,849	12,490	20,910
Electricity demand for cooling	32,385	7,570	2,081	4,182
Domestic hot water demand (DHW)	8,064	8,064	8,064	8,064
Electricity demand for DHW	5,072	5,072	1,024	1,080
Electricity demand for appliances/lighting	33,302	33,302	13,145	25,902
Total electricity demand	105,785	50,294	17,944	32,155
Electricity production from PV on the roof	0	24,387	22,550	16,627
Electricity production from BIPV	0	368	368	2,145
Total Electricity production from PV	0	24,755	22,918	18,772
Net electricity after covering heating/cooling	0	12,835	19,143	13,599
Net electricity demand from the grid	0	25,539	-4,974*	13,382
Primary energy analysis				
Primary energy demand for heating	132,406	12,615	4,913	2,874
Primary energy demand for cooling	93,917	21,953	6,035	12,128
Primary energy demand for hot water	14,709	14,709	2,970	3,132
Primary energy demand for appliances/lighting	96,576	96,576	38,120	75,115
Primary energy production from the PV	0	71,790	66,462	54,439
Total primary energy demand	337,607	145,853	52,038	93,248
Total primary energy demand with PV included*	337,607	74,062	-14,423*	38,809

* The negative value indicates that the building is a positive one

Kommenterede [AA12]: Table not figure. Please implement in all document.

Figure 11 Summary of energy analysis of the three renovation scenarios with respect to the proposed targets

Goal	Proposal (kWh/m ²)			Scenario 1	Scenario 3	Scenario 4
	Baseline	Retrofitted	Reduction	Reduction	Reduction	Reduction
Energy demand	250	45	82%	57% / 78%*	85% / 100%*	72% / 89%*
Heating demand	100	5	95%	90%	96%	98%
DHW demand	30	10	67%	0%	80%	79%
Cooling demand	70	10	86%	77%	94%	87%
Other demand	50	20	60%	0% / 39%*	61% / 100%*	22% / 63%*

* With the use of electricity from PV

It can be seen that Scenario 3 and Scenario 4 both meet the targets set out at the Grant Agreement for the Greek demo. Scenario 4 also leads to positive energy performance where all energy consumption of the building is covered by the PV and excess energy is sold to the grid. Scenario 1 also leads to significant energy savings; however these do not meet the targets set out at the Grant Agreement.

5.2.3 Summary of LCA/LCC analysis (VERIFY tool)

Below a summary of the various KPIs exported by VERIFY to conduct a comparison of the three renovation scenarios is presented. Table 9 lists the KPIs that result from the LCA analysis whilst Table 10 includes the results exported from the LCC analysis.

Figure 12 Comparison of the three scenarios according to the list of LCA KPIs

KPI	Scenario 1	Scenario 3	Scenario 4	Unit
Embodied Energy	38,941	46,448	39,824	kWh/year
Yearly Lifecycle Global Warming Potential Savings	50,032	71,696	63,077	kg/year
Yearly Primary Energy Savings	258,896	369,699	325,616	kWh/year
Yearly Energy Self-Supply by RES	34	42	37	%

Considering Yearly Embodied Energy, Scenario 1 has the best performance with 38,941 kWh/year, followed by Scenario 4 with 39,824 kWh/year, while scenario 3 has the highest yearly embodied energy with 46,448 kWh/year. Considering environmental savings Scenario 3 has the best performance in both Primary Energy costs and CO2 emissions, 369,699 kWh/year and 71,696 kg/year respectively. The same scenario has also the highest self-supply percentage; 42% compared to 37% for Scenario 4 and 34% for Scenario 1.

Figure 13 Comparison of the three scenarios according to the list of LCC KPIs

KPI	Scenario 1	Scenario 3-ref	Scenario 4	Unit
Return on Investment	228	292	277	%
Yearly Lifecycle Cost Savings	18,555.54	27,102.49	23,830.45	€/year
Payback Period	7.83	6.58	6.5	Years
Initial Investments (CAPEX)	118,709.86	145,002.54	131,763.24	€
Annual O&M + Fuels	11,322.10	3,940.17	6,439.93	€/year

About the economic performance of the three alternative scenarios, scenario 3 has the highest Return on Investment, 292% followed by 277% for scenario 4 and 228% for scenario 1. In addition, Scenario 3 has the highest yearly Lifecycle Cost savings (€27,102.49/year) and the lowest operation and maintenance costs. In terms of payback

period, scenario 4 is the best performing of the three alternatives with a payback period of 6.5 years followed by Scenario 3 (6.58 years) and Scenario 1 (7.83 years). Finally, Scenario 1 has the lowest CAPEX of the three alternatives; €118,709.86 whilst the CAPEX of Scenario 2 is €131,763.24 and €145,002.54. In terms of annual operation and maintenance costs, Scenario 3 has the best performance with €3,940.17/year, followed by Scenario 4 with €6,439.93/year and Scenario 1 with €11,322.10/year.

5.2.4 Summary of the TEA tool analysis (user disruption and waste management)

Below is a summary of the various KPIs exported by the TEA tool to compare the three renovation scenarios.

Figure 14 Comparison of the three scenarios according to the list of KPIs in user disruption and waste management

	Scenario 1	Scenario 3	Scenario 4	Unit
Average daily project waste	81.3	79.4	95.2	dm ³
Overall project waste	41,700	44,948	44,069	dm ³
Average Daily Disruption (UTILITIES)	0.003	0.014	0.017	-
Average Project Disruption (UTILITIES)	0.003	0.014	0.017	-
Average Daily Disruption (TRAFFIC)	0.029	0.0265	0.032	-
Average Project Disruption (TRAFFIC)	0.029	0.0265	0.032	-
Average Daily Disruption (PHYSICAL SPACE)	0.161	0.181	0.222	-
Average Project Disruption (PHYSICAL SPACE)	0.161	0.181	0.222	-
Average Daily Disruption (INTERNAL ENVIRONMENT)	1.829	1.814	1.773	-
Average Project Disruption (INTERNAL ENVIRONMENT)	1.829	1.814	1.773	-
Project duration	513	566	463	-

5.2.5 Selection of optimum scenario through the RINNO Optimiser and Planner

Based on the multicriteria analysis conducted with the use of the i) INTEMA building tool for the energy analysis, ii) the VERIFY platform for the LCA/LCC analysis and iii) the TEA tool for the techno-economic analysis (user disruption and waste management), a set of indicators were produced. They provide a holistic overview of the performance of the building under the various renovation scenarios. A summary of the indicators fed to the DSS (Decision Support System) are provided in the table below.

The indicators were fed to the Decision Support System of the RINNO Optimiser and Planner to derive the optimum renovation scenario. Selection of the optimum renovation scenario is then conducted, following a Multi-Criteria Decision-Making (MCDM) method, which involves ranking and scoring the alternative scenarios; The scenario with the highest score is the highest performing scenario overall and thus the optimum solution based on the user preferences. A comprehensive description of the methodology is provided in 'Deliverable 3.7: RINNO Renovation Optimiser & Planner (V1)'.

A summary of indicators used by the DSS in the selection of the optimum renovation scenario is shown in Table 12.

Figure 15 Summary of indicators used by the DSS in the selection of the optimum renovation scenario

Indicator	Unit	Scenario 1	Scenario 3	Scenario 4
Environmental indicators				
Yearly Lifecycle Life Cycle Global Warming Potential savings	KgCO ₂ /year	50,032	71,696	63,077
Yearly embodied energy	kWh/year	38,941	46,448	39,824
Average daily project waste	dm ³	81.3	79.4	95.2
Overall project waste	dm ³	41,700	44,948	44,069
Yearly Energy Self-Supply by RES	%	34	42	37
Energy Indicators				
Yearly Primary energy savings - PES	kWh/year	258,896	369,699	325,616
Decrease in Energy Consumption	%	56.80	84.60	72.40
Savings in Primary Energy consumption for heating	%	90.50	96.30	97.80
Savings in Primary Energy consumption for cooling	%	76.60	93.60	87.10
Savings in Primary Energy consumption for DHW	%	0	79.80	78.70
Increase in RES based electricity production	kWh	24,755	22,918	18,772
Increase in RES based heating production	kWh	0	4,048	3,992
Cost and Financial indicators				
Return on Investment	%	228	292	277
Payback period	Years	7.83	6.58	6.5
Yearly Lifecycle Cost Savings	€/year	18,555.54	27,102.49	23,830.45
Initial Investment (CAPEX)	€	118,709.86	145,002.54	131,763.24
Annual O&M Costs	€/year	11,322.10	3,940.17	6,439.93
User disruption indicators				
Average Daily Disruption (UTILITIES)	Dimensionless	0.003	0.014	0.017
Average Project Disruption (UTILITIES)	Dimensionless	0.003	0.014	0.017

Average Daily Disruption (TRAFFIC)	Dimensionless	0.029	0.0265	0.032
Average Project Disruption (TRAFFIC)	Dimensionless	0.029	0.0265	0.032
Average Daily Disruption (PHYSICAL SPACE)	Dimensionless	0.161	0.181	0.222
Average Project Disruption (PHYSICAL SPACE)	Dimensionless	0.161	0.181	0.222
Average Daily Disruption (INTERNAL ENVIRONMENT)	Dimensionless	1.829	1.814	1.773
Average Project Disruption (INTERNAL ENVIRONMENT)	Dimensionless	1.829	1.814	1.773
Project duration	days	513	566	463

The analysis at this stage was conducted considering equal weights in each category, i.e. the relevant weight of each category was considered 25%.

Scenario 3 has the highest score in 3 out of 4 categories, i.e. the energy, the environmental and the cost and financial category. It has the lowest score in the user disruption category, however very close to the other two alternatives. Based on the above analysis, the overall score of the three alternative scenarios is as follows:

- Scenario 1: 75.0
- Scenario 3: 92.0
- Scenario 4: 86.75

Based on the results presented, **Scenario 3** was found to be the optimum renovation scenario for the Greek demo:

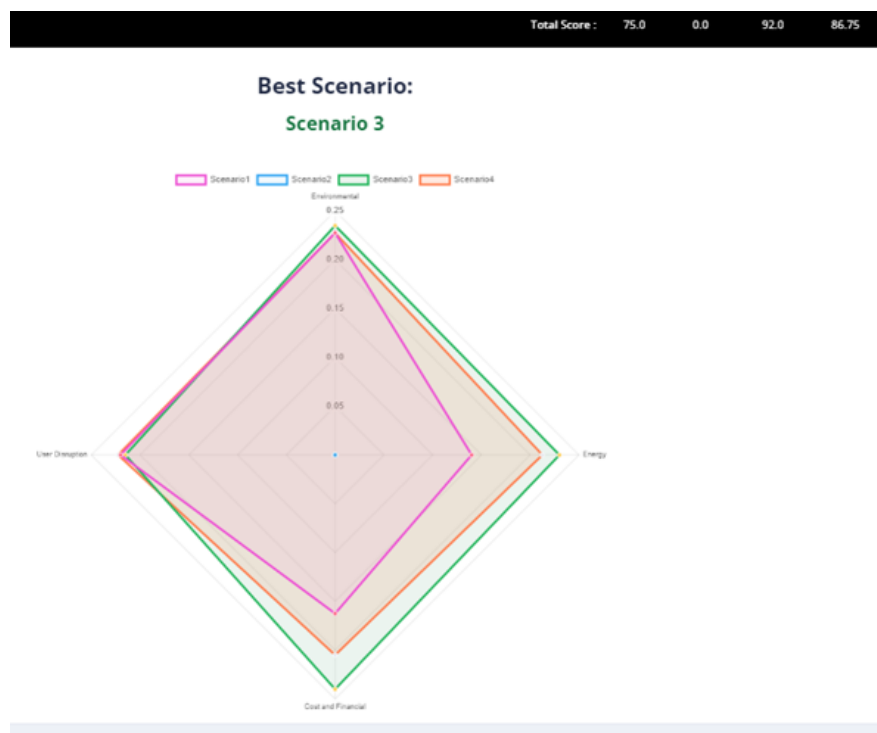


Figure 16 Selection of Optimum renovation scenario for the Greek demo by the Renovation Scenario DSS

5.2.6 Renovation Scenario to be implemented

The Greek demo leader will implement the Renovation Scenario 3 which was the scenario selected by the DSS. Therefore, no deviation to the RPDA selection process is observed.

5.3 Selected scenarios for the Polish demo site

The three scenarios presented in Section 2.3.2 (Scenario 2, Scenario 3 and Scenario 4) were analysed by the tools of the RINNO Simulation and Assessment Toolbox (T3.3). The selection of the optimum renovation scenario was conducted from the Renovation Scenario DSS (T3.4). The description of these scenarios and the results of the analysis are presented in the following paragraphs.

5.3.1 Description of the Polish Demo Renovation Scenarios

5.3.1.1 Scenario 2

The **Polish Scenario 2** aims to improve both the building envelope and also to use of highly efficient energy systems. The envelope is enhanced in order to minimize thermal losses and so to reduce energy needs. Below, the retrofitting interventions of the building are listed:

A) Adding Insulation

Goal: Reduce the thermal losses, reduce the U-value, reduce the absorbance of solar irradiation.

- External walls: Addition of 15 cm insulation with $k=0.033$ W/mK; the new U-value is 0.20 W/m²K.
- Roof: Addition of 21 cm Isocell insulation with $k=0.037$ W/mK; the new U-value is 0.15 W/m²K.
- Basement ceiling: Addition of 8 cm insulation with $k=0.026$ W/mK in an area of 60 m²; the new U-value is 0.25 W/m²K (double layer panels from K-FLEX).

B) Windows replacement

Goal: Reduce the thermal losses, reduce the infiltration rate and manage properly the solar irradiation.

Use of triple-glazed low-e aluminium/pvc windows. Window with total U-value=0.9 W/m²K (75% glass and 25% frame) and g-value=0.75. The airtightness of the envelope will be reduced from 0.7 air changes per hour to 0.6 air changes per hour.

C) Solar thermal collectors coupled to a storage tank

Goal: Provide domestic hot water by exploiting solar irradiation and avoiding electricity demand.

Use of an integrated solar thermal system in every apartment separately. Selective solar thermal collectors of 15 m² coupled to an insulated storage tank of 1000 L, are selected. The collectors are located on the west-oriented roof with an inclination of 36°. Also, the system includes an auxiliary natural gas boiler.

D) Installation of a natural gas boiler

Goal: Cover the heating and DHW needs with an efficient energy system.

The highly efficient natural gas boiler is used both for heating and DHW purposes.

Heating mode: Average seasonal efficiency at 83%, taking into account 93.5% nominal efficiency, 100% distribution efficiency and 89% regulation efficiency.

DHW mode: Average seasonal efficiency at 68%, taking into account 93.5% nominal efficiency, 85% distribution efficiency and 85% regulation efficiency.

E) Zappa PV Facade solutions (EKOLAB)

Goal: Electricity production from solar irradiation and insulating the south wall.

Installation of highly efficient PV panels in the south façade and insulating properly the south wall. The ZAPPA technology 20 m² of photovoltaic panels has a nominal electrical efficiency of 13.3%.

G) Piping insulation (K-FLEX)

Goal: Reduction of the distribution of thermal losses.

Use of Bio-based pipes insulation to insulate the pipe network with low thermal conductivity of 0.038 W/mK

H) Improvement of the lighting installation

Goal: Partial reduction of the electricity demand.

Replacement of the lighting equipment with energy-efficient systems in the common areas. The nominal specific lighting power becomes equal to 2.3 W/m² from 2.5 W/m² in the baseline scenario.

5.3.1.2 Scenario 3

The **Polish Scenario 3** aims to improve both the building envelope and also to use of highly efficient energy systems. The envelope is enhanced in order to minimize thermal losses and so to reduce energy needs. The difference in this scenario, compared to the previous one is the addition of extra insulation in the external walls in order to reduce a greater percentage of the thermal losses. Below, the retrofiting interventions of the building are listed:

A) Adding Insulation

Goal: Reduce the thermal losses, reduce the U-value, reduce the absorbance of solar irradiation.

- External walls: Addition of 20 cm insulation with $k=0.033$ W/mK; the new U-value is 0.15 W/m²K.
- Roof: Addition of 21 cm Isocell insulation with $k=0.037$ W/mK; the new U-value is 0.15 W/m²K.
- Basement ceiling: Addition of 8 cm insulation with $k=0.026$ W/mK in an area of 60 m²; the new U-value is 0.25 W/m²K (double layer panels from K-FLEX).

B) Windows replacement

Goal: Reduce the thermal losses, reduce the infiltration rate and manage properly the solar irradiation.

Use of triple-glazed low-e aluminium/pvc windows. Window with total U-value=0.9 W/m²K (75% glass and 25% frame) and g-value=0.75. The airtightness of the envelope will be reduced from 0.7 air changes per hour to 0.6 air changes per hour.

C) Solar thermal collectors coupled to storage tanks

Goal: Provide domestic hot water by exploiting solar irradiation and avoiding electricity demand.

Use of an integrated solar thermal system in every apartment separately. Selective solar thermal collectors of 15 m² coupled to an insulated storage tank of 1000 L, are selected. The collectors are located on the west-oriented roof with an inclination of 36°. Also, the system includes an auxiliary natural gas boiler.

D) Installation of a natural gas boiler

Goal: Cover the heating and DHW needs with an efficient energy system.

The highly efficient natural gas boiler is used both for heating and DHW purposes.

Heating mode: Average seasonal efficiency at 83%, taking into account 93.5% nominal efficiency, 100% distribution efficiency and 89% regulation efficiency.

DHW mode: Average seasonal efficiency at 68%, taking into account 93.5% nominal efficiency, 85% distribution efficiency and 85% regulation efficiency.

E) Zappa PV Facade solutions (EKOLAB)

Goal: Electricity production from solar irradiation and insulating the south wall.

Installation of highly efficient PV panels in the south façade and insulating properly the south wall. The ZAPPA technology 20 m² of photovoltaic panels has a nominal electrical efficiency of 13.3%.

G) Piping insulation (K-FLEX)

Goal: Reduction of the distribution of thermal losses.

Use of Bio-based pipes insulation to insulate the pipe network with low thermal conductivity of 0.038 W/mK

H) Improvement of the lighting installation

Goal: Partial reduction of the electricity demand.

Replacement of the lighting equipment with energy-efficient systems in the common areas. The nominal specific lighting power becomes equal to 2.3 W/m² from 2.5 W/m² in the baseline scenario.

5.3.1.3 Scenario 4

The **Polish scenario 4** aims to improve the building envelope, use highly efficient energy systems and produce electricity by using photovoltaics. The envelope is enhanced in order to minimize thermal losses and so to reduce energy needs. Below, the retrofitting interventions of the building are listed:

A) Adding Insulation

Goal: Reduce the thermal losses, reduce the U-value, reduce the absorbance of solar irradiation.

- External walls: Addition of 20 cm insulation with $k=0.033$ W/mK; the new U-value is 0.15 W/m²K.
- Roof: Addition of 21 cm Isocell insulation with $k=0.037$ W/mK; the new U-value is 0.15 W/m²K.
- Basement ceiling: Addition of 8 cm insulation with $k=0.026$ W/mK in an area of 60 m²; the new U-value is 0.25 W/m²K (double layer panels from K-FLEX).

B) Windows replacement

Goal: Reduce the thermal losses, reduce the infiltration rate and manage properly the solar irradiation.

Use of triple-glazed low-e aluminium/pvc windows. Window with total U-value=0.9 W/m²K (75% glass and 25% frame) and g-value=0.75. The airtightness of the envelope will be reduced from 0.7 air changes per hour to 0.6 air changes per hour.

C) Solar photovoltaic panels

Goal: Provide electricity for covering a part of the building needs.

Use typical PV panels of 10 kW_p capacity separated into east and west with capacities of 5 kW_p and 5 kW_p respectively. The PV slope is the same as the roof slope and it is 36° for both sides. An inverter efficiency of 95% is assumed with a net-metering connection.

D) Installation of a natural gas boiler

Goal: Cover the heating and DHW needs with an efficient energy system.

The highly efficient natural gas boiler is used both for heating and DHW purposes.

Heating mode: Average seasonal efficiency at 83%, taking into account 93.5% nominal efficiency, 100% distribution efficiency and 89% regulation efficiency.

DHW mode: Average seasonal efficiency at 68%, taking into account 93.5% nominal efficiency, 85% distribution efficiency and 85% regulation efficiency.

E) Zappa PV Facade solutions (EKOLAB)

Goal: Electricity production from solar irradiation and insulating the south wall.

Installation of highly efficient PV panels in the south façade and insulating properly the south wall. The ZAPPA technology 20 m² of photovoltaic panels has a nominal electrical efficiency of 13.3% and a capacity of 2 kWp. An inverter efficiency of 95% is assumed with a net-metering connection.

F) Piping insulation (K-FLEX)

Goal: Reduction of the distribution of thermal losses.

Use of Bio-based pipes insulation to insulate the pipe network with low thermal conductivity of 0.038 W/mK

G) Improvement of the lighting installation

Goal: Partial reduction of the electricity demand.

Replacement of the lighting equipment with energy-efficient systems in the common areas. The nominal specific lighting power becomes equal to 2.3 W/m² from 2.5 W/m² in the baseline scenario.

5.3.2 Summary of energy analysis (INTEMA.building tool)

Table 13 below summarizes the results with INTEMA.building for the Polish demo for the baseline and the renovation scenarios.

Figure 17 Summary of energy parameters of the Polish demo scenarios

Energy parameters (kWh)	CERTH			
	Baseline	SC2	SC3	SC4
Heating demand	64,019	17,147	15,917	15,917
Wood/coal demand for heating	128,039	0	0	0
Natural gas demand for heating	0	20,660	19,178	19,178
Domestic hot water demand (DHW)	9,037	9,037	9,037	9,037
Wood/coal demand for DHW	25,104	0	0	0
Natural gas for DHW	0	7,195	7,195	13,295
Electricity demand for appliances/lighting	10,323	10,042	10,042	10,042
Total PV production	0	2,090	2,090	8,821
Total electricity demand with PV included*	10,323	7,952	7,952	1,221
Primary energy analysis				
Primary energy demand for heating	140,843	22,726	21,096	21,096
Primary energy demand for hot water	27,614	7,915	7,915	14,625
Primary energy demand for appliances/lighting	30,969	30,126	30,126	30,126
Primary energy production from the PV	0	6,270	6,270	26,463
Total primary energy demand	199,426	60,767	59,136	65,846

Total primary energy demand with PV included*	199,426	54,706	52,866	39,383
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A summary of the relevant energy performance achieved of each renovation scenario relative to the proposed targets set at the GA is shown in Table 14. It should be noted that for the renovation scenarios to reach all targets set during the proposal stage some additional measures are recommended. For renovation scenarios 2 and 3 some additional PV panels are required to reach the target goals. For scenario 4 the installation of solar thermal collectors will facilitate in reaching the targets.

Figure 18 Summary of energy analysis of the three renovation scenarios with respect to the proposed targets

Goal	Proposal (kWh/m2)			Scenario 2	Scenario 3	Scenario 4
	Baseline	Retrofitted	Reduction	Reduction	Reduction	Reduction
Energy demand	300	63	79%	70% / 73%*	70% / 73%*	67% / 80%*
Heating demand	250	40	84%	83%	84%	84%
DHW demand	50	23	54%	71%	71%	47%
Other demand	10	5	50%	3% / 23%*	3% / 23%*	3% / 88%*

* With the use of electricity from PV

It can be seen that Renovation Scenario meets most targets set out at the Grant Agreement, i.e. exceeding the overall energy demand reduction target (including the use of the electricity produced by the PV) as well as the heating demand reduction target and the other demand reduction target, whilst it is also close to reaching the DHW demand reduction target. On the other hand, Scenario 2 and 3 do not meet the other demand reduction target and the overall energy consumption reduction target. Furthermore, Scenario 2 does not also meet the heating demand reduction target although it is very close in reaching it.

5.3.3 Summary of LCA/LCC analysis (VERIFY tool)

Below a summary of the various KPIs exported by VERIFY to conduct a comparison of the three renovation scenarios is presented. Table 15 lists the KPIs that result from the LCA analysis whilst Table 16 includes the results exported from the LCC analysis

Figure 19 Comparison of the three scenarios according to the list of LCA KPIs

KPI	Scenario 2	Scenario 3	Scenario 4	Unit
Embodied Energy	18,724	21,921	23,351	kWh/year
Yearly Lifecycle Global Warming Potential Savings	14,320	14,388	19,901	kg/year

Yearly Primary Energy Savings	142,507	144,140	155,263	kWh/year
Yearly Energy Self-Supply by RES	18	18	37	%

It can be seen that considering Yearly Embodied Energy Scenario 2 (reference) has the best performance with 18,724 kWh/year, followed by Scenario 3 with 21,921 kWh/year, whilst scenario 4 has the highest yearly embodied energy with 23,351 kWh/year. Considering environmental savings Scenario 4 has the best performance in both Primary Energy savings and CO₂ emissions savings, 155,263kWh/year and 19,901 kg/year respectively. The same scenario has also the highest self-supply percentage; 37% compared to 18% for Scenarios 2 and 3.

Figure 20 Comparison of the three scenarios according to the list of LCC KPIs

KPI	Scenario 2	Scenario 3	Scenario 4	Unit
Return on Investment	65.0	52.0	63.0	%
Yearly Lifecycle Cost Savings	3,944.45	3,657.42	4,139.50	€/year
Payback Period	12.75	14.00	13.42	Years
Initial Investments (CAPEX)	82,409.77	91,329.77	89,989.77	€
Annual O&M costs	3,003.96	2,934.20	3,196.88	€/year

With regard to the economic performance of the three alternative scenarios it can be seen that scenario 2 (reference) has the highest Return on Investment, 65% followed by 63% for scenario 4 and 52% for scenario 3. Scenario 4 has the highest yearly Lifecycle Cost savings (€4,139.50/year) followed by Scenario 2 (€3,944.45/year) and Scenario 3 (€3,657.42/year). In terms of payback period, scenario 2 is the best performing of the three alternatives, with a payback period of 12.75 years followed by Scenario 4 (13.42 years) and Scenario 3 (14.00 years). Finally, Scenario 2 has the lowest CAPEX of the three alternatives; €82,409.77 whilst the CAPEX of Scenario 4 is €89,989.77 and Scenario 3 is €91,329.77. In terms of annual operation and maintenance costs, Scenario 3 has the lowest O&M costs; €2,934.20/year followed by Scenario 2 with €3,003.96/year and Scenario 4 with €3,196.88/year.

5.3.4 Summary of the TEA tool analysis (user disruption and waste management)

Below is a summary of the various KPIs exported by the TEA tool to compare the three renovation scenarios.

Figure 21 Comparison of the three scenarios according to the list of KPIs in user disruption and waste management

	Scenario 2	Scenario 3	Scenario 4	Unit
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Average daily project waste	211.7	211.7	200.3	dm ³
Overall project waste	27,099	27,099	26,645	dm ³
Average Daily Disruption (UTILITIES)	0.0648	0.0648	0.0361	-
Average Project Disruption (UTILITIES)	0.0648	0.0648	0.0361	-
Average Daily Disruption (TRAFFIC)	0.0781	0.0781	0.0752	-
Average Project Disruption (TRAFFIC)	0.0781	0.0781	0.0752	-
Average Daily Disruption (PHYSICAL SPACE)	0.0219	0.0219	0.0211	-
Average Project Disruption (PHYSICAL SPACE)	0.0219	0.0219	0.0211	-
Average Daily Disruption (INTERNAL ENVIRONMENT)	1.9742	1.9742	1.9068	-
Average Project Disruption (INTERNAL ENVIRONMENT)	1.9742	1.9742	1.9068	-
Project duration	128	128	133	-

5.3.5 Selection of optimum scenario through the RINNO Optimiser and Planner

Based on the multicriteria analysis conducted with the use of the i) INTEMA building tool for the energy analysis, ii) the VERIFY platform for the LCA/LCC analysis and iii) the TEA tool for the techno-economic analysis (user disruption and waste management), a set of indicators were produced which provide a holistic overview of the performance of the building under the various renovation scenarios.

These indicators were then fed to the Decision Support System of the RINNO Optimiser and Planner to derive the optimum renovation scenario. Selection of the optimum renovation scenario is then conducted following a Multi-Criteria Decision-Making (MCDM) method which involves ranking and scoring the alternative scenarios; The scenario with the highest score is the highest performing scenario overall and thus the optimum solution based on the user preferences. A comprehensive description of the methodology is provided in 'Deliverable 3.7: RINNO Renovation Optimiser & Planner (V1)'.

A summary of indicators used by the DSS in the selection of the optimum renovation scenario is provided in Table 18:

Figure 22 Summary of indicators used by the DSS in the selection of the optimum renovation scenario

Indicator	Unit	Scenario 2	Scenario 3	Scenario 4
Environmental indicators				

Yearly Lifecycle Life Cycle Global Warming Potential savings	KgCO ₂ /year	14,320	14,388	19,901
Yearly embodied energy	kWh/year	18,724	21,921	23,351
Average daily project waste	dm ³	211.7	211.7	200.3
Overall project waste	dm ³	27,099	27,099	26,645
Yearly Energy Self-Supply by RES	%	17.51	17.51	36.75
Energy Indicators				
Yearly Primary energy savings – PES	kWh/year	27,099	27,099	26,645
Decrease in Energy Consumption	%	69.50	70.30	67.00
Savings in Primary Energy consumption for heating	%	83.00	84.00	84.00
Savings in Primary Energy consumption for cooling	%	0.00	0.00	0.00
Savings in Primary Energy consumption for DHW	%	71.30	71.30	47.00
Increase in RES based electricity production	kWh	2,090	2,090	8,821
Increase in RES based heating production	kWh	4,144.4	4,144.4	0.0
Cost and Financial indicators				
Return on Investment	%	65.0	52.0	63.0
Payback period	Years	12.75	14.00	13.42
Yearly Lifecycle Cost Savings	€/year	3,944.45	3,657.42	4,139.50
Initial Investment (CAPEX)	€	82,409.77	91,329.77	89,989.77
Annual O&M Costs	€/year	3,003.96	2,934.2	3,196.88
User disruption indicators				
Average Daily Disruption (UTILITIES)	Dimensionless	0.0648	0.0648	0.0361
Average Project Disruption (UTILITIES)	Dimensionless	0.0648	0.0648	0.0361
Average Daily Disruption (TRAFFIC)	Dimensionless	0.0781	0.0781	0.0752
Average Project Disruption (TRAFFIC)	Dimensionless	0.0781	0.0781	0.0752
Average Daily Disruption (PHYSICAL SPACE)	Dimensionless	0.0219	0.0219	0.0211
Average Project Disruption (PHYSICAL SPACE)	Dimensionless	0.0219	0.0219	0.0211
Average Daily Disruption (INTERNAL ENVIRONMENT)	Dimensionless	1.9742	1.9742	1.9068
Average Project Disruption (INTERNAL ENVIRONMENT)	Dimensionless	1.9742	1.9742	1.9068
Project duration	days	128	128	133

The analysis at this stage was conducted considering equal weights in each category, i.e. the relevant weight of each category was considered 25%.

Scenario 4 is the best performing scenario in 2 out of 4 categories; environmental and user disruption. Scenario 3 is the best performing in the energy category whilst Scenario 2 was found to have the highest performance in the cost and financial category. Overall, the three scenarios were found to have very minor differences in their performance in the various categories.

Based on the above analysis, the overall score of the three alternative scenarios is as follows:

- Scenario 2: 83.75
- Scenario 3: 80.75
- Scenario 4: 84.00

Based on the results presented, **Scenario 4** was found to be the optimum renovation scenario for the Polish demo:

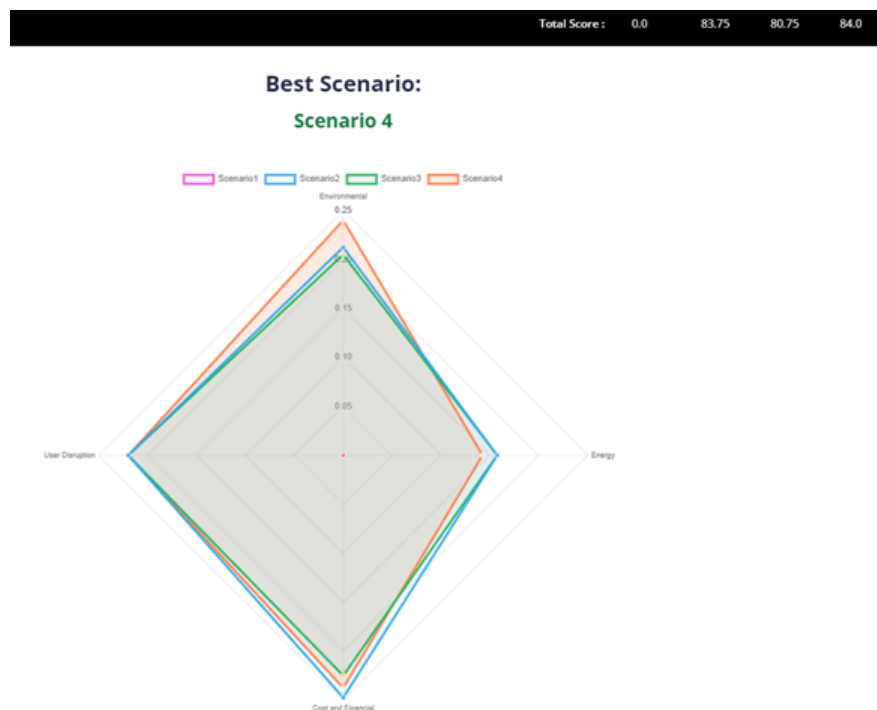


Figure 23 Selection of Optimum renovation scenario for the Polish demo by the Renovatiojn Scenario DSS

5.3.6 Renovation Scenario to be implemented

The Polish demo leader will implement Renovation Scenario 4 which was the scenario selected by the DSS. Therefore, no deviation to the RPDA selection process is observed.

5.4 Selected scenarios for the Danish demo site

The two scenarios presented in Section 2.4.2 (Scenario 1 and Scenario 2) were analysed by the tools of the RINNO Simulation and Assessment Toolbox (T3.3). The selection of the optimum renovation scenario was conducted from the Renovation Scenario DSS (T3.4). The description of these scenarios and the results of the analysis are presented in the following paragraphs

5.4.1 Description of the Danish Demo Renovation Scenarios

5.4.1.1 Scenario 1

The Danish **Scenario 1** aims to improve both the building envelope and the use of highly efficient energy systems. The envelope is enhanced to minimize thermal losses and to reduce energy needs. Below, the retrofitting interventions of the building are listed:

A) Windows replacement

Goal: Reduction of the thermal losses, reduction of the infiltration rate and proper management of the solar irradiation.

Use of advanced triple-glazed windows. Windows with total U-value=0.9 W/m²K (75% glass and 25% frame) and g-value=0.65. The airtightness of the envelope (infiltration) will be reduced from 0.4 air changes per hour to 0.3 air changes per hour.

B) Piping insulation (K-FLEX)

Goal: Reduction of the distribution of thermal losses.

Use of bio-based pipes insulation with low thermal conductivity of 0.038 W/mK.

C) Decentralized Mechanical Ventilation with heat recovery (EKOLAB)

Goal: Provide the proper fresh air by reducing the load due to the use of heat recovery.

Retrofitting of the mechanical ventilation system in every apartment (MicroVent – EKOLAB). The total mechanical ventilation rate will be around 0.8 air changes per hour with a heat recovery efficiency of 90% and an electricity consumption of 300 J/m³.

D) Installation of PV panels (ZAPPA)

Goal: Electricity production from solar irradiation in order to cover all the possible needs and be positive.

Installation of around 166 m² of ZAPPA with a PV area of 107 m². More specifically, the vertical PVs area located in the south is 72 m² and in the west direction 35 m².

5.4.1.2 Scenario 2

The Danish **Scenario 2** aims to improve both the building envelope and the use of highly efficient energy systems. The envelope is enhanced to minimize thermal losses and to reduce energy needs. Below, the retrofitting interventions of the building are listed:

A) Adding Isocell Cellulose Insulation in the south and west external walls (EKOLAB)

Goal: Reduction of the thermal losses, reduction of the U-value, reduction of the absorbance of solar irradiation.

External walls: Addition of 10 cm Isocell insulation with k=0.035 W/mK.

B) Windows replacement

Goal: Reduction of the thermal losses, reduction of the infiltration rate and proper management of the solar irradiation.

Use of advanced triple-glazed windows. Windows with total U-value=0.9 W/m²K (75% glass and 25% frame) and g-value=0.65. The airtightness of the envelope (infiltration) will be reduced from 0.4 air changes per hour to 0.3 air changes per hour.

C) Piping insulation (K-FLEX)

Goal: Reduction of the distribution of thermal losses.

Use of bio-based pipes insulation with low thermal conductivity of 0.038 W/mK.

D) Decentralized Mechanical Ventilation with heat recovery (EKOLAB)

Goal: Provide the proper fresh air by reducing the load due to the use of heat recovery.

Retrofitting of the mechanical ventilation system in every apartment (MicroVent – EKOLAB).). The total mechanical ventilation rate will be around 0.8 air changes per hour with a heat recovery efficiency of 90% and an electricity consumption of 300 J/m³.

E) Installation of PV panels (ZAPPA)

Goal: Electricity production from solar irradiation in order to cover all the possible needs and be positive.

Installation of around 166 m² of ZAPPA with a PV area of 107 m². More specifically, the vertical PVs area located in the south is 72 m² and in the west direction 35 m².

5.4.2 Summary of energy analysis (INTEMA.building tool)

Table 19 below summarizes the results for the Danish demo on the baseline and the renovation scenarios with INTEMA.building tool. A summary of the relevant energy performance achieved of each renovation scenario relative to the proposed targets set at the GA is shown in Table 20

Figure 24 Summary of energy parameters of the Danish demo scenarios

Energy parameters (kWh)	CERTH		
	Baseline	SC1	SC2
Heating demand	71,618	46,685	39,648
District heat demand for space heating	73,704	48,064	40,819
Domestic hot water demand (DHW)	11,502	11,502	11,502
District heat demand for DHW	20,958	17,731	17,731
Total district heat demand (both heating and DHW)	94,662	65,795	58,550
Electricity demand for appliances/lighting	24,332	22,313	22,313
Total PV production	0	22,877	22,877
Exploited electricity from the PV	0	8,769	8,769
Total electricity demand with PV included*	24,332	13,544	13,544
Primary energy analysis			
Primary energy demand for heating	62,648	40,854	34,696
Primary energy demand for DHW	17,814	15,071	15,071
Primary energy demand for appliances/lighting	46,231	42,395	42,395
Primary energy production from the PV exploitation	0	16,661	16,661
Total primary energy demand	126,694	98,320	92,162

Total primary energy demand with PV included*	126,694	81,659	75,501
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Figure 25 Summary of energy analysis of the two renovation scenarios with respect to the proposed targets

Goal	Proposal (kWh/m²)			Scenario 1	Scenario 2
	Baseline	Retrofitted	Reduction		
Energy consumption	159	108	32.1%	22.4% / 35.5%	27.3% / 40.4%
Heating consumption	97	65	41.4%	34.8%	44.6%
DHW consumption	29	26	10.0%	15.4%	15.4%
Other consumption	34	17	50.0%	8.3% / 44.3%*	8.3% / 44.3%*

* With the use of electricity from PV

It can be seen that Scenario 2 meets most of the targets set out at the Grant Agreement – only the other consumption target is not met but is somewhat approached. On the other hand, Scenario 1 does not meet the heating consumption reduction target and the other consumption reduction target (although again this was somewhat approached). A battery system for better exploitation of the produced electricity by the PV would help reach the other consumption target as well.

5.4.3 Summary of LCA/LCC analysis (VERIFY tool)

Below a summary of the various KPIs exported by VERIFY to conduct a comparison of the two renovation scenarios. Table 21 lists the KPIs that result from the LCA analysis whilst Table 22 includes the results exported from the LCC analysis

Figure 26 Comparison of the two scenarios according to the list of LCA KPIs

KPI	Scenario 1	Scenario 2-ref	Unit
Embodied Energy	12,418	13,729	kWh/year
Yearly Lifecycle Global Warming Potential Savings	32,272	39,058	kg/year
Yearly Primary Energy Savings	50,141	56,927	kWh/year
Yearly Energy Self-Supply by RES	36	36	%

Considering Yearly Embodied Energy, Scenario 1 has the best performance with 12,418 kWh/year, compared to Scenario 2 with 13,729 kWh/year. Considering the environmental savings, Scenario 2 has the best performance in both Yearly Primary Energy savings and CO₂ emissions savings, with 56,927 kWh/year and 39,058 kg/year respectively. Regarding the Yearly Energy Self-Supply by RES the two scenarios have the same performance with 36%.

Figure 27 Comparison of the two scenarios according to the list of LCC KPIs

KPI	Scenario 1	Scenario 2-ref	Unit
Return on Investment	1	7	%

Yearly Lifecycle Cost Savings	1,584.67	2,089.11	€/year
Payback Period	27	23,08	Years
Initial Investments (CAPEX)	125.185,58	129,540.68	€
Annual O&M + Fuels	9.630,66	8,952.01	€/year

With regard to the economic performance of the two alternative scenarios, it can be seen that Scenario 2 has the highest Return on Investment and the highest Yearly Lifecycle cost savings, 7% and €2,089.11 /year respectively. It also has the lowest payback period of 23,08 years, while the respective value for Scenario 1 was 27 years. Scenario 1 has lower initial investment, €125,185.58 compared to 129,540.68 for Scenario 2. Finally, in terms of annual operation and maintenance costs, Scenario 2 has the lowest O&M costs; €8,952.01/year compared to €9,630.66/year for Scenario 1.

5.4.4 Summary of the TEA tool analysis (user disruption and waste management)

Below a summary of the various KPIs exported by the TEA tool is presented to conduct a comparison of the two renovation scenarios.

Figure 28 Comparison of the two scenarios according to the list of KPIs in user disruption and waste management

	Scenario 1	Scenario 2	Unit
Average daily project waste	157.7	133.3	dm ³
Overall project waste	27,448	51,060	dm ³
Average Daily Disruption (UTILITIES)	0.000	0.000	-
Average Project Disruption (UTILITIES)	0.000	0.00	-
Average Daily Disruption (TRAFFIC)	0.086	0.039	-
Average Project Disruption (TRAFFIC)	0.086	0.039	-
Average Daily Disruption (PHYSICAL SPACE)	0.047	0.324	-
Average Project Disruption (PHYSICAL SPACE)	0.047	0.324	-
Average Daily Disruption (INTERNAL ENVIRONMENT)	1.309	1.957	-
Average Project Disruption (INTERNAL ENVIRONMENT)	1.309	1.957	-
Project duration	174	383	days

5.4.5 Selection of optimum scenario through the RINNO Optimiser and Planner

Based on the multicriteria analysis conducted with the use of the i) INTEMA building tool for the energy analysis, ii) the VERIFY platform for the LCA/LCC analysis and iii) the TEA tool for the techno-economic analysis (user disruption and waste management), a set of indicators were produced which provide a holistic overview of the performance of the building under the various renovation scenarios.

These indicators were then fed to the Decision Support System of the RINNO Optimiser and Planner to derive the optimum renovation scenario. Selection of the optimum renovation scenario is then conducted following a Multi-Criteria Decision-Making (MCDM) method which involves ranking and scoring the alternative scenarios; The scenario with the highest score is the highest performing scenario overall and thus the optimum solution based on the user preferences. A comprehensive description of the methodology is provided in 'Deliverable 3.7: RINNO Renovation Optimiser & Planner (V1)'.

A Summary of indicators used by the DSS in the selection of the optimum renovation scenario is provided in Table 24:

Figure 29 Summary of indicators used by the DSS in the selection of the optimum renovation scenario

Indicator	Unit	Scenario 1	Scenario 2
Environmental indicators			
Yearly Lifecycle Life Cycle Global Warming Potential savings	KgCO ₂ /year	32,272	39,058
Yearly embodied energy	kWh/year	12,418	13,729
Average daily project waste	dm ³	157.7	133.3
Overall project waste	dm ³	27,448	51,060
Yearly Energy Self-Supply by RES	%	36	36
Energy Indicators			
Yearly Primary energy savings – PES	kWh/year	50,141	56,927
Decrease in Energy Consumption	%	22.40	27.30
Savings in Primary Energy consumption for heating	%	34.80	44.60
Savings in Primary Energy consumption for cooling	%	0.00	0.00
Savings in Primary Energy consumption for DHW	%	15.40	15.40
Increase in RES based electricity production	kWh	8,769	8,769
Increase in RES based heating production	kWh	0.00	0.00
Cost and Financial indicators			
Return on Investment	%	1	7
Payback period	Years	1,584.67	2,089.11
Yearly Lifecycle Cost Savings	€/year	27	23,08
Initial Investment (CAPEX)	€	125,185,58	129,540.68
Annual O&M Costs	€/year	9,630,66	8,952.01
User disruption indicators			
Average Daily Disruption (UTILITIES)	Dimensionless	0.000	0.000

Average Project Disruption (UTILITIES)	Dimensionless	0.000	0.00
Average Daily Disruption (TRAFFIC)	Dimensionless	0.086	0.039
Average Project Disruption (TRAFFIC)	Dimensionless	0.086	0.039
Average Daily Disruption (PHYSICAL SPACE)	Dimensionless	0.047	0.324
Average Project Disruption (PHYSICAL SPACE)	Dimensionless	0.047	0.324
Average Daily Disruption (INTERNAL ENVIRONMENT)	Dimensionless	1.309	1.957
Average Project Disruption (INTERNAL ENVIRONMENT)	Dimensionless	1.309	1.957
Project duration	days	174	383

The analysis was conducted considering the preferences of the Danish demo leader by setting specific weights in each category. The following category weights were used:

- 1. Environmental 20%
- 2. Energy 30%
- 3. Cost and Financial 30%
- User disruption 20%

Scenario 2 outperformed Scenario 1 in the energy and cost and financial categories, whilst scenario 1 performed better in the environmental and user disruption categories. Based on the above analysis the overall score of the two alternative scenarios was as follows:

- Scenario 1: 65.10
- Scenario 2: 73.80

Based on the results presented, **Scenario 2** was found to be the optimum renovation scenario for the Danish demo:

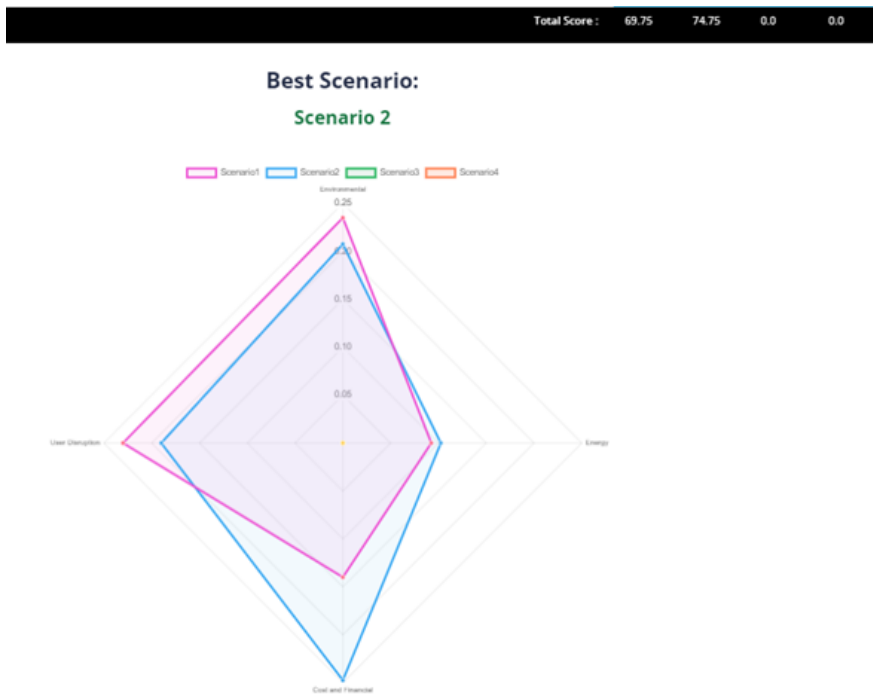


Figure 30 Selection of Optimum renovation scenario for the Danish demo by the Renovation Scenario DSS

5.4.6 Renovation Scenario to be implemented

The Danish demo leader is interested in implementing Renovation Scenario 2 which was the scenario selected by the DSS. Therefore, no deviation to the RPDA selection process is observed. However, the Danish demo is also investigating the possibility of an additional scenario which will include the PINK storage system. At the time of writing this report, this additional scenario was not available. In case this is implemented, the renovation scenario that includes the PINK system will be presented in Deliverable D6.3 – Pilot Planning and Setup (Final Version update).

6 Timeplans and set ups for the retrofitting

Below the timetables – revised several times during the RP2.

The demosites are in different fases of the building process. The timetables reflect the state of the renovation process.

6.1 Time schedule for French demo site

Retrofitting		Start M	End M
Tender and signing for selection of retrofitting contractor and subcontractors	demo leaders, advisors	Jun.22	
Sending administrative authorization of works	demo leaders, advisors	Jun.22	
Bill of Quantities	demo leaders, advisors	Jan.23	
Material/Product orders	demo leaders / contractor	Jan.23	
Preparing works	demo leaders / contractor	Jan.23	
Training of workers	Demo leaders /advisors/CERTH	Feb.23	
Works in the building to apply the technologies of scenario 3 (Thermal works)	Constructor	Mar.23	
Works in the interior of flats	Constructor	Jun.23	Nov.23

6.2 Time schedule for Greek demo site

Retrofitting		Start M	End M
Selection of the Renovation Scenario to be executed	demo leader	Feb.22	
Bill of Quantities	Design office / contractor	Jun.22	
Developing the campaign strategy	Demo leader	Jun.22	
Website of the project	Demo leader	Jun.22	
Starting the crowdfunding campaign	Demoleader + Partners	Nov.22	
Material/Product orders	Demo Leader	Mar.22	
Site preparation	demo leader	Apr.22	
Training of workers	Demo leaders /advisors/CERTH	May 23	
Delivery of material/products	Technology providers	May.22	
Retrofitting (deployment/installation)	demo leader / contractors	Jun.23	Sep.23

6.3 Time schedule for Polish demo site

Retrofitting		Start M	End M
Definition of authorisations/licenses required, Contact with relevant authorities	demo leaders	Dec.22	
Identifying funding mechanisms and applying for/securing funding	demo leaders/owners	Jan.23	
Application for relevant licenses (in parallel with conceptual and detailed design)	demo leaders (design office)	Feb.23	
Obtaining relevant licenses	demo leaders (design office)	Mar.23	
Bill of Quantities	demo leaders (contractor)	Apr.23	
Tender and signing for selection of retrofitting contractor and subcontractors	demo leaders	Apr.23	
Material/Product orders	demo leaders (contractor)	Apr.23	
Site preparation	demo leaders (contractor)	Apr.23	
Training of workers	demo leader / advisor /CERTH	May.23	
Delivery of material/products	Technology providers	May.23	
Retrofitting (deployment/installation)	demo leaders (contractor)	Jun.23	Oct.23

6.4 Time schedule for Danish demo site

The Danish demo site has been changed by an amendment during the process of the project due to problems with time schedule for implementation. The new demo site has caught up with some of the delay, and the revised timetable is shown below.

Retrofitting		Start M	End M
Finalisation of monitoring equipment	demo leader	Mar.22	
Selection of the Renovation Scenario to be executed	demo leader/building owner	Mar.22	
Appointing Design Office	demo leader/building owner	Nov.22	
Detailing project	Design Office	Feb.23	
Tender and signing for selection of retrofitting contractor and subcontractors	demo leader/ Design Office	Mar.23	
Bill of Quantities	demo leader / contractor	Mar.23	
Material/Product orders	demo leaders / contractor	Apr.23	
Delivery of material/products	Technology providers	May.23	
Site preparation	Contractor	May.23	
Training of workers	Demo leader / advisors/ CERTH	Jun.23	
Start works	Contractor	Aug.23	
Retrofitting (deployment/installation)	Contractor	Aug.23	Dec.23

7 Conclusion

The planning and scheduling of the demo sites have been challenging. There have been

delays for many different reasons, and the demo sites are at the end of the value chains. As mentioned in the beginning of this report, it is important to note that the innovation process and implementation process in the RINNO project is a dynamic, interactive process. Purpose is to test the different elements in the RINNO Suite and eliminate barriers and obstacles in the process to pave the way for replication. But it also means that the process not always is the straight and direct. There has been delays and exchanges of demo sites along the way. This is described in part 4, Deviations from the Grant Agreement.

Another big challenge is the budget. In any building or retrofitting project, it will always be the money that decides at the end. Budget allocation in an innovative demonstration project is extremely difficult, as the choice and price of the technologies to be implemented are unknown at the time of the budgeting. But all four demo sites have been very adaptive to the situation, they have accepted the solutions and the process to reach the result.

The analysis has been of great interest among the building owners. The results should perhaps have been presented earlier in the process to give the full impact. But that is one of the things that can be changed in a replication of the process.

Next steps

During the coming period, the demosites will be implementing the technologies. RINNO project will follow the process and document step by step.

Monitoring is being prepared. The work starts in M30, but as it is considered important to follow the renovation process, we will start the work in Q1 2023. Monitoring will include both metering, interviews and questionnaires.

ABOUT RINNO

RINNO is a four-year EU-funded research project that aspires to deliver greener, bio-based, less energy-intensive from a life cycle perspective and easily applicable building renovation elements and energy systems that will reduce the time and cost required for deep energy renovation, while improving the building energy performance. Its ultimate goal is to develop, validate and demonstrate an operational interface with augmented intelligence and an occupant-centered approach that will streamline and facilitate the whole lifecycle of building renovation.

For more information, please visit <https://rinno-h2020.eu/>



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