RINNO

RINNO PROJECT

An augmented intelligence-enabled stimulating framework for deep energy renovation delivering occupant-centred innovations

Deliverable D3.3: Renovation Digital Twining tool and Scenarios definition (V1)
Work Package 3: RINNO Toolkits for Improving the Building Renovation Planning & Design Phase

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Executive Summary

This Deliverable 3.3 is the first release of the report that documents the development of Renovation Digital Twin tool and scenarios definition in the RINNO project. T3.2 aiming to develop the renovation Digital Twin Scenarios Definition that prepares the virtual representation models of the buildings, defining and generating potential renovation scenarios.

Within the RINNO project, VTT upgraded the existing VTT Digital Twin toolkit to be able to provide the competency to support quick and easy building energy renovation scenarios modelling. The advanced Digital Twin tool is quick and easy to use by non-expert and provide reliable estimations for different energy renovation scenarios. The tool can be used to easily test the effect of various renovation measures on a building's energy consumption. Digital Twin toolkit enables also some more detailed data to be entered to the tool to provide more accurate estimations of various renovation measures on a building's energy consumption.

VTT Digital Twin toolkit integration with RINNO platform is described in the Figure 1.

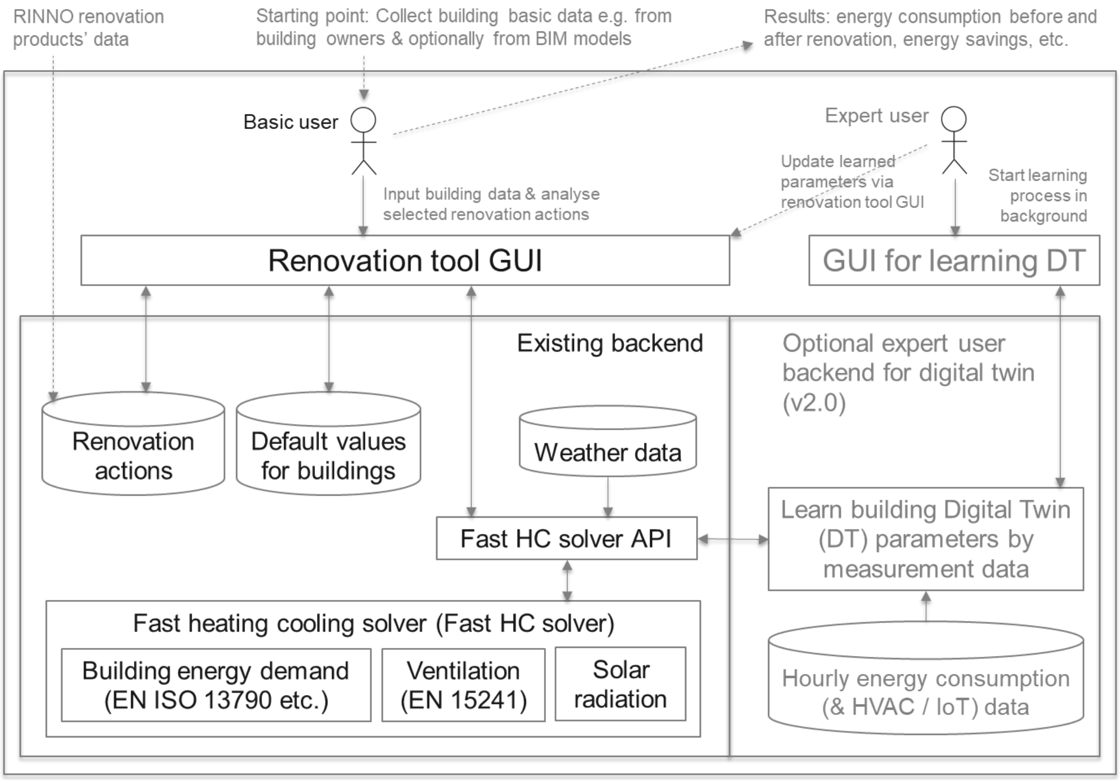

Figure 1: VTT Digital Twin tool in RINNO architecture

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Abbreviations List

API	Application Programming Interface
BEMS	Building Energy Management System
Digital Twin	A digital twin is a virtual representation of a physical object or process.
DH/DC	district heating/district cooling
DHW	Domestic Hot Water
DT	Digital Twin
GSA	Gross Surface Area
GUI	Graphical User Interface
HC	heating/cooling
HVAC	Heating, ventilation and air conditioning
IoT	Internet Of Things
N/A	not available
PV	Photovoltaic
RE	Renewable Energy
SB	System Boundaries
U-value	The rate of transfer of heat through a structure, divided by the difference in temperature across the structure.
WP	Work Package
W/O	without

1. Introduction

1.1 Purpose

The main purpose of Task 3.3 was to develop the Renovation Digital Twin that prepares the virtual representation models of the buildings that can be used in generating potential energy renovation scenarios. This was achieved by upgrading the existing VTT Digital Twin toolkit[1] to work with RINNO products and demo sites by modifying and updating the tool to work in different countries, different weather zones and with different local and product-related input data.

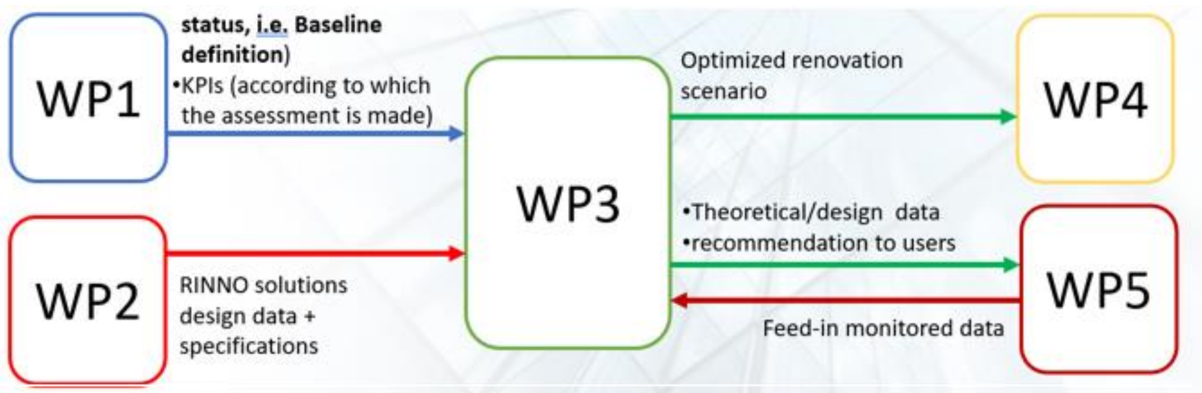
1.2 Contributions and partners

VTT is the leader of Task 3.2 and responsible for the Deliverable 3.3. In this role, VTT has upgraded the existing VTT Digital-Twin toolkit to be able to provide the competency to support building energy and cost-efficient renovation scenarios modelling for RINNO project. VTT have also participated widely many online meetings where renovation scenarios have been defined. RINA-C has been part of defining renovation scenarios to be used in VTT Digital Twin toolkit.

1.3 Relations to other activities

The Digital Twin tool receives the basic buildings geometric information from T3.1 and the specifications from the RINNO products developed within WP2. The outputs are 2-3 scenarios that are then analyzed in detail by the tool of T3.3.

Task 3.2 is part of Work Package 3 (WP3). WP3 relations to other work packages are presented in the Figure 2.



[1] http://cic.vtt.fi/epass/vtt/step_1.php?lang=en&country=

Figure 2: Overall illustration of WP3 relations to other WPs and Tasks, not describing individual products.

Purpose of the T3.1 is capturing building data and mapping of building information. T3.2 utilizes information gathered and created in the T3.1. T3.2 have direct relation to the task 3.3 and to the task 3.4 where this toolkit is utilized in scenario definition. In the RINNO renovation process Digital Twin Assessment is made after task 1.5 where RINNO scenarios are created and before task 3.3. which commits multi-criteria analysis. T3.2 relations to other tasks are presented in the Figure 3.

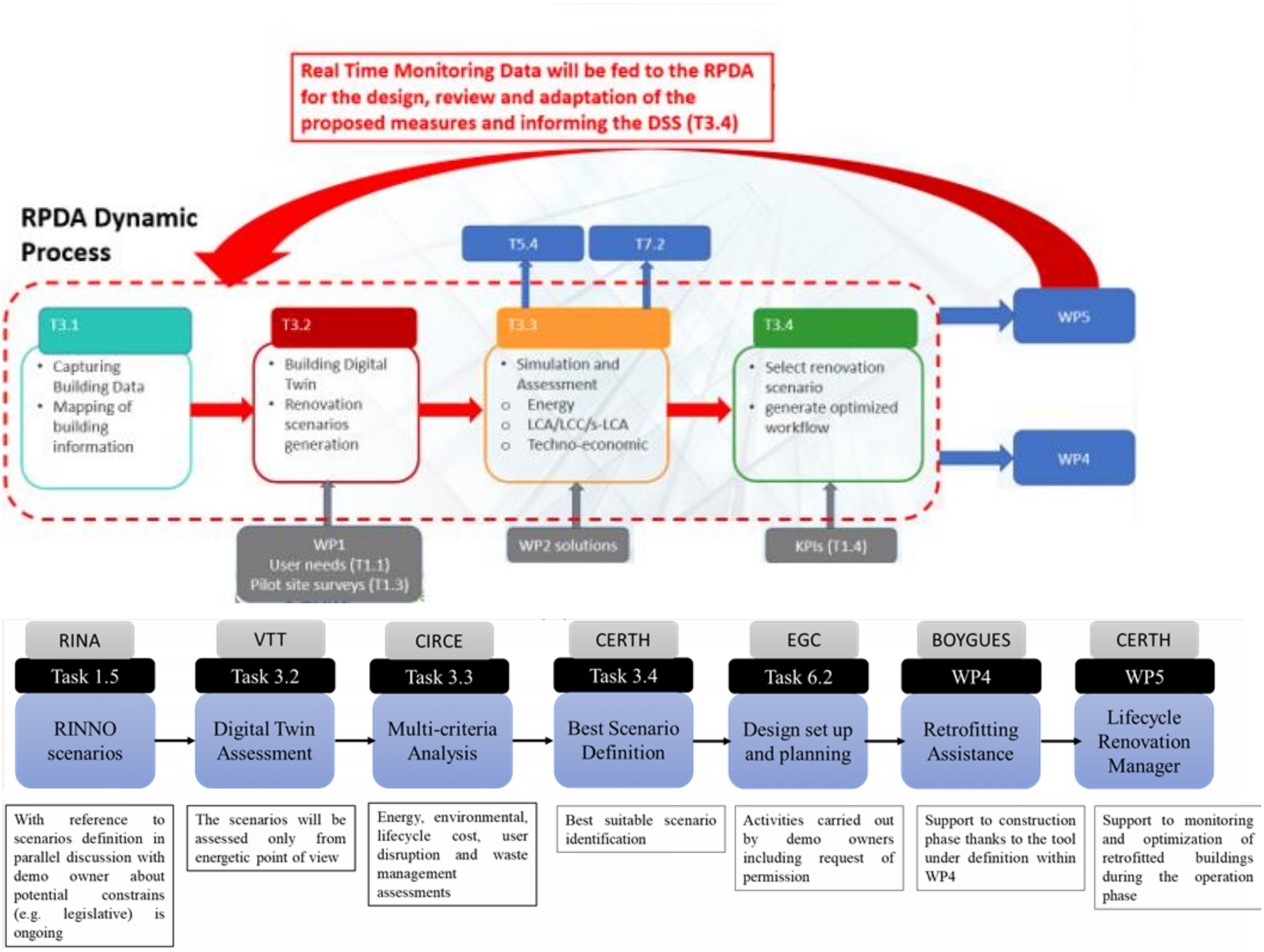


Figure 3: T3.2 relations to other Tasks and WPs.

2 Background of the VTT Digital Twin -toolkit

VTT Digital Twin -toolkit is a software tool to predict renovation actions' energy savings for the building by providing very little basic information. VTT provided existing VTT Digital Twin -toolkit asset to be used part of the RINNO project. VTT Digital Twin -toolkit is extended during the RINNO project in order to meet the needs of the RINNO project. The first version of the VTT Digital Twin -toolkit (E-PASS software) was created in the NewBEE EU project and now it is further developed in RINNO and Stardust EU projects Thus, the described work utilized results of previous EU founded projects.

VTT's expertise in the field of digital twin, energy renovations, holistic energy-performance assessment and indoor environment of buildings has been implemented in several European projects, such as STARDUST[2], MEEFS[3], MODER[4] and DESIGN4ENERGY[5], as well as development of strategic research agendas of ECTP and E2Bc. VTT has a wide experience in crossing various domains into multidisciplinary innovation processes. VTT is member of the IBPSA (International Building Performance Simulation Association). In addition, VTT has a representative within EIP SCC in the high-level group and in the Sherpa group. VTT developed the current roadmap for Smart Cities within CIB and contributes to the UN New Urban Agenda. Nationally, VTT has been a representative on the Climate change panel, which advises the Finnish Parliament regarding sustainable cities, energy, and transport systems. In addition, VTT supports Finnish legislation in urban planning, energy certificates, biofuels, and the definition of building codes, among other areas.

2.1 Status of the tool prior to RINNO (M1)

E-PASS, the tool RINNO digital tool is based on, is an assessment tool for energy efficiency improvements. The E-PASS tool developed by VTT is an easy-to-use tool for assessing the profitability of renovation measures. The tool is mainly targeted to residential buildings, but there are also alternatives for office building renovation solutions. The user's work has been facilitated as much as possible to make the assessment of the current condition of the building straightforward. It is sufficient for the user to know the key quantities of a few building

[2] https://stardustproject.eu/
[3] https://cordis.europa.eu/project/id/285411
[4] https://cordis.europa.eu/project/id/680447
[5] http://www.design4energy.eu/

parameters (extent, type of building, age, etc.), after which the energy estimate of the building can be calculated before repairs. Typical renovation actions are pre-listed for the user, after which the key performance indicators (kWh / m², kgCO2 / m², energy costs, payback periods) of the renovation action or actions can be seen. The E-PASS is meant for rough building-level energy assessments between the reference and the planned renovation actions. E-PASS was created to provide preliminary estimation about the energy flows in Figure 4 below. When using the E-PASS, detailed planning as well as component and system sizing are assumed to be done with other tools. RINNO tool is developed from E-PASS tool and covers some sizing aspects too.

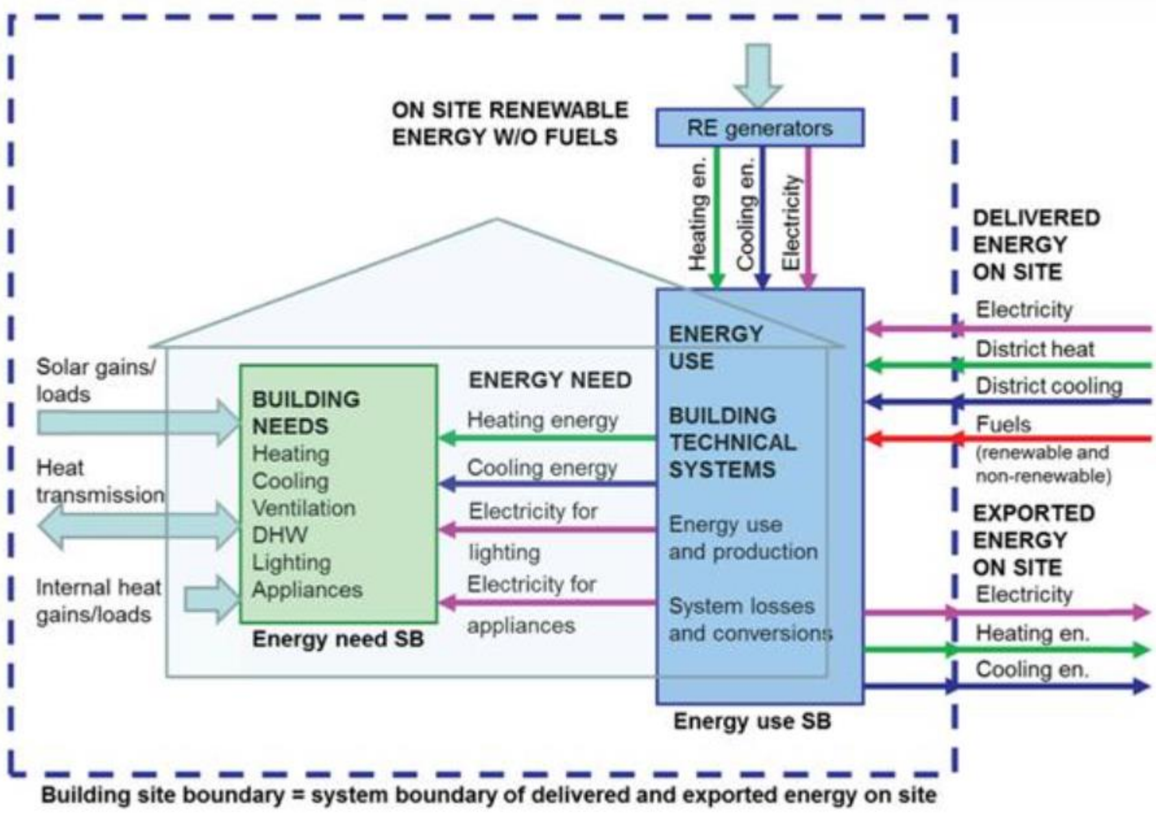


Figure 4: E-PASS was created to provide rough estimation about these energy flows. Figure from (Kurnitski, 2013).

Most of the input data, that the calculation needs, is located in a knowledge database, from where it is collected during the first assessment. These intelligent assumptions and the knowledge database were customized and fine-tuned for the selected European countries. The user has to know only few parameters of the building in the first phase of assessment; the complex simulation model is made with the help of default values stored in the databases. The tool makes assumptions for the refurbished building. Assumptions are based on the basic data of the building (location, building type etc.). The E-PASS fetches all necessary details (the U-values, window-types, water consumptions, electricity consumptions, electric appliances etc.) from the database. The building and system details can be specified afterwards as needed.

The easy-to-use-principle is as follows:

- Only few input data needed
- Results are available in few seconds
- When assessing the change because of different refurbishment measures, the basic data can be changed rather easily.

In the starting point the required initial information is as follows:
Building type

- Weather zone
- Construction year
- Room temperature (Heating set point and Cooling set point)
- Heating type
- Cooling type
- Building volume
- Floor height
- Number of floors
- Dimensions
- Number of occupants
- Number of apartments.

To assess the saving potential data about structures, windows, ventilation, hot water, electricity use, and heating type has to be handled.

VTT Digital Twin toolkit original version E-PASS can be found from this URL-address: http://cic.vtt.fi/epass/vtt/step_1.php?lang=en&country=

2.2 Advancements achieved in RINNO by M24

VTT upgraded the existing Digital Twin -toolkit to be able to provide the competency to support quick and easy building energy renovation scenarios modelling. The advanced Digital Twin-tool enables quick and easy building energy renovation scenarios modelling. The advanced Digital Twin -tool quick and easy to use by non-expert and provide reliable estimations for different renovation scenarios. The tool can be used to easily test the effect of various renovation measures on a building's energy consumption. Digital Twin -toolkit enables also more detailed data to be entered to the tool to provide more accurate estimations of various renovation measures on a building's energy consumption.

A bit similar simplified energy analysis tool was used for analyzing energy renovation scenarios in (Paiho et al., 2015c, 2013) utilizing the common approach for selecting renovation scenarios (Figure 5). Similarly, the E-pass-based tool is able to assess energy savings of different energy renovation scenarios compared to the current level of the building to be renovated. It is not meant for system level analyses. However, such simplified analyses can be used even in scientific analyses and can form the basis of wider analyses for a certain renovation process, i.e., (Paiho et al., 2015a, 2015b, 2014).

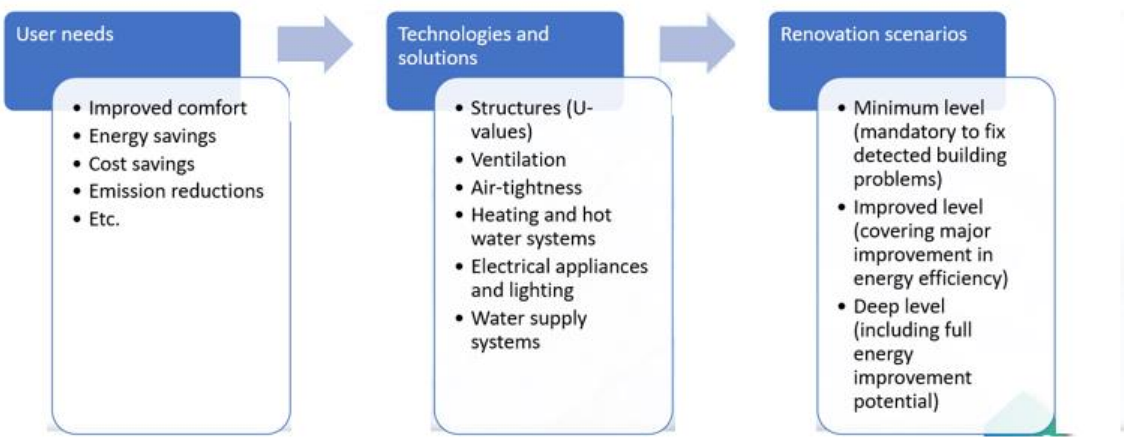


Figure 5: A common approach of defining energy renovation scenarios.

The E-pass tool was substantially modified and upscaled for RINNO. The new modifications/calculations included:

- Adding support and connectivity to Rinno renovation process toolkit
- Adding support for climate data in different geographic climates
- Adding support and connectivity to Rinno demo building solutions and technologies
- Estimated annual mechanical air flow change from original mechanical air flow before renovation
- Estimated annual infiltration air flow change from original infiltration air flow before renovation
- The U-value and total window area change from original U-value and total window area

- Total estimated windows area after replacement of windows
- The U-value changes of walls after renovations and estimation of RINNO project participants K-FLEX and EKOLAB insulation thickness if used in the renovation
- Base floor U-value change estimation after renovation and estimation of RINNO project participant K-FLEX insulation thickness if used in the renovation
- The U-value change of upper floor after renovations and estimation of RINNO project participants K-FLEX and EKOLAB insulation thickness if used in the renovation
- Efficiency estimation of heat recovery for ventilation system after renovation
- Solar collector estimation of efficiency, system loss and area targets estimations after renovation
- Main space heating estimation of delivered energy demand after renovation
- Domestic hot water estimation of delivered heating energy after renovation
- Air-to-air heat pump estimation of delivered heating energy after renovation
- Local production and solar radiation estimation of PV panels after renovation

3 VTT Digital Twin -toolkit implementation to the RINNO project

3.1 Original development plan

Figure 6 shows the original planned implementation of the VTT Digital Twin. The main idea was to utilize hourly data from the demonstration buildings (such as energy data, indoor environment measurements, control and monitoring data, etc.) and local weather data for producing a machine learning based digital twin of each building. Another model would have been made for building-level energy renovation actions. Combining these two models would have resulted as the rough energy saving assessments in the building scale. Since no hourly data was available from the RINNO demonstration buildings, this plan could not be realized. However, if such data is available later, the tool can be modified.

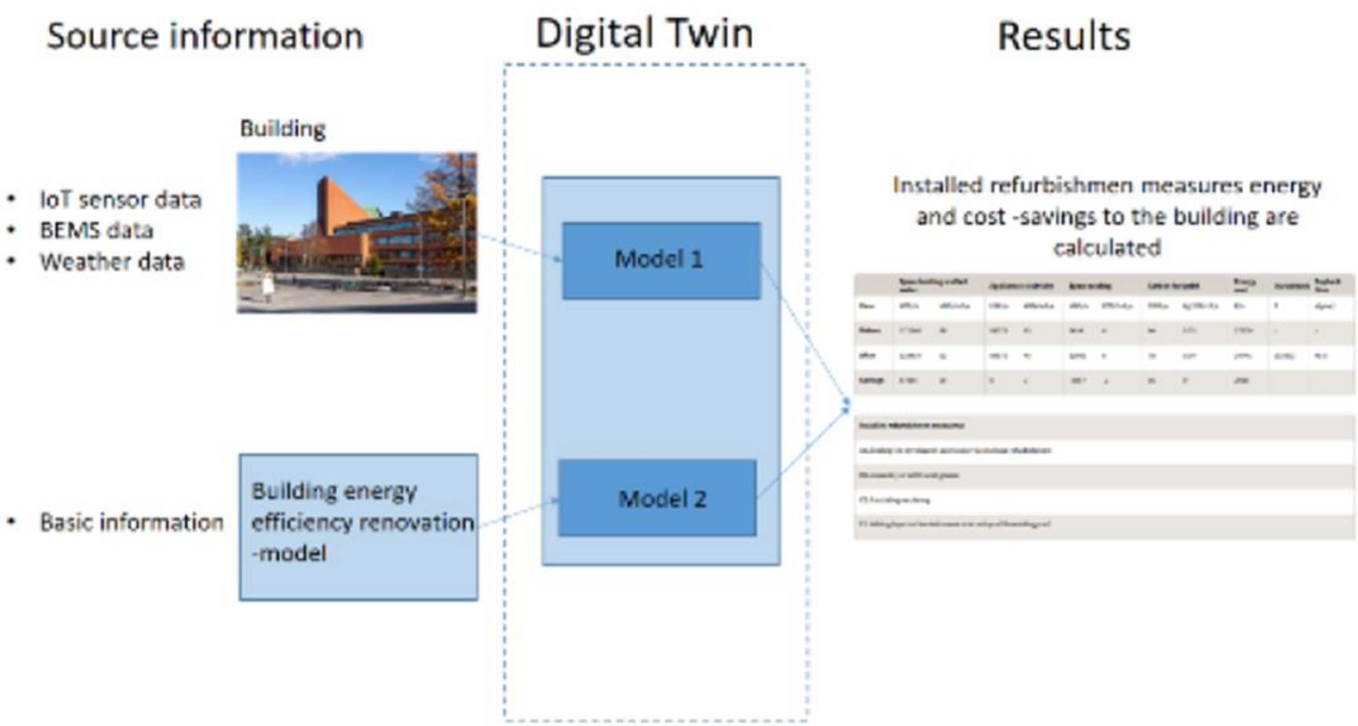


Figure 6: The original plan of VTT Digital Tool for RINNO.

3.2 Realized implementation of VTT Digital Twin -toolkit to the RINNO platform

New plan to implement VTT Digital Twin -toolkit to the RINNO platform is described in the Figure 7.

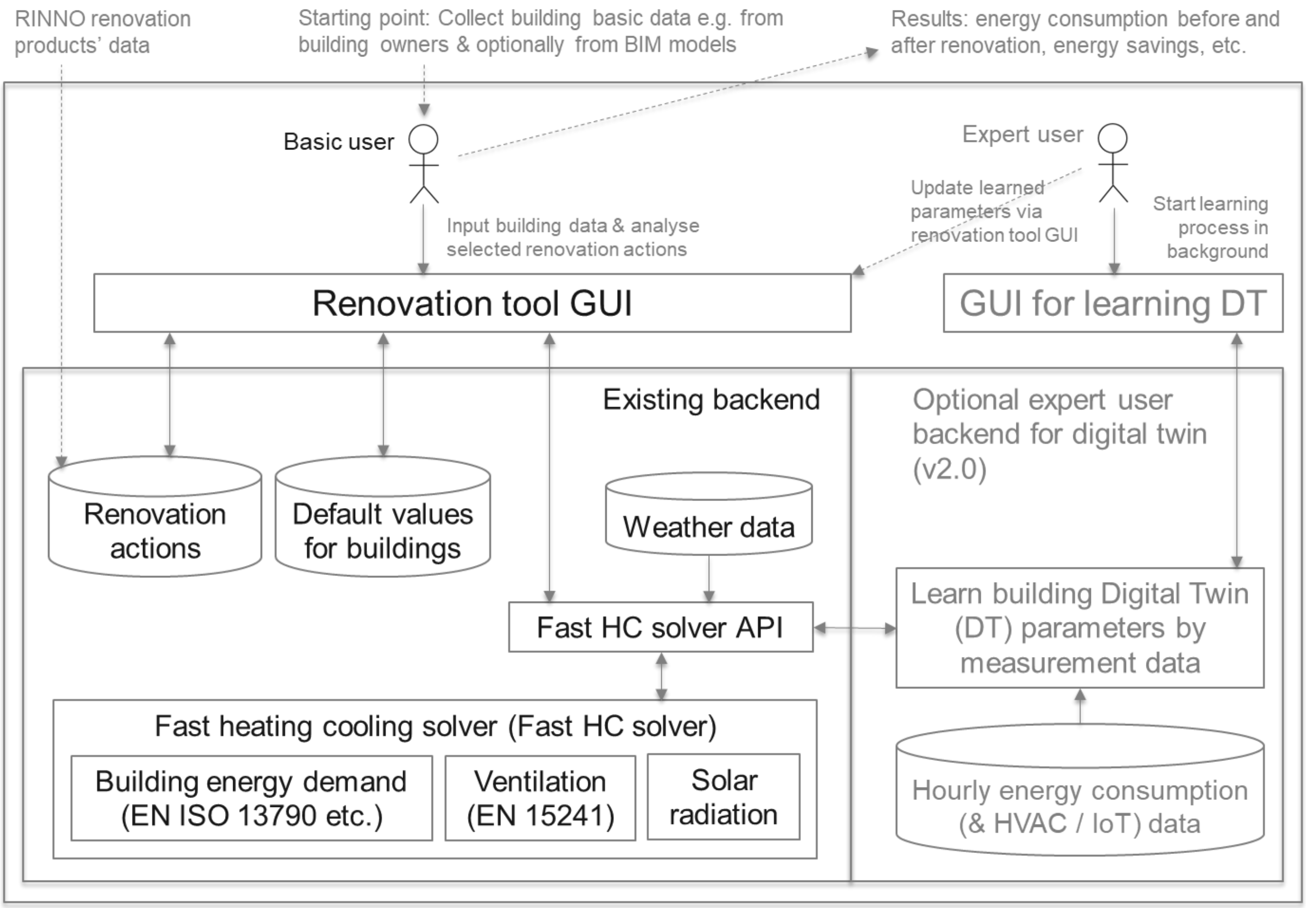


Figure 7: Architecture of the VTTs Digital Twin toolkit

With the new plan there was a need to implement new software version from previously created VTT Digital Twin toolkit to be used in RINNO platform.

3.2.1 Server installation for new version of VTT Digital Twin toolkit

VTT Digital Twin toolkit implementation to the server started by installing new server where we could start implement new version from VTT Digital Twin toolkit. Server installation included operating system installations, fixing proper user rights and firewall adjustments.

3.2.2 Infrastructure installation for use of VTT Digital Twin toolkit

After server installation proper JAVA and web infrastructure were installed to the server. After that VTT Digital Twin toolkit software was installed in the server.

3.2.3 Adapting VTT Digital Twin toolkit to local weather conditions

VTT Digital Twin toolkit needed to adapt for local weather conditions.

- Solar radiation from local weather stations were collected from every demo site of the RINNO project. The key information of the collected data sets were: timestamp, Global Horizontal Radiation [Wh / m^2], Direct normal Radiation [Wh / m^2], Diffuse Horizontal Radiation [Wh / m^2]
- Conversion to the weather data were made manually for each demo location weather data to get them in TM2 format, so that they could be utilized in the VTT Digital Twin toolkit.
- After conversion to the TM2 format, the necessary timestamp, Global Horizontal Radiation [Wh / m^2], Direct normal Radiation [Wh / m^2], Diffuse Horizontal Radiation [Wh / m^2] radiation data were entered into the VTT Digital Twin toolkit software

3.2.4 Local database for RINNO demo case building information.

Local database was implemented for different RINNO demo buildings input values for the use of VTT Digital Twin toolkit tool.

3.2.5 Baseline fine-tuning

Calculated baseline for each demo buildings were fine-tuned with RINNO partners.

3.2.6 Creating new software core to the VTT Digital Twin toolkit

Current E-PASS application has a basic renovation-options template made for the Finnish environment. Since some RINNO needs go partly beyond the purpose and functionality that the original E-PASS application can provide, modifying the renovation template of the RINNO tool to match the products of the RINNO project was surprisingly time consuming.

Every scenario has a set of renovation options. Every renovation option had to be implemented to the VTT Digital Twin toolkit. VTT Digital Twin toolkit core had to be totally renewed to be able to create new set of renovation options template to the VTT Digital Twin toolkit.

3.2.7 Detailed information to the results page

VTT Digital Twin software had to be modified to be able to calculate detailed information about renovation results:

- Estimated annual mechanical air flow change from original mechanical air flow before renovation
- Estimated annual infiltration air flow change from original infiltration air flow before renovation
- The U-value and total window area change from original U-value and total window area
- Total estimated windows are after replacement of windows
- The U-value changes of walls after renovations and estimation of RINNO project participants K-FLEX and EKOLAB insulation thickness if used in the renovation
- Base floor U-value change estimation after renovation and estimation of RINNO project participant K-FLEX insulation thickness if used in the renovation
- The U-value change of upper floor after renovations and estimation of RINNO project participants K-FLEX and EKOLAB insulation thickness if used in the renovation
- Efficiency estimation of heat recovery for ventilation system after renovation
- Solar collector estimation of efficiency, system loss and area targets estimations after renovation
- Main space heating estimation of delivered energy demand after renovation
- Domestic hot water estimation of delivered heating energy after renovation
- Air-to-air heat pump estimation of delivered heating energy after renovation
- Local production, area and solar radiation estimation of PV panels after renovation

4 RINNO project demo buildings

4.1 Greek demo building

The pilot building is a flat block of 4 floors and 2 flats per floor of 75 m^2, 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. More detailed information about the building in Table 1.

Table 1: Detailed information about the Greek building

Renovation Demo Site #1: Multi-family dwelling, GREECE	
Pilot Location	Greece / Attica / Moschato-Tavros Municipality / Piraeus Str.
Building General Info	Multifamily building,4 floors, 2×75 m^2 apartments per floor, 8 owners Part of a big social housing complex // Construction year: 1970 Conventional concrete and brick construction, no insulation, aluminium frames in windows with single glazing, oil used for heating // No BIM available
Gross Surface Area (GSA):	560 m^2
Pilot Renovation Area (PRA)	560 m^2
Purpose / Scope of Renovation:	Deep Energy Renovation of the whole building according to the Passive House Premium standard. After completion the building will be certified as the first

Renovation Demo Site #1: Multi-family dwelling, GREECE	
	EnerPHit Premium in SE Europe.
OVERVIEW OF ENERGY SUB-SYSTEMS/TECH	
RES Systems:	Already installed: Solar panels for DHW in some apartments. Included in renovation planning: a) Heat pumps (mainly mini split units) for heating/cooling, b) Solar panels for DHW and heating, c) PV's on top and on walls for the production of electricity, d) PV glazing in windows.
Electricity Storage:	Already installed: N/A. Included in renovation planning: Virtual net metering and storing the electricity produced in the public network. The owners will create an energy community and use the additional produced electricity for common uses.
Heat / Cool Storage:	Already installed: N/A. Included in renovation planning: Heat pumps.
Hybrid Systems:	Already installed: N/A. Included in renovation planning: N/A
Novel Solutions for Ventilation:	Already installed: N/A. Included in renovation planning: Ventilation systems with heat recovery and enthalpy, low noise, with smart censors for CO2, humidity and temperature, air-flow control.
Insulation Materials for the Building Envelope:	Already installed: N/A. Included in renovation planning: Exterior Insulation and Finish Systems (EIFS) with sustainable materials, calculated according to passive house standard.
Glazing:	Already installed: Single and some double glazing. Included in renovation planning: Triple glazing Low-e

Renovation Demo Site #1: Multi-family dwelling, GREECE	
	with high g-Value and additional shading system.
DH/DC Network:	Already installed: N/A. Included in renovation planning: Net metering, Installation of PV and new solar panels on the roof and on the south west external walls
Electro-mobility:	Already installed: N/A. Included in renovation planning: Charge stations for electric cars.
Parameters of the building	
Basic information:	
Building Year:	1951-1960
Cooling set point (°C):	26
Heating set point (°C):	20
Space heating type:	Old direct electricity, space heating
Heating type auxiliary:	Pellet stove, auxiliary
Space cooling type:	Electric chiller or split unit
Household electricity type:	Household electricity system
Conditioned floor area (m^2):	704
Number of floors:	4
Floor height (m):	2,85
Number of residents (-):	14

Renovation Demo Site #1: Multi-family dwelling, GREECE		
Window information		
Window type	Single	
Windows U-value (W/m²,k)	4,85	
Share of window area to south	0,35	
Share of window area of the floor area	0,35	
Building envelope properties		
	Area (m²)	U-value (W/m²K)
Outside walls	560	2,4
Roof	176	3,85
Floor	176	4,2
Ventilation and infiltration		
Mechanical ventilation system		
Air change (1/h)	2	
Heat recovery efficiency (-)	0	
Leakage air value n50 Pa (1/h)	2	
User profiles and internal gains		
Occupants (W/m²)	2	
Appliances (W/m²)	2,4	
Lighting (W/m²)	3	
Hot water system		

Renovation Demo Site #1: Multi-family dwelling, GREECE	
Total water consumption (l/person,day)	150
Share of hot water (-)	0,312
Hot water circulation pipe losses (kWh/m^2,a)	11,4
Hot water temperature (°C)	45
Cold water temperature (°C)	18
Hot water heating type main	Old direct electricity, hot water heating
Hot water heating type auxiliary	No auxiliary hot water heating system

Multi-family Building in Moschato-Tavros in Athens presented in Figure 8.

Figure 8: Greek demo building: Multi-family Building in Moschato-Tavros, Athens

4.2 French demo building

The French demonstrator is a 5-storey multi-family building (4 floors plus the ground floor) built in 1976, subdivided into 6 small flats (less than 40 sqm) per floor, each one with a single large window on the east or west side. The flats are accessed via a corridor running along the central axis of the building. The north and south fronts are completely blind. The heating system is centralized with heat generation provided by a natural gas boiler located in the boiler room. Concerning the envelope, both the walls and the roof are characterized by a low level of insulation. More detailed information about the building in Table 2.

Table 2: Detailed information about the French building

Renovation Demo Site #2: Multi-family dwelling, FRANCE	
Pilot Location	Clichy sous-bois - 74-78 chemin des Postes - FRANCE
Building General Info	30 flats multi-owner residential building with 5 floors Considered extremely inefficient due to its poorly insulation and outdated heating systems (Rated Class F) Roof area is around 400m^2. blind façade area is 300 m^2

Renovation Demo Site #2: Multi-family dwelling, FRANCE	
	and facades with opening of a total surface of 1,359 m² Construction date: 1970 // No BIM available.
Gross Surface Area (GSA):	2,000m²
Pilot Renovation Area (PRA)	2,000m²
Purpose / Scope of Renovation:	The users' association representative decided to renovate this building in order to reduce the energy bill and to valorise the asset.
OVERVIEW OF ENERGY SUB-SYSTEMS/TECH	
RES Systems:	Already installed: N/A. Included in renovation planning: A PV system will be installed on the roof, serving the objective of 12 kWh/m²/y as per thermal French regulation for RE production on site.
Electricity Storage:	Already installed: N/A. Included in renovation planning: N/A.
Heat / Cool Storage:	Already installed: N/A. Included in renovation planning: A hot water tank will be installed in the heat production room to offset the peak demand and lower the maximum capacity of the HP.
Hybrid Systems:	Already installed: N/A. Included in renovation planning: A heat pump will be installed in place of the centralized boiler.
Novel Solutions for Ventilation:	Already installed: Centralized extraction fans installed in kitchen and bathrooms. Fresh air inlet is integrated in the façade. Included in renovation planning: New centralized extraction fan with heat recovery devices will

Renovation Demo Site #2: Multi-family dwelling, FRANCE	
	be installed.
Insulation Materials for the Building Envelope:	Already installed: N/A. Included in renovation planning: Foam for the roof and glass wool for external walls with cladding as finishes will be used.
Glazing:	Already installed: Single-glazed. Included in renovation planning: Double glazed with a low e-coating.
DH/DC Network:	Already installed: N/A. Included in renovation planning: N/A.
Electro-mobility:	Already installed: N/A. Included in renovation planning: Installation of cabling infrastructure.
Parameters of the building	
Basic information:	
Building Year:	1971-1980
Cooling set point (°C):	-
Heating set point (°C):	19
Space heating type:	Old gas boiler, space heating
Heating type auxiliary:	No auxiliary space heating system
Space cooling type:	No mechanical cooling
Household electricity type:	Household electricity system
Conditioned floor area (m^2):	

Renovation Demo Site #2: Multi-family dwelling, FRANCE		
Number of floors:	5	
Floor height (m):	3	
Number of residents (-):	32	
Window information		
Window type	Double	
Windows U-value (W/m^2,k)	2	
Share of window area to south	0	
Share of window area of the floor area	0,157	
Buliding envelope properties		
	Area (m^2)	U-value (W/m^2K)
Outside walls	1000	2
Roof	310	0,31
Floor	310	0,29

Figure 9: France demo building: Sarrazins Building in Lille

4.3 Polish demo building

The Polish demonstrator is a detached building of traditional load-bearing masonry, built in 1949, with three floors above ground and a semi-basement level on the north side. It is 12 meters high and consists of 5 flats accessible through a central unheated staircase. More detailed information about the building in Table 3.

Table 3: Detailed information about the Polish building

Renovation Demo Site #3: Multi-family dwelling, Poland	
Pilot Location	Poland / Masovia Voivodship / Rajszew. Storczykowa Str. 10
Building General Info	Building consists of 5 flats, 2 floors and a cellar // Owned and managed by Commune Jablonna // Residents are rather poor people, some of them retired, some jobless, one person unable to work due to weak health condition Each dwelling is equipped with coal fired stove, there is no walls insulation (brick walls) //

Renovation Demo Site #3: Multi-family dwelling, Poland	
	Construction year: 1949 No BIM available.
Gross Surface Area (GSA):	346 m^2
Pilot Renovation Area (PRA)	346 m^2
Purpose / Scope of Renovation:	Improve thermal comfort and reduce energy use/costs. Complex modernization of the building envelope, ventilation system as well as the heating system is foreseen.
OVERVIEW OF ENERGY SUB-SYSTEMS/TECH	
RES Systems:	Already installed: N/A. Included in renovation planning: Installation of 25 kWp PV panels to cover the electricity demand of common areas and partially drive the heat pump.
Electricity Storage:	Already installed: N/A. Included in renovation planning: N/A.
Heat / Cool Storage:	Already installed: DHW storage. Not Included in renovation planning. Part of solar collector system.
Hybrid Systems:	Already installed: N/A. Included in renovation planning: N/A.
Novel Solutions for Ventilation:	Already installed: N/A. Included in renovation planning: Hybrid ventilation.
Insulation Materials for the Building Envelope:	Already installed: N/A (U=1.3 W/ m^2K). Included in renovation planning: Thermal insulation from recycled materials (0.15 W/ m^2K).
Glazing:	Already installed: Double glazing (U=3.5 W/ m^2K). Included in renovation planning: Double glazing (U=0.9

Renovation Demo Site #3: Multi-family dwelling, Poland	
	W/ m²K).
DH/DC Network:	Already installed: N/A. Included in renovation planning: N/A.
Electro-mobility:	Already installed: N/A. Included in renovation planning: N/A.
Parameters of the building	
Basic information:	
Building Year:	1941-1950
Cooling set point (°C):	-
Heating set point (°C):	20
Space heating type:	New gas boiler, space heating
Heating type auxiliary:	No auxiliary space heating system
Space cooling type:	No mechanical cooling
Household electricity type:	Commercial electricity system
Conditioned floor area (m²):	257,8
Number of floors:	3
Floor height (m):	2,80
Number of residents (-):	12
Window information	

Renovation Demo Site #3: Multi-family dwelling, Poland		
Window type	Double	
Windows U-value (W/m²,k)	1,7	
Share of window area to south	0,150	
Share of window area of the floor area	0,157	
Building envelope properties		
	Area (m²)	U-value (W/m²K)
Outside walls	450,3	0,95
Roof	247,1	0,72
Floor	201,5	1,20
Ventilation and infiltration		
Mechanical ventilation system	The building has only natural ventilation system (gravity ventilation)	
Air change (1/h)	0,5	
Heat recovery efficiency (-)	-	
Leakage air value n50 Pa (1/h)	3,0	
User profiles and internal gains		
Occupants (W/m²)	2,11	
Appliances (W/m²)	5,59	
Lighting (W/m²)	2,67	
Hot water system		
Total water	90	

Renovation Demo Site #3: Multi-family dwelling, Poland	
consumption (l/person, day)	
Share of hot water (-)	0,4
Hot water circulation pipe losses (kWh/m²,a)	-
Hot water temperature (°C)	55
Cold water temperature (°C)	10
Hot water heating type main	New gas boiler, hot water heating
Hot water heating type auxiliary	No auxiliary hot water heating system

Figure 10: Poland demo building: Masovia Voivodship in Rajszew

5 Calculating baselines for demo buildings

First, baselines were defined for demo cases. Energy consumption of each demo case were set out to define the RINNO project baseline energy consumption of each demo case building. The default data were adjusted in VTTs Digital Twin toolkit to match the demo site values. Greek demo case was used as an example in this deliverable to show how we defined baselines for all RINNO demo case building. First, the basic information was entered from the Greek demo case building to VTTs Digital Twin toolkit by using VTT Digital Twin tool user interface. User interface of the VTT Digital Twin toolkit is shown in Figure 11 below. This is how the first digital Twin estimation model was formed from a Greek building.

Users need to fill the name of the building and then choose from a drop-down list the country information, building type information and weather data information. After the user have entered these information VTTs Digital Twin toolkit fills the remaining information: cooling set point, heating set point, space heating type, space cooling type, conditioned floor area, number of floors, floor height and number of residents. Optionally the user can also change these values if needed.

The values entered, as well as the estimation results are shown in Figure 12.

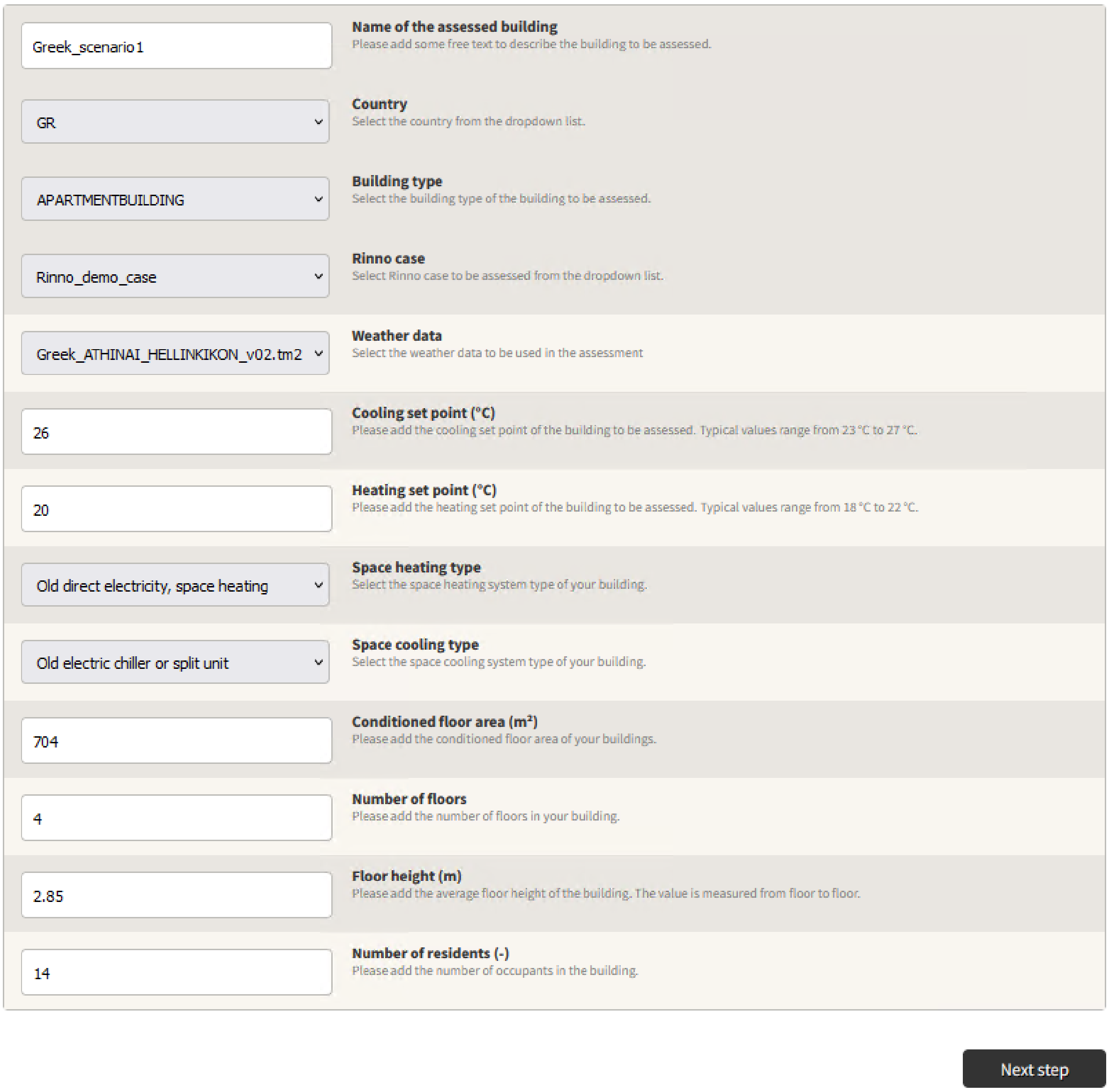


Figure 11: Greek demo case basic information in VTT Digital Twin toolkit

Please check the first estimate of your building energy consumption before refurbishment measures. If you want to check detailed input data of your building, please press the edit button below and make the changes, if needed.

Name of the assessed building	Greek_scenario1	**Country**	GR
Weather data	Greek_ATHINAI_HELLINKIKON_v02.tm2	**Building type**	APARTMENTBUILDING
Construction year	Rinno_demo_case	**Conditioned floor area (m²)**	704

Heating		
Energy	116822 kWh/a	166 kWh/m²,a
-space	100465 kWh/a	143 kWh/m²,a
-hot water	16357 kWh/a	23 kWh/m²,a
Peak load	69 kW	99 W/m²
CO2-Emissions	29 t/a	41 kg/m²,a

Cooling		
Energy	18217 kWh/a	26 kWh/m²,a
Peak load	25 kW	35 W/m²
CO2-Emissions	6 t/a	9 kg/m²,a

Electricity		
Energy	10729 kWh/a	15 kWh/m²,a
Peak load	1.2 kW	2 W/m²
CO2-Emissions	4 t/a	5 kg/m²,a

Water consumption		
Hot water consumption	239 m³/a	0.3 m³/m²,a

Edit more details   Next Step

Figure 12: Calculated first estimation model of Greek demo building by using VTTs Digital Twin toolkit.

After that more detailed information about the Greek demo building was entered to get a more accurate Digital twin of the Greek demo. This detailed information was obtained through collaboration with other partners as well as utilized the initial data and information obtained from the demo leaders.

We entered the following values into the VTT Digital twin Toolkit:

- Building name
- Building type: Apartment Building
- Building year: 1951-1960
- Cooling set point: 26 °C
- Heating set point: 20 °C
- Space heating type: VTT Digital twin toolkit have been modelled a set of space heating types. The closest modelled space heating type was chosen for Greek demo building. The closest heating type was ‘Old direct electricity, space heating’.
- Heating type auxiliary: Pellet stove, auxiliary
- Space cooling type: Electric chiller or split unit
- Household electricity type: Household electricity system
- Conditioned floor area: 704 m^2
- Number of floors: 4
- Floor height: 2,85 m
- Number of residents: 14
- Window type: Single
- Window U-value: 4.,5 W/m^2, k
- Share of window area to south: 0,35
- Share of window area of the floor area: 0,35
- Outside walls: 560 m^2
- Roof: 176 m^2
- Floor: 176 m^2
- Air change: 2 1/h
- Heat recovery efficiency: 0
- Leakage air value: 8 n50 Pa (1/h)
- Occupants: 2 W/m^2
- Appliances. Used 60% of commonly used Finnish values here, because it seemed the best estimation for the demo building: 2,4 W/m^2
- Lighting: Used 60% of commonly used values here, because it seemed the best estimation for the demo building: 3 W/m^2
- Commonly used total water consumption in Finland is 150 l/person, day. And share of hot water from whole water consumption is 31% in Finland. Hot water consumption estimation is 0,312 x 150 l/person/day = 46,8 l/person/day in our model.

- Total water consumption: 150 l/person, day
- Share of hot water: 0,312
- Hot water circulation pipe losses: 11,4 kWh/ m², a
- Hot water temperature: 45 °C
- Cold water temperature: 18 °C
- Hot water heating type main: Old direct electricity, hot water heating
- Hot water heating type auxiliary: No auxiliary hot water heating system

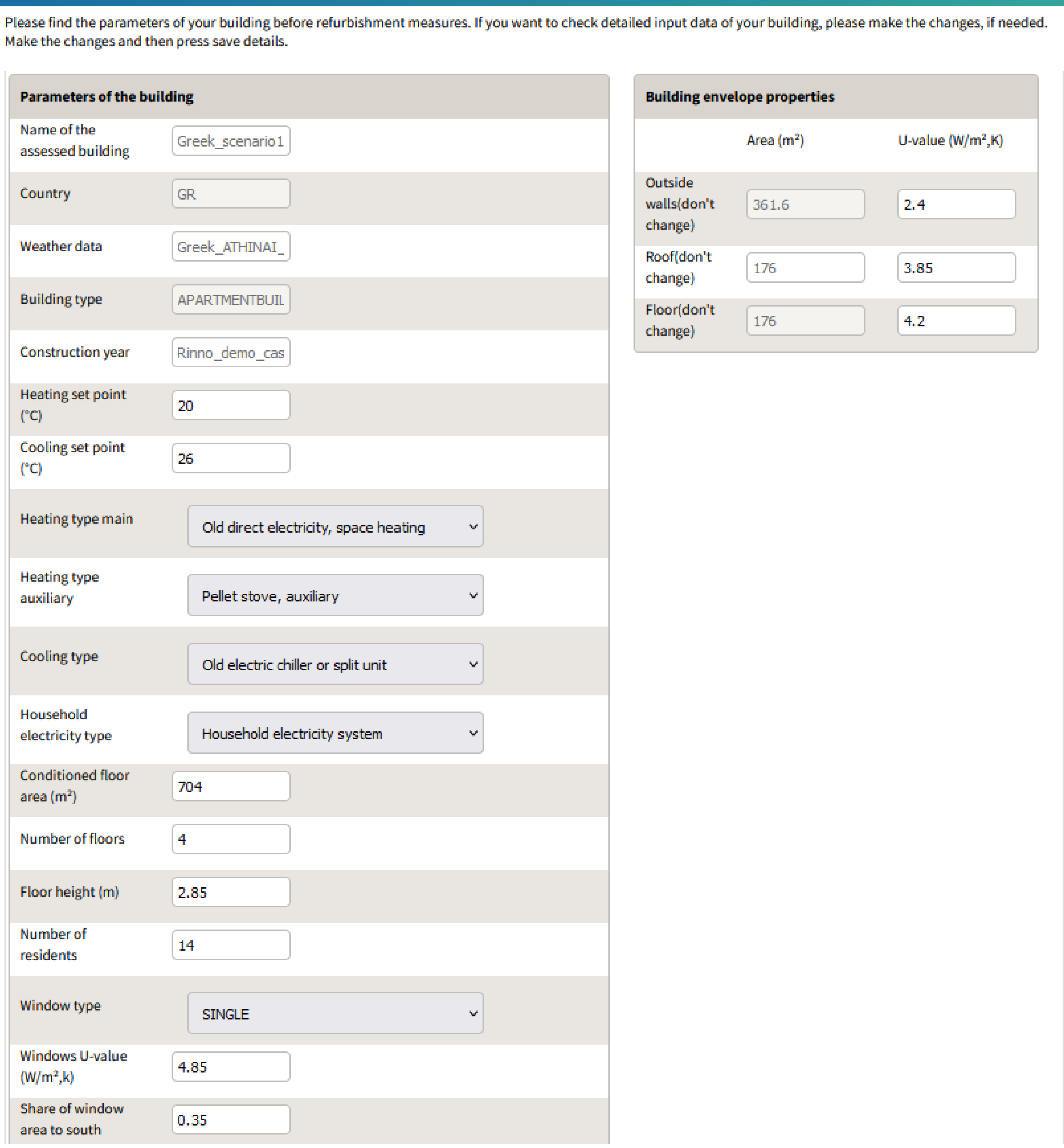
Entered values are presented in the following Table 4.

Table 4: Input values for VTT Digital twin toolkit from demo leaders.

Parameters of the building	
Basic information:	
Building name:	Multifamily Building Moschato-Tavros
Address:	Karaiskaki Str. 1 , GR-17778 Moschato
RINNO demo site name:	MOSCHATO - TAVROS (GREECE)
Building type:	Apartment Building
Building Year:	1951-1960
Cooling set point (°C):	26
Heating set point (°C):	20
Space heating type:	Old direct electricity, space heating
Heating type auxiliary:	Pellet stove, auxiliary
Space cooling type:	Electric chiller or split unit
Household electricity type:	Household electricity system
Conditioned floor area (m²):	704
Number of floors:	4
Floor height (m):	2,85
Number of residents (-):	14
Window information	
Window type	Single
Windows U-value (W/m²,k)	4,85
Share of window area to south	0,35

Share of window area of the floor area	0,35
Building envelope properties	**Area (m²)**
Outside walls	560
Roof	176
Floor	176
Ventilation and infiltration	
Mechanical ventilation system	
Air change (1/h)	2
Heat recovery efficiency (-)	0
Leakage air value n50 Pa (1/h)	8
User profiles and internal gains	
Occupants (W/m²)	2
Appliances (W/m²)	2,4
Lighting (W/m²)	3
Hot water system	
Total water consumption (l/person, day)	150
Share of hot water (-)	0,312
Hot water circulation pipe losses (kWh/m²,a)	11,4
Hot water temperature (°C)	45
Cold water temperature (°C)	18
Hot water heating type main	Old direct electricity, hot water heating
Hot water heating type auxiliary	No auxiliary hot water heating system

By entering these more detailed values, VTT Digital Twin toolkit was able to build a more accurate Digital Twin model of the Greek demo building. These values were inputted to VTTs Digital Twin toolkit user interface, which are shown in Figure 13 - Figure 14 - Figure 15.


Please find the parameters of your building before refurbishment measures. If you want to check detailed input data of your building, please make the changes, if needed. Make the changes and then press save details.

Parameters of the building	
Name of the assessed building	Greek_scenario1
Country	GR
Weather data	Greek_ATHINAI_
Building type	APARTMENTBUIL
Construction year	Rinno_demo_cas
Heating set point (°C)	20
Cooling set point (°C)	26
Heating type main	Old direct electricity, space heating
Heating type auxiliary	Pellet stove, auxiliary
Cooling type	Old electric chiller or split unit
Household electricity type	Household electricity system
Conditioned floor area (m²)	704
Number of floors	4
Floor height (m)	2.85
Number of residents	14
Window type	SINGLE
Windows U-value (W/m²,k)	4.85
Share of window area to south	0.35

Building envelope properties	Area (m²)	U-value (W/m²,K)
Outside walls(don't change)	361.6	2.4
Roof(don't change)	176	3.85
Floor(don't change)	176	4.2

Figure 13: (1/3) Greek demo case detailed information in VTTs Digital Twin toolkit

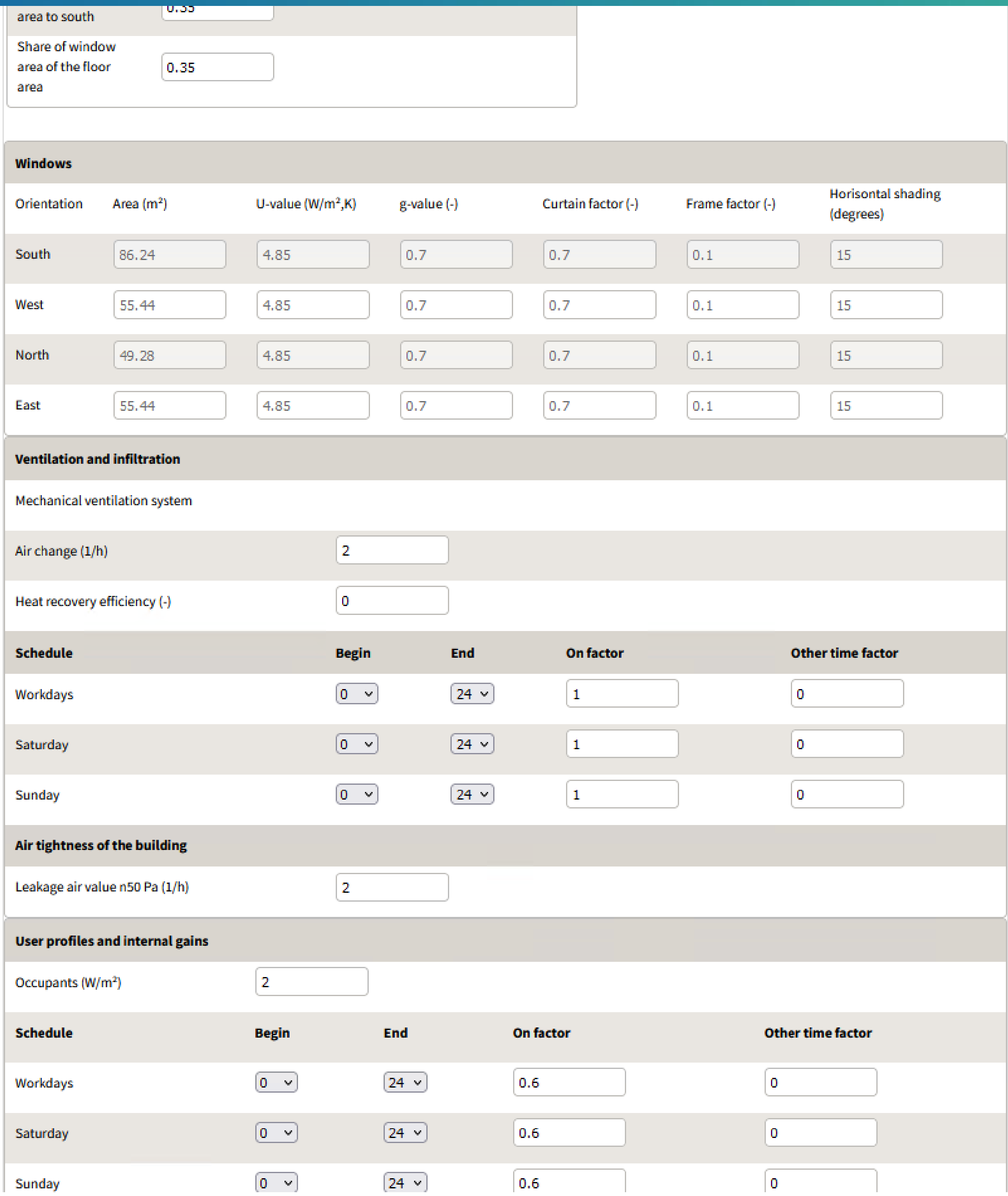


Figure 14: (2/3) Greek demo case detailed information in VTTs Digital Twin toolkit

Appliances (W/m²)	2.4			
Schedule	**Begin**	**End**	**On factor**	**Other time factor**
Workdays	0	24	0.6	0
Saturday	0	24	0.6	0
Sunday	0	24	0.6	0
Lighting (W/m²)	3			
Schedule	**Begin**	**End**	**On factor**	**Other time factor**
Workdays	0	24	0.1	0
Saturday	0	24	0.1	0
Sunday	0	24	0.1	0

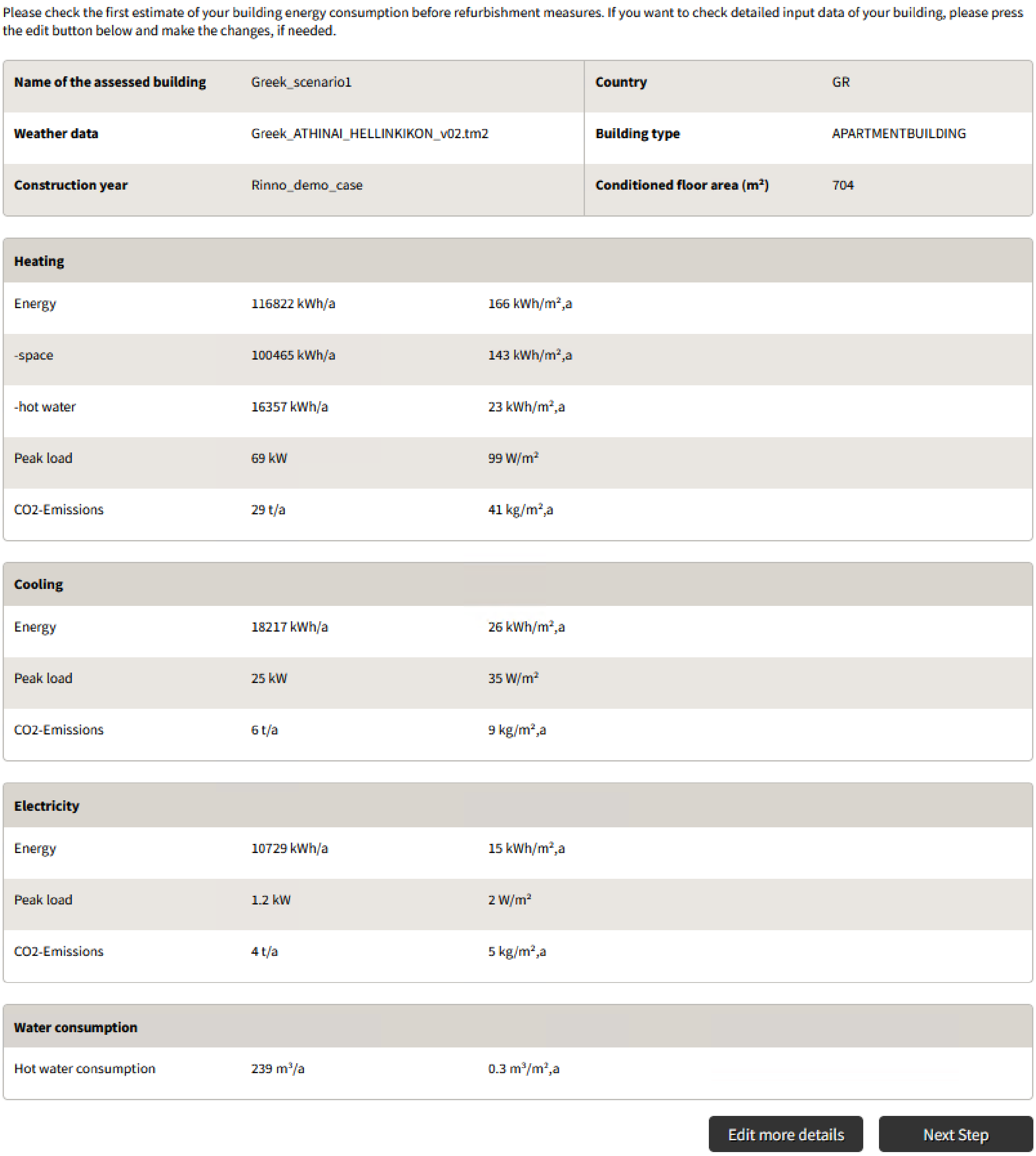
Hot water system	
Total water consumption (l/person,day)	150
Share of hot water (-)	0.312
Hot water circulation pipe losses (kWh/m²,a)	11.4
Hot water temperature (°C)	45
Cold water temperature (°C)	18
Hot water heating type main	Old direct electricity, hot water heating
Hot water heating type auxiliary	No auxiliary hot water heating system

Save details

Figure 15: (3/3) Greek demo case detailed information in VTTs Digital Twin toolkit

First the indicative digital twin from Greek demo case building was created, by entering few basic information variables into digital twin tool about the target building. Then more detailed parameters of the building were entered in the VTTs Digital Twin toolkit, which enabled us to create a more accurate Digital Twin from the Greek demo case building. This more detailed digital twin from Greek demo case building is shown in the following figure.

Later, when the different scenarios are completed, the impact of the energy consumption and RES production for different renovation options on the Greek demo case, can be assessed.



Please check the first estimate of your building energy consumption before refurbishment measures. If you want to check detailed input data of your building, please press the edit button below and make the changes, if needed.

Name of the assessed building	Greek_scenario1	**Country**	GR
Weather data	Greek_ATHINAI_HELLINKIKON_v02.tm2	**Building type**	APARTMENTBUILDING
Construction year	Rinno_demo_case	**Conditioned floor area (m^2)**	704

Heating		
Energy	116822 kWh/a	166 kWh/m^2,a
-space	100465 kWh/a	143 kWh/m^2,a
-hot water	16357 kWh/a	23 kWh/m^2,a
Peak load	69 kW	99 W/m^2
CO2-Emissions	29 t/a	41 kg/m^2,a

Cooling		
Energy	18217 kWh/a	26 kWh/m^2,a
Peak load	25 kW	35 W/m^2
CO2-Emissions	6 t/a	9 kg/m^2,a

Electricity		
Energy	10729 kWh/a	15 kWh/m^2,a
Peak load	1.2 kW	2 W/m^2
CO2-Emissions	4 t/a	5 kg/m^2,a

Water consumption		
Hot water consumption	239 m^3/a	0.3 m^3/m^2,a

Edit more details | Next Step

Figure 16: Baseline for scenarios definition after inputted detailed information.

6 Scenario definition methodology

Overall methodology for assessing the Greek Demo case renovation steps in RINNO project through the tools of the RINNO Planning and Design Assistant were:

- Preliminary evaluation and scenario definition by using VTT Digital Twin toolkit:
- The qualitative scenarios provided by RINA-C were quantified with the use of the Digital Twin toolkit. Different combinations of the existing renovation techniques were simulated. Determination of the most appropriate scenarios (2-3 scenarios). Preliminary assessment of the energy performance of these scenarios will be conducted from CERTH and HPHI and the two most promising scenarios will be selected for detailed analysis.
- Simulation with INTEMA.building (detailed energy analysis):
- The two most appropriate renovation scenarios are examined with INTEMA.building in detail to determine their energy performance and evaluate the achievement of the energy savings and power production target goals set in the GA.
- Simulation with VERIFY platform:
- The selected scenarios will also be examined with the VERIFY platform to determine the environmental and cost performance of the scenarios expressed through appropriate KPIs.
- Simulation with the TEA tool:
- The selected scenarios will also be examined to determine additional KPIs such as used disturbance and waste production.

First step in the process in renovation steps is described in this deliverable D3.3.

The use of the VTTs digital twin toolkit in the overall workflow of the renovation process in the RINNO project is described in the Figure 17, whereby the use of the VTTs digital Twin toolkit is marked with red square.

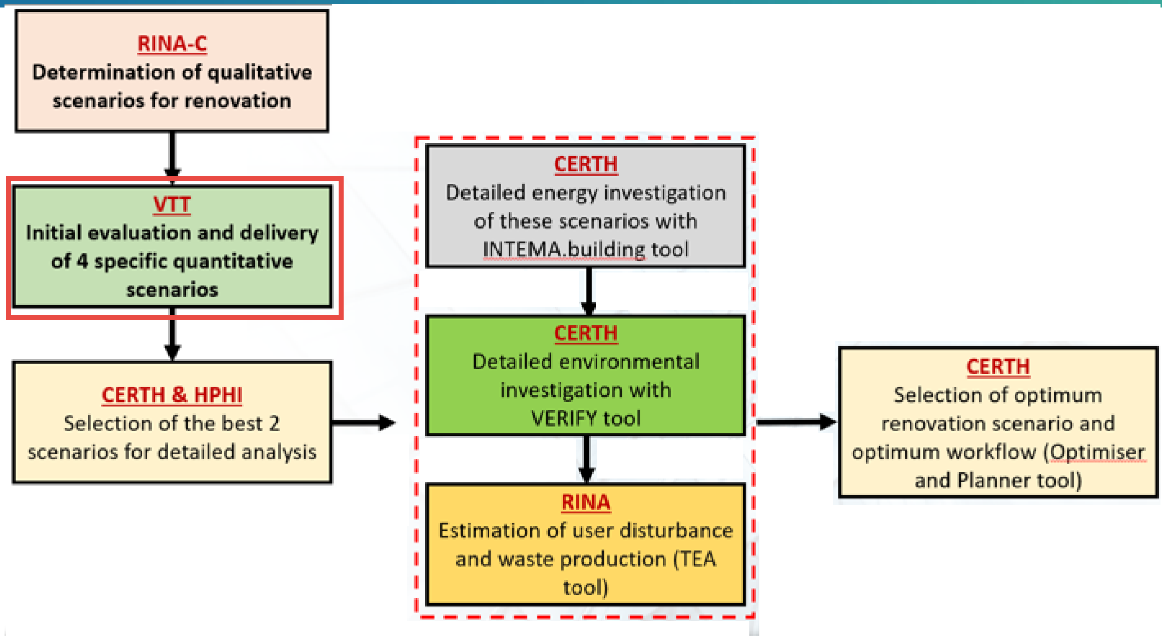


Figure 17. Use of the VTTs digital twin toolkit in red square

Initially, the plan was to utilize the RINNO scenarios defined in Task 1.3 (RINNO project, 2021). However, those scenarios did not fully take into account the needs and limitations of the actual demo buildings. Therefore, the considered scenarios were defined in one-to-one telcos with each demo sites.

7 Results after scenario renovations to the baseline

Next, we present the calculation process of different renovation scenarios using VTTs digital Twin tool. Previously, we calculated the first overall estimation for the Greek demo site utilizing VTTs digital Twin toolkit tool, as well as a more detailed baseline assessment of the site by entering more detailed information from the demo site. Afterwards estimations were calculated, which indicates how much energy consumption changes in all RINNO demo building in different scenarios. Each scenario includes renovation measures being done to the building and aim is to calculate how the renovation options, which are included in the different scenarios, will affect the demo site. The used scenarios are described more in detail in the following section 7.1.

7.1 Scenarios for demo buildings

This section presents different scenarios of all demo buildings.

7.1.1 Scenarios for Greek demo building

In this paragraph three Greek scenarios are presented. Energy saving potential of these three scenarios were calculated with VTT Digital Twin toolkit. The aim was to find the most potential energy saving scenario. Afterwards the most potential energy saving scenario will be calculated more accurately, by using more accurate tools later in the RINNO project. The three Greek scenarios and interventions of scenarios are presented in Figure 18.

Greek demo						
Intervention scenarios	**Intervention**	**Rinno technology (Yes/No)**	**If Yes, which RINNO tech**	**Number of RINNO tech per each Scenario**	**Where the intervention is done**	**VTT comments**
Scenario 1	Walls external insula	YES	Bio-based double layer panels (K-FLEX)	3	WHERE? Which facade? ALL	Ok
	Windows replacemer	NO			some thermochromic or BIPV glasses TBD? Where? No, just conventional double/triple pane window and Uf<1W/m2K	Not selected, we use thermocromic for all windows.
	Roof external insulation combined with gravel layer to reduce solar absorption	YES	Bio-based double layer panels (K-FLEX)			Ok, but no reduse to absorpti
	Installation of PV panels on the Roof	NO				Ok, target 100%
	Installation of thermochromic glasses to reduce solar absorption	YES	Thermochromic glass (GREENSTRUCT)		WHERE? Which facade? South west wall	Ok, for all windows.
	Installation of BIPV glasses	YES	integrated photovoltaic glass (GREENSTRUCT)		WHERE? Which facade? South east wall	Ok, description in results page for south wall.
	Heating generation system substitution: Air-Water Heat pumps for heating, cooling and DHW production	NO				Ok, but cooling is air-to-air
	Heating emission system substitution: mini split units	NO				Ok, AUX air-to-air
	Buffer hot water storage	YES	domestic hot water solution (PINK)			No
	South and West façade: Ventilated facade system + Blown Insulation	NO			NB: ventilated facade (classical) in place of the ZAPPA facade - is it ok @HPHI? EIFS SYSTEM	Ok, but normal insulation
	North and East façade: Ventilated facade system + Blown Insulation	NO			NB: ventilated facade (classical) in place of the ZAPPA facade - is it ok ? EIFS SYSTEM	Ok, but normali insulation
	Windows replacemer	NO			some thermochromic or BIPV glasses TBD? Where? No, just conventional double/triple pane window and Uf<1W/m2K	Not selected, we use thermocromic for all windows.

Scenario 2	Installation of thermochromic glasses to reduce solar absorption	YES	Thermochromic glass (GREENSTRUCT)	2	**WHERE? Which facade?** South west wall	Ok, for all windows.
	Installation of BIPV glasses	YES	Building integrated photovoltaic glass		**WHERE? Which facade?** South east wall	**Ok, description in results page for south wall.**
	Ventilated Roof External insulation combined with gravel layer to reduce solar	NO				Ok, but no reduse to absorpti
	Heat pump for heating, cooling and DHW production (Centralized	NO				Ok, ground souvce heat pump
	Heating emission system substitution: mini split units	NO				Ok, AUX air-to-air
	inertial storages are required both for the DHW and cooling and heating	NO				No
	Walls external insula	YES	Bio-based double layer panels (K-FLEX)		**Is it external or internal insulation?** External	Ok
	Elimination/reduction of thermal bridges	NO			**Is it a separate intervention from the previous insulation? IF YES PLEASE SPECIFY** This internvention concerns the insulation of balconies, overhangs and parapets with 5cm insulation	No
	Insulation of the basement ceiling	YES	Bio-based double layer panels (K-FLEX)			OK, base floor insulation
	Improvement of airtightness of the envelope (this will be tested at the end with a blower door test, according to the Passive House criteria n50<1,0 ACH)	NO			**Which intervention will be done specifically for this? Can we include this in the substitution of windows?** The interventions are: 1. Plastering, 2. Use of specific collars for penetrations 3. Use of specific tapes in the window installation	Ok
Scenario 3 (former SC4)	Use of cool paints and vapor retard plastering	NO		4		No
	Windows replacement	NO			Replacement with triple-glazed low-e aluminium/pvc	Not selected, we use thermocromic for all windows.
	Installation of BIPV glasses in each floor of the west	YES	Building integrated photovoltaic glass		**WHERE? Which facade?** South east wall	Ok, target 100%
	Installation of thermochromic glasses to reduce solar absorption	YES	Thermochromic glass (GREENSTRUCT)		**WHERE? Which facade?** South west wall	Ok, for all windows.
	Installation of solar collectors for hot water production	NO			**WHERE?** Roof	OK, AUX target 60%
	Installation of pv panels for electricity production	NO			**WHERE? Roof**	Ok, target 100%
	Centralized Air-water Heat pump for heating and	NO			Some specifications TO BE AGREED WITH CERTH FOR THE CORRECT SIMULATION	Ok
	Heating emission system substitution: mini split units	NO			Some specifications TO BE AGREED WITH CERTH FOR THE CORRECT SIMULATION	Ok
	Decentralized Mechanical Ventilation with heat recovery (1 unit per apartment)	YES			Some specifications TO BE AGREED WITH CERTH FOR THE CORRECT SIMULATION IT IS ALREADY SIMULATED BY CERTH	Ok
	Buffer storage	NO				No

Figure 18. Scenarios for the Greek demo building

7.1.2 Scenarios for Polish demo building

In this paragraph three Polish scenarios are presented. Energy saving potential of these three scenarios were calculated with VTT Digital Twin toolkit. The aim was to find the most potential energy saving scenario. Afterwards the most potential energy saving scenario will be calculated more accurately, by using more accurate tools later in the RINNO project. The three Polish scenarios and interventions of scenarios are presented in the Figure 19.

Polish DEMO							
Intervention scenarios	**Intervention**	**Rinno techn**	**If Yes, which RINNO tech**	**Number of RINNO tech per each Sce**	**Comments**	**Additional information for energy simulations**	VTT comments
Scenario 1 *The objective consists of fulfilling the minimum energy performance requirements for buildings in Poland*	Basement ceiling	YES	Bio-based double layer panels (K-FLEX)	4	insulation of the ceiling above the basement (area of about 60 m^2, U_{max} = 0,25 W/m^2K)		Ok
	External wall insulation	NO	-		ETICS U_{max} = 0,20 W/m^2K	Estimated area = Preferred insulation material (e.g. EPS, rockwool etc) Thickness =	Ok
	Roof insulation	YES	Isocell Cellulose Insulation (EKOLAB)		insulation of attics above flats 1, 3, 4 and 5 (area of about 120 m^2, U_{max} = 0,15 W/m^2K)	Estimated area =	OK
	Pipes insulation	YES (2)	Bio-based pipes insultation + K-BOX (both by K-FLEX)		DHW pipes insulation only (installation of solar collectors)	Estimated length pf pipes	Ok
	Flats windows substitution + basement windows substitution	NO	-		U = 0,90 W/m^2K (for heated rooms)	where?, U-value, g-values? Frame portion (if possible)?	Ok
	Installation of solar collectors on the roof	NO	-		Energy coverage for DHW at least 40%.	Which Kind of solar collector (e.g. selective flat plate collector), Area (m2)	Ok
	On-wall hot water storage tanks	YES	De-centralized domestic hot water solution (PINK)		The cooperation of the storage tank by PINK with solar collectors and gas boiler.	Details for the storage tank (Volume, insulation)	NO
	Replacement of lighting in common areas	NO			LED lighting in the staircase, basement and entrance (external)		NO, very little effect
Scenario 2 *The OBJECTIVE consists of*	Basement ceiling	YES	Bio-based double layer panels (K-FLEX)		insulation of the ceiling above the basement (area of about 60 m^2, U_{max} = 0,25 W/m^2K)		Ok
	External wall insulation	NO	-		ETICS U_{max} = 0,20 W/m^2K	Estimated area = Preferred insulation material (e.g. EPS, rockwool etc) Thickness =	Ok
	Roof insulation	YES	Isocell Cellulose Insulation (EKOLAB)		insulation of attics above flats 1, 3, 4 and 5 (area of about 120 m^2, U_{max} = 0,15 W/m^2K)	Estimated area =	Ok
	Pipes insulation	YES (2)	Bio-based pipes insultation + K-BOX (both by K-		DHW pipes insulation only (installation of solar collectors)	Estimated length pf pipes	Ok

fulfilling the minimum energy performance requirements for buildings in Poland	Flats windows substitution + basement windows substitution	NO	-	5	U = 0,90 W/m²K (for heated rooms)	where?, U-value, g-values? Frame portion (if possible)?	Ok
	Installation of solar collectors on the roof	NO	-		Energy coverage for DHW at least 40%.	Which Kind of solar collector (e.g. selective flat plate collector), Area (m2)	Ok
	On-wall hot water storage tanks	YES	De-centralized domestic hot water solution (PINK)		The cooperation of the storage tank by PINK with solar collectors and gas boiler.	Details for the storage tank (Volume, insulation)	NO
	Replacement of lighting in common areas	NO			LED lighting in the staircase, basement and entrance (external)		NO
	External walls ventilated facade – insulation + PV (south facade)	YES	Zappa PV Facade solutions (EKOLAB) + Bio-based double layer panels (K-		The PV installation should cover the needs of common parts (at least 3 kWp of PV)	where - which façade? Area	Ok
Scenario 3 *The OBJECTIVE consists of fulfilling the minimum energy performance requirements for buildings in Poland (as in scenario 2 but with additional insulation of external walls, U=0,15 W/m²K)*	Basement ceiling	YES	Bio-based double layer panels (K-FLEX)	5	insulation of the ceiling above the basement (area of about 60 m², U_{max} = 0,25 W/m²K)		Ok
	External wall insulation	NO	-		**ETICS U_{max} = 0,15 W/m²K**	Estimated area = Preferred insulation material (e.g. EPS, rockwool etc) Thickness =	Ok
	Roof insulation	YES	Isocell Cellulose Insulation (EKOLAB)		insulation of attics above flats 1, 3, 4 and 5 (area of about 120 m², U_{max} = 0,15 W/m²K)	Estimated area =	Ok
	Pipes insulation	YES (2)	Bio-based pipes insultation + K-BOX (both by K-		DHW pipes insulation only (installation of solar collectors)	Estimated length pf pipes	Ok
	Flats windows substitution + basement windows substitution	NO	-		U = 0,90 W/m²K (for heated rooms)	where?, U-value, g-values? Frame portion (if possible)?	Ok
	Installation of solar collectors on the roof	NO	-		Energy coverage for DHW at least 40%.	Which Kind of solar collector (e.g. selective flat plate collector), Area (m2)	Ok
	On-wall hot water storage tanks	YES	De-centralized domestic hot water solution (PINK)		The cooperation of the storage tank by PINK with solar collectors and gas boiler.	Details for the storage tank (Volume, insulation)	NO
	Replacement of lighting in common areas	NO			LED lighting in the staircase, basement and entrance (external)		NO
	External walls ventilated facade - insulation + PV (south facade)	YES	Zappa PV Facade solutions (EKOLAB) + Bio-based double layer panels (K-FLEX)		The PV installation should cover the needs of common parts (at least 3 kWp of PV)	where - which façade? Area	Ok

Figure 19: Scenarios for the Polish demo building

7.1.3 Scenarios for French demo building

In this paragraph three French scenarios are presented. Energy saving potential of these three scenarios were calculated with VTT Digital Twin toolkit. The aim was to find the most potential energy saving scenario. Afterwards the most potential energy saving scenario will be calculated more accurately, by using more accurate tools later in the RINNO project. The three French scenarios and interventions of scenarios are presented in Figure 20.

French Demo							
:ervention scenari	Intervention	no technology (Yes/	If Yes, which RINNO tech	Numbe r of RINNO tech per each s	Comments	Additional information for energy simulations	VTT comments
Scenario 1	Insulation of Walls (exterior side)	NO		2		Estimated area = Insulation material (e.g. EPS, rockwool etc) for thermal conductivity (W/mK) Thickness =	Ok
	Windows replacement	NO				where? Double or triple? Desired U-value, g-values? Frame portion and preferred material (if possible)?	Ok
	Pipes insulation	YES (2)	Bio-based pipes insultation + K-BOX (both by K-			Estimated length of pipes, insulation thickness and material	Ok
	Substitution of heating generation with a condensing boiler	NO				It is natural gas? Boiler efficiency? Capacity?	Ok, we use new oil boiler - it has same efficiency 0.92 / Old space and hot water heating
	Centralized double coil heat storage tank	NO				Details for the storage tank (Volume, insulation thickness)	No
	Solar collectors installed on the roof	NO				Which Kind of solar collector (e.g. selective flat plate collector), Area (m2)	Ok, we used 60% targe
Scenario 2	Insulation of Walls (exterior side)	NO		3		Estimated area = Insulation material (e.g. EPS, rockwool etc) for thermal conductivity (W/mK) Thickness =	Ok
	Windows replacement	NO				where? Double or triple? Desired U-value, g-values? Frame portion and preferred material (if possible)?	Ok
	Pipes insulation	YES (2)	Bio-based pipes insultation + K-BOX (both by K-FLEX)			Estimated length pf pipes	Ok
	Roof insulation	YES	Isocell Cellulose insulation (EKOLAB)			Estimated area = Target U-value = Target thickness (mm)	Ok
	Substition of heating generation with a Heat Pump	NO				It is an Air to Air heat pump? What is the efficiency (COP / EER) ? Capacity (kW) ?	Ok
	Substitution of emission system with radiant floor panels	NO					No, these are heat distribution
	Centralized single coil heat storage tank	NO				Details for the storage tank (Volume, insulation thickness)	No, these are heat distribution
	Centralized extraction with heat recovery	NO				Flow rate per apartment (e.g. 100 m3/h) Heat recovery effectivness (e.g. 72%) (if possible)	Ok

	PV panels installed on the roof	NO				Area (m2), slope (°), nominal efficiency or kW/m2	Ok, target 50%
Scenario 3*	Insulation of Walls (exterior side)	NO		5		Estimated area = Insulation material (e.g. EPS, rockwool etc) for thermal conductivity (W/mK) Thickness =	Ok, we chose better U-value
	Internal insulation of walls (for the single unit of the demo)	YES			K-flex double layer panels	Estimated area = Insulation material (e.g. EPS, rockwool etc) for thermal conductivity (W/mK) Thickness =	Ok
	Windows replacement	NO				where? Double or triple? Desired U-value, g-values? Frame portion and preferred material (if possible)?	Ok
	Pipes insulation	YES (2)	Bio-based pipes insultation + K-BOX (both by K-			Estimated length of pipes, insulation thickness and material	Ok
	Roof insulation	YES	Isocell Cellulose insulation (EKOLAB)			Estimated area = Target U-value = Target thickness (mm)	Ok
	Inventilate micro-ventilation unit	YES	MicroVent sustainable Ventilation system (EKOLAB)			number of units per apartment (2,4,6?) = target flow rate =	Ok, we used 0.72 - is it too low?
	Substitution of heating generation with a condensing boiler	NO				It is natural gas? Boiler efficiency?	Ok, we use new oil boiler - it has same efficiency 0.92 / Old space and hot water heating
	Centralized double coil heat storage tank	NO				Details for the storage tank (Volume, insulation thickness, material)	No, these are heat distribution
	Solar collectors installed on the roof	NO				Which Kind of solar collector (e.g. selective flat plate collector), Area (m2) Are these solar collectors for hot water?	Ok, target 60%

Figure 20: Scenarios for the French demo building

7.2 Results for the Greek scenarios

This section shows the results for the different Greek scenarios. A summary of the core results is given in the end of this section.

7.2.1 Greek scenario 1

Estimated energy consumption savings for Greek scenario 1. are compared to other scenarios in paragraph 7.2.4 Comparison between Greek scenarios.

Estimated results for Greek scenario 1 energy consumption estimation results with a list of installed renovation options are presented in Figure 21.

Installed refurbishment measures and additional information for Greek scenario 1:

- Replacement of windows with improved thermal performance (U-value) – The U-value has changed from 4,85 to 0,25 [W/ m^2,K]. Total estimated window area is 247,0 m^2.
- Replacement of windows with a new type (G-value). Window glazing has changed from SINGLE to THERMOCROMIC_GLASS. Total estimated window area is 247,0 m^2.
- Insulation of outside walls. U-value changed from 2,4 to 0,25 [W/m^2,K]. VTT Digital Twin

tool also calculated thickness values for the K-FLEX and EKOLAB products, if these products would be used to do this refurbishment measure.

- Main space heating, air to water heat pump. Annual delivered main space heating energy is 8,0 % from the original. Local production is 57,0% from the demand of 11605,0 kWh.
- DHW Air to water heat pump. Annual delivered domestic hot water heating energy is 64,0% from the original. Local production is 34,0% from the demand of 15540,0 kWh. Auxiliar hot water heating demand is 0 kWh.
- Air-to-air heat pump as an auxiliar space heating system. Annual delivered auxiliar space heating energy is 46,0% from the original. Local production is 67,0% from the demand of 46415,0 kWh. Main space heating demand is 11604,0 kWh.
- New cooling device. Annual delivered space cooling energy is 7,0 % from the original. Local production is 81,0% from the demand of 5826,0 kWh.
- Installation of PV panels, production target 100%. Estimated areas for PV panels.
    - PV roof panels (efficiency: 19,0%, system loss: 14,0%, direct: south, slope: local latitude). Estimated annual solar radiation is 2046,0 kWh/m^2. Area needed to reach the target is around 33,0 m^2.
    - PV wall panels (efficiency:14,0%, system loss: 14,0%, direct: south, slope: 90 degree). Estimated annual solar radiation is 1274,0 kWh/m^2. Are needed to reach the target is around 70,0 m^2.

Done!
Please find the results of the applied refurbishment measures. The impact is listed by sub-system type and summarized as an impact on the operational costs and CO2-emissions.

	Space heating			Hot water			Appliance electricity			Space cooling		
Delivered/Local production	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a
Before	100465	143	0	16357	23	0	10729	15	0	18217	26	18217
After	20516	29	37501	10359	15	5180	0	0	10729	1165	2	4660
Savings	79949	114		5998	8		10729	15		17052	24	

Installed refurbishmen measures:

B8. Replacement of windows with improved thermal performance (U-value) -- The U-value has changed from 4.85 to 0.25 [W/m2,K]. Total estimated window area is 247.0 m².

B11. Replacement of windows with a new type (G-value) -- Window glazing has changed from SINGLE to THERMOCHROMIC_GLASS. Total estimated window area is 247.0 m².

C2. Insulation of outside walls -- U-value changed from 2.4 to 0.25 [W/m2,K].
• K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 90.0 mm.
• EKOLAB (λ=0.037 W/mK) insulation thickness needed is around 133.0 mm.

E2. Improving heat insulation of the upper floor -- U-value changed from 3.85 to 0.16 [W/m2,K].
• K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 150.0 mm.
• EKOLAB (λ=0.037 W/mK) insulation thickness needed is around 222.0 mm.

J8. Main space heating, air to water heat pump -- Annual delivered main space heating energy is 8.0 % from the original. Local production is 57.0 % from the demand of 11604.0 kWh. Auxiliary space heating demand is 46415.0 kWh.

M8. DHW Air to water heat pump -- Annual delivered domestic hot water heating energy is 64.0 % from the original. Local production is 34.0 % from the demand of 15540.0 kWh. Auxiliary hot water heating demand is 0.0 kWh.

K5. Air-to-air heat pump as an auxiliary space heating system -- Annual delivered auxiliary space heating energy is 46.0 % from the original. Local production is 67.0 % from the demand of 46415.0 kWh. Main space heating demand is 11604.0 kWh.

L2. New cooling device -- Annual delivered space cooling energy is 7.0 % from the original. Local production is 81.0 % from the demand of 5826.0 kWh.

N8. Installation of pv panels, production target 100% -- Estimated areas for PV panels.
• PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 2046.0 kWh/m2. Area needed to reach the target is around 33.0 m².
• PV wall panels (efficiency: 14.0 % , system loss:14.0%, directed: south, slope: 90 degrees). Estimated annual solar radiation is 1274.0 kWh/m2. Area needed to reach the target is around 70.0 m².

Figure 21: Greek scenario 1 energy consumption estimation results and installed renovation options.

7.2.2 Greek scenario 2

Estimated energy consumption savings for Greek scenario 2. are compared to other scenarios in paragraph 7.2.4 Comparison between Greek scenarios.

Estimated results for Greek scenario 2 energy consumption estimation results with a list of installed renovation options are presented in the Figure 22.

Installed refurbishment measures and additional information for Greek scenario 2:

- Replacement of windows with improved thermal performance (U-value) – The U-value has changed from 4,85 to 0,25 [W/m^2,K]. Total estimated window area is 247,0 m^2.
- Replacement of windows with a new type (G-value). Window glazing has changed

from SINGLE to THERMOCROMIC_GLASS. Total estimated window area is 247,0 m^2.

- Improving heat insulation of upper floor. U-value changed from 3,85 to 0,16 [W/m^2,K] VTT Digital Twin tool also calculated thickness values for the K-FLEX and EKOLAB products, if these products would be used to do this refurbishment measure.
- Main space heating, ground source heat pump. Annual delivered main space heating energy is 6,0 % from the original. Local production is 70,0% from the demand of 11604,0 kWh.
- DHW: Ground source heat pump. Annual delivered domestic hot water heating energy is 42,0% from the original. Local production is 57,0% from the demand of 15540,0 kWh. Auxiliar hot water heating demand is 0 kWh. Values are coming from improved system efficiency.
- Air-to-air heat pump as an auxiliar space heating system. Annual delivered auxiliar space heating energy is 46,0% from the original. Local production is 67,0% from the demand of 46415,0 kWh. Main space heating demand is 11604,0 kWh.
- New cooling device. Annual delivered space cooling energy is 7,0 % from the original. Local production is 81,0% from the demand of 5826,0 kWh.
- Installation of PV panels, production target 100%. Estimated areas for PV panels.
  - PV roof panels (efficiency: 19,0%, system loss: 14,0%, direct: south, slope: local latitude). Estimated annual solar radiation is 2046,0 kWh/m^2. Area needed to reach the target is around 33,0 m^2.
  - PV wall panels (efficiency:14,0%, system loss: 14,0%, direct: south, slope: 90 degree). Estimated annual solar radiation is 1274,0 kWh/m^2. Are needed to reach the target is around 70,0 m^2.

Done!
Please find the results of the applied refurbishment measures. The impact is listed by sub-system type and summarized as an impact on the operational costs and CO2-emissions.

	Space heating			Hot water			Appliance electricity			Space cooling		
Delivered/Local production	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a
Before	100465	143	0	16357	23	0	10729	15	0	18217	26	18217
After	18988	27	39030	6756	10	8783	0	0	10729	1165	2	4660
Savings	81477	116		9601	13		10729	15		17052	24	

Installed refurbishmen measures:

B8. Replacement of windows with improved thermal performance (U-value) -- The U-value has changed from 4.85 to 0.25 [W/m2,K]. Total estimated window area is 247.0 m².

B11. Replacement of windows with a new type (G-value) -- Window glazing has changed from SINGLE to THERMOCHROMIC_GLASS. Total estimated window area is 247.0 m².

C2. Insulation of outside walls -- U-value changed from 2.4 to 0.25 [W/m2,K].
* K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 90.0 mm.
* EKOLAB (λ=0.037 W/mK) insulation thickness needed is around 133.0 mm.

E2. Improving heat insulation of the upper floor -- U-value changed from 3.85 to 0.16 [W/m2,K].
* K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 150.0 mm.
* EKOLAB (λ=0.037 W/mK) insulation thickness needed is around 222.0 mm.

J5. Main space heating, ground source heat pump -- Annual delivered main space heating energy is 6.0 % from the original. Local production is 70.0 % from the demand of 11604.0 kWh. Auxiliary space heating demand is 46415.0 kWh.

M5. DHW Ground source heat pump -- Annual delivered domestic hot water heating energy is 42.0 % from the original. Local production is 57.0 % from the demand of 15540.0 kWh. Auxiliary hot water heating demand is 0.0 kWh.

K5. Air-to-air heat pump as an auxiliary space heating system -- Annual delivered auxiliary space heating energy is 46.0 % from the original. Local production is 67.0 % from the demand of 46415.0 kWh. Main space heating demand is 11604.0 kWh.

L2. New cooling device -- Annual delivered space cooling energy is 7.0 % from the original. Local production is 81.0 % from the demand of 5826.0 kWh.

N8. Installation of pv panels, production target 100% -- Estimated areas for PV panels.
* PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 2046.0 kWh/m2. Area needed to reach the target is around 33.0 m².
* PV wall panels (efficiency: 14.0 % , system loss:14.0%, directed: south, slope: 90 degrees). Estimated annual solar radiation is 1274.0 kWh/m2. Area needed to reach the target is around 70.0 m².

Figure 22: Greek scenario 2 energy consumption estimation results and installed renovation options.

7.2.3 Greek scenario 3

Estimated energy consumption savings for Greek scenario 3. are compared to other scenarios in paragraph 7.2.4 Comparison between Greek scenarios.

Estimated results for Greek scenario 3 energy consumption estimation results with a list of installed renovation options are presented in the Figure 23.

Installed refurbishment measures and additional information for Greek scenario 3:

- Installing new ventilation system. Estimated annual mechanical air flow is 23,0% from original.
- Sealing the envelope. Estimated annual infiltration air flow is 21,0% from original.
- Replacement of windows with improved thermal performance (U-value) – The U-value

has changed from 4,85 to 0,25 [W/m^2,K]. Total estimated window area is 247,0 m^2.

- Replacement of windows with a new type (G-value). Window glazing has changed from SINGLE to THERMOCROMIC_GLASS. Total estimated window area is 247,0 m^2.
- Insulation of outside walls. U-value changed from 2,4 to 0,25 [W/m^2,K]
  VTT Digital Twin tool also calculated thickness values for the K-FLEX and EKOLAB products, if these products would be used to do this refurbishment measure.
- Improving heat insulation of upper floor. U-value changed from 3,85 to 0,16 [W/m^2,K]
  VTT Digital Twin tool also calculated thickness values for the K-FLEX and EKOLAB products, if these products would be used to do this refurbishment measure.
- Heat recovery for ventilation system. Efficiency has changed from 0,0 to 0,89.
- Solar collector as an auxiliary hot water system, share target 60%. Estimated annual solar radiation is 2046,0 kWh/m^2. Solar collector (efficiency: 38,0 %, system loss:14,0%, direct: south, slope: local latitude) needed to reach the target is around 10,0 m^2. Total annual solar radiation is estimated from the local weather data estimation and from the target of generating 60% with solar collectors.
- Main space heating, air to water heat pump. Annual delivered main space heating energy is 1,0 % from the original. Local production is 57,0% from the demand of 18,0 kWh.
- DHW Air to water heat pump. Annual delivered domestic hot water heating energy is 26,0% from the original. Local production is 34,0% from the demand of 6216,0 kWh. Auxiliar hot water heating demand is 9324 kWh.
- Air-to-air heat pump as an auxiliar space heating system. Annual delivered auxiliar space heating energy is 1,0% from the original. Local production is 34,0% from the demand of 6216 kWh. Main space heating demand is 9324,0 kWh.
- New cooling device. Annual delivered space cooling energy is 37,0 % from the original. Local production is 81,0% from the demand of 32828,0 kWh.
- Installation of PV panels, production target 100%. Estimated areas for PV panels.
  - PV roof panels (efficiency: 19,0%, system loss: 14,0%, direct: south, slope: local latitude). Estimated annual solar radiation is 2046,0 kWh/m^2. Area needed to reach the target is around 33,0 m^2.
  - PV wall panels (efficiency:14,0%, system loss: 14,0%, direct: south, slope: 90 degree). Estimated annual solar radiation is 1274,0 kWh/m^2. Are needed to

reach the target is around 70,0 m^2.

Done!
Please find the results of the applied refurbishment measures. The impact is listed by sub-system type and summarized as an impact on the operational costs and CO2-emissions.

	Space heating			Hot water			Appliance electricity			Space cooling		
Delivered/Local production	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a
Before	100465	143	0	16357	23	0	10729	15	0	18217	26	18217
After	31	0	57	4144	6	11395	0	0	10729	6566	9	26262
Savings	100434	143		12213	17		10729	15		11651	17	

Installed refurbishmen measures:
A2. Installing new ventilation system -- Estimated annual mechanical air flow is 23.0 % from original.
A5. Sealing the envelope -- Estimated annual Infilatration air flow is 21.0 % from original.
B8. Replacement of windows with improved thermal performance (U-value) -- The U-value has changed from 4.85 to 0.25 [W/m2,K]. Total estimated window area is 247.0 m².
B11. Replacement of windows with a new type (G-value) -- Window glazing has changed from SINGLE to THERMOCHROMIC_GLASS. Total estimated window area is 247.0 m².
C2. Insulation of outside walls -- U-value changed from 2.4 to 0.25 [W/m2,K]. * K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 90.0 mm. * EKOLAB (λ=0.037 W/mK) insulation thickness needed is around 133.0 mm.
D2. Adding layers of insulation material on top of the base floor -- U-value changed from 4.2 to 0.83 [W/m2,K]. * K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 25.0 mm.
E2. Improving heat insulation of the upper floor -- U-value changed from 3.85 to 0.16 [W/m2,K]. * K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 150.0 mm. * EKOLAB (λ=0.037 W/mK) insulation thickness needed is around 222.0 mm.
G2. Heat recovery for ventilation system -- Efficiency has changed from 0.0 to 0.89.
H5. Solar collector as an auxiliary hot water system, share target 60% -- Estimated annual solar radiation is 2046.0 kWh/m2. Solar collector (efficiency: 38.0 % , system loss:14.0%, directed: south, slope: local latitude) needed to reach the target is around 10.0 m²
J8. Main space heating, air to water heat pump -- Annual delivered main space heating energy is 1.0 % from the original. Local production is 57.0 % from the demand of 18.0 kWh. Auxiliary space heating demand is 71.0 kWh.
M8. DHW Air to water heat pump -- Annual delivered domestic hot water heating energy is 26.0 % from the original. Local production is 34.0 % from the demand of 6216.0 kWh. Auxiliary hot water heating demand is 9324.0 kWh.
K5. Air-to-air heat pump as an auxiliary space heating system -- Annual delivered auxiliary space heating energy is 1.0 % from the original. Local production is 67.0 % from the demand of 71.0 kWh. Main space heating demand is 18.0 kWh.
L2. New cooling device -- Annual delivered space cooling energy is 37.0 % from the original. Local production is 81.0 % from the demand of 32828.0 kWh.
N8. Installation of pv panels, production target 100% -- Estimated areas for PV panels. * PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 2046.0 kWh/m2. Area needed to reach the target is around 33.0 m². * PV wall panels (efficiency: 14.0 % , system loss:14.0%, directed: south, slope: 90 degrees). Estimated annual solar radiation is 1274.0 kWh/m2. Area needed to reach the target is around 70.0 m².

Figure 23: Greek scenario 3 energy consumption estimation results and installed renovation options.

7.2.4 Comparison between Greek scenarios

All three Greek scenarios main results are collected to on table 5. Comparison shows clearly that calculated estimation is that scenario 3 is saving energy most of the tree scenarios.

Table 5: Three Greek scenarios main results

Space heating						
	Scenario 1		**Scenario 2**		**Scenario 3**	
	Delivered	Local	Delivered	Local	Delivered	Local

	kWh/a	production	kWh/a	production	kWh/a	production
Before	100465	0	100465	0	100465	0
After	20516	37501	18988	39030	31	57
Savings	**79949**		**81477**		**100434**	
Hot water						
	Scenario 1		**Scenario 2**		**Scenario 3**	
	Delivered kWh/a	Local production	Delivered kWh/a	Local production	Delivered kWh/a	Local production
Before	16357	0	16357	0	16357	0
After	10359	5180	6756	8783	4144	11395
Savings	**5998**		**9601**		**12213**	
Appliance electricity						
	Scenario 1		**Scenario 2**		**Scenario 3**	
	Delivered kWh/a	Local production	Delivered kWh/a	Local production	Delivered kWh/a	Local production
Before	10729	0	10729	0	10729	0
After	0	10729	0	10729	0	10729
Savings	**10729**		**10729**		**10729**	
Space cooling						
	Scenario 1		**Scenario 2**		**Scenario 3**	
	Delivered kWh/a	Local production	Delivered kWh/a	Local production	Delivered kWh/a	Local production
Before	18217	18217	18217	18271	18217	18217
After	1165	4660	1165	4660	6566	26262
Savings	**17052**		**17052**		**11651**	

7.3 Results for the Polish scenarios

This section shows the results for the different Polish scenarios. A summary of the core results is given in the end of this section.

7.3.1 Polish scenario 1

Estimated energy consumption savings for Polish scenario 1. are compared to other scenarios in paragraph 7.3.4 Comparison between Polish scenarios.

Estimated results for Polish scenario 1 energy consumption estimation results with a list of installed renovation options are presented in the Figure 24.

Installed refurbishment measures and additional information for Polish scenario 1:

- Replacement of windows with improved thermal performance (U-value) – The U-value has changed from 1,7 to 0,9 [W/m^2,K]. Total estimated window area is 41,0 m^2.
- Replacement of windows with a new type (G-value). Window glazing has changed from DOUBLE to SELECTIVEDOUBLE. Total estimated window area is 41,0 m^2.
- Insulation of outside walls. U-value changed from 0,95 to 0,2 [W/m^2,K]
  VTT Digital Twin tool also calculated thickness values for the K-FLEX and EKOLAB products, if these products would be used to do this refurbishment measure.
- Adding layer of insulation material on top of the base floor. U-value changed from 1,2 to 0,25 [W/m^2,K].
- Improving heat insulation of upper floor. U-value changed from 0,72 to 0,15 [W/m^2,K]
  VTT Digital Twin tool also calculated thickness values for the K-FLEX and EKOLAB products, if these products would be used to do this refurbishment measure.
- Solar collector as an auxiliary hot water system, when share target is 40%. Estimated annual solar radiation is 918,0 kWh/m^2. Solar collector (efficiency: 38,0 %, system loss:14,0%, direct: south, slope: local latitude) needed to reach the target is around 11,0 m^2. 40% share target means how much of the needed annual hot domestic water is produced by the solar heat collectors.
- Insulating hot water heating system pipes. Hot water circulation pipe losses from 10,0 to 5,0 kWh/m^2,a. Target is to halve pipe losses.

Done!
Please find the results of the applied refurbishment measures. The impact is listed by sub-system type and summarized as an impact on the operational costs and CO2-emissions.

	Space heating			Hot water			Appliance electricity			Space cooling		
Delivered/Local production	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a
Before	76759	298	0	17546	68	0	8183	32	0	0	0	0
After	23925	93	0	8980	35	0	8183	32	0	0	0	0
Savings	52834	205		8566	33		0	0		0	0	

Installed refurbishmen measures:
B2. Replacement of windows with improved thermal performance (U-value) -- The U-value has changed from 1.7 to 0.9 [W/m2,K]. Total estimated window area is 41.0 m².
B5. Replacement of windows with a new type (G-value) -- Window glazing has changed from DOUBLE to SELECTIVEDOUBLE. Total estimated window area is 41.0 m².
C2. Insulation of outside walls -- U-value changed from 0.95 to 0.2 [W/m2,K]. • K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 99.0 mm. • EKOLAB (λ=0.037 W/mK) insulation thickness needed is around 147.0 mm.
D2. Adding layers of insulation material on top of the base floor -- U-value changed from 1.2 to 0.25 [W/m2,K]. • K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 80.0 mm.
E2. Improving heat insulation of the upper floor -- U-value changed from 0.72 to 0.15 [W/m2,K]. • K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 132.0 mm. • EKOLAB (λ=0.037 W/mK) insulation thickness needed is around 196.0 mm.
H2. Solar collector as an auxiliary hot water system, share target 40% -- Estimated annual solar radiation is 918.0 kWh/m2. Solar collector (efficiency: 38.0% , system loss:14.0%, directed: south, slope: local latitude) needed to reach the target is around 11.0 m²
O2. Insulating hot water heating system pipes -- Hot water circulation pipe losses from 10.0 to 5.0 kWh/m²,a

Figure 24: Polish scenario 1 energy consumption estimation results and installed renovation options.

7.3.2 Polish scenario 2

Estimated energy consumption savings for Polish scenario 2. are compared to other scenarios in paragraph 7.3.4 Comparison between Polish scenarios.

Estimated results for Polish scenario 2 energy consumption estimation results with a list of installed renovation options are presented in the Figure 25.

Installed refurbishment measures and additional information for Polish scenario 2:

- Replacement of windows with improved thermal performance (U-value) – The U-value has changed from 1,7 to 0,9 [W/m^2,K]. Total estimated window area is 41,0 m^2.
- Replacement of windows with a new type (G-value). Window glazing has changed from DOUBLE to SELECTIVEDOUBLE. Total estimated window area is 41,0 m^2.
- Adding layer of insulation material on top of the base floor. U-value changed from 1,2 to 0,25 [W/m^2,K]. VTT Digital Twin tool also calculated thickness values for the K-FLEX and EKOLAB products, if these products would be used to do this refurbishment measure.

- Solar collector as an auxiliary hot water system, share target 40%. Estimated annual solar radiation is 918,0 kWh/m². Solar collector (efficiency: 38,0 %, system loss:14,0%, direct: south, slope: local latitude) needed to reach the target is around 11,0 m².
- Installation of PV panels, production target 50%. Estimated areas for PV panels to cover the target. Appliance electricity, local production is 4092,0 kWh/a.

    - PV roof panels (efficiency: 19,0%, system loss: 14,0%, direct: south, slope: local latitude). Estimated annual solar radiation is 2046,0 kWh/m². Area needed to reach the target is around 28,0 m².
    - PV wall panels (efficiency:14,0%, system loss: 14,0%, direct: south, slope: 90 degree). Estimated annual solar radiation is 1274,0 kWh/m². Are needed to reach the target is around 70,0 m².
- Insulating hot water heating system pipes. Hot water circulation pipe losses from 10,0 to 5,0 kWh/m²,a

Done!
Please find the results of the applied refurbishment measures. The impact is listed by sub-system type and summarized as an impact on the operational costs and CO2-emissions.

	Space heating			Hot water			Appliance electricity			Space cooling		
Delivered/Local production	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a
Before	76759	298	0	17546	68	0	8183	32	0	0	0	0
After	23925	93	0	8980	35	0	4091	16	4091	0	0	0
Savings	52834	205		8566	33		4092	16		0	0	

Installed refurbishmen measures:

B2. Replacement of windows with improved thermal performance (U-value) -- The U-value has changed from 1.7 to 0.9 [W/m2,K]. Total estimated window area is 41.0 m².

B5. Replacement of windows with a new type (G-value) -- Window glazing has changed from DOUBLE to SELECTIVEDOUBLE. Total estimated window area is 41.0 m².

C2. Insulation of outside walls -- U-value changed from 0.95 to 0.2 [W/m2,K].
• K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 99.0 mm.
• EKOLAB (λ=0.037 W/mK) insulation thickness needed is around 147.0 mm.

D2. Adding layers of insulation material on top of the base floor -- U-value changed from 1.2 to 0.25 [W/m2,K].
• K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 80.0 mm.

E2. Improving heat insulation of the upper floor -- U-value changed from 0.72 to 0.15 [W/m2,K].
• K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 132.0 mm.
• EKOLAB (λ=0.037 W/mK) insulation thickness needed is around 196.0 mm.

H2. Solar collector as an auxiliary hot water system, share target 40% -- Estimated annual solar radiation is 918.0 kWh/m2. Solar collector (efficiency: 38.0% , system loss:14.0%, directed: south, slope: local latitude) needed to reach the target is around 11.0 m²

N2. Installation of pv panels, production target 50% -- Estimated areas for PV panels to cover the target.
Appliance electricity, local production is 4092.0 kWh/a.
• PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 918.0 kWh/m2. Area needed to reach the target is around 28.0 m².
• PV wall panels (efficiency: 14.0 % , system loss:14.0%, directed: south, slope: 90 degrees). Estimated annual solar radiation is 648.0 kWh/m2. Area needed to reach the target is around 53.0 m².
All delivered electricity, production target is 4092.0 kWh/a.
• PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 918.0 kWh/m2. Area needed to reach the target is around 28.0 m².
• PV wall panels (efficiency: 14.0 % , system loss:14.0%, directed: south, slope: 90 degrees). Estimated annual solar radiation is 648.0 kWh/m2. Area needed to reach the target is around 53.0 m².

O2. Insulating hot water heating system pipes -- Hot water circulation pipe losses from 10.0 to 5.0 kWh/m²,a

Figure 25. Polish scenario 1 energy consumption estimation results and installed renovation options.

7.3.3 Polish scenario 3

Estimated energy consumption savings for Polish scenario 2. are compared to other scenarios in paragraph 7.3.4 Comparison between Polish scenarios.

Estimated results for Polish scenario 3 energy consumption estimation results with a list of installed renovation options are presented in the Figure 26.

Installed refurbishment measures and additional information for Polish scenario 2:

- Replacement of windows with improved thermal performance (U-value) – The U-value has changed from 1,7 to 0,9 [W/ m^2,K]. Total estimated window area is 41,0 m^2.
- Replacement of windows with a new type (G-value). Window glazing has changed from DOUBLE to SELECTIVEDOUBLE. Total estimated window area is 41,0 m^2.
- Insulation of outside walls. U-value changed from 0,95 to 0,15 [W/m^2,K]

- VTT Digital Twin tool also calculated thickness values for the K-FLEX and EKOLAB products, if these products would be used to do this refurbishment measure
- Adding layer of insulation material on top of the base floor. U-value changed from 1,2 to 0,25 [W/m^2,K]. VTT Digital Twin tool also calculated thickness values for the K-FLEX and EKOLAB products, if these products would be used to do this refurbishment measure.
- Improving heat insulation of the upper floor. U-value changed from 0,72 to 0,15 [W/m^2,K]
- Solar collector as an auxiliary hot water system, share target 40%. Estimated annual solar radiation is 918,0 kWh/ m^2. Solar collector (efficiency: 38,0 %, system loss:14,0%, direct: south, slope: local latitude) needed to reach the target is around 11,0 m^2.
- Installation of PV panels, production target 50%. Estimated areas for PV panels to cover the target. Appliance electricity, local production is 4092,0 kWh/a.
    - PV roof panels (efficiency: 19,0%, system loss: 14,0%, direct: south, slope: local latitude). Estimated annual solar radiation is 2046,0 kWh/m^2. Area needed to reach the target is around 28,0 m^2.
    - PV wall panels (efficiency:14,0%, system loss: 14,0%, direct: south, slope: 90 degree). Estimated annual solar radiation is 1274,0 kWh/ m^2. Are needed to reach the target is around 70,0 m^2.
- Insulating hot water heating system pipes. Hot water circulation pipe losses from 10,0 to 5,0 kWh/m^2,a

Done!
Please find the results of the applied refurbishment measures. The impact is listed by sub-system type and summarized as an impact on the operational costs and CO2-emissions.

	Space heating			Hot water			Appliance electricity			Space cooling		
Delivered/Local production	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a
Before	76759	298	0	17546	68	0	8183	32	0	0	0	0
After	21619	84	0	8980	35	0	4091	16	4091	0	0	0
Savings	55140	214		8566	33		4092	16		0	0	

Installed refurbishmen measures:

B2. Replacement of windows with improved thermal performance (U-value) -- The U-value has changed from 1.7 to 0.9 [W/m2,K]. Total estimated window area is 41.0 m².

B5. Replacement of windows with a new type (G-value) -- Window glazing has changed from DOUBLE to SELECTIVEDOUBLE. Total estimated window area is 41.0 m².

C5. Insulation of outside walls -- U-value changed from 0.95 to 0.15 [W/m2,K].
* K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 141.0 mm.
* EKOLAB (λ=0.037 W/mK) insulation thickness needed is around 208.0 mm.

D2. Adding layers of insulation material on top of the base floor -- U-value changed from 1.2 to 0.25 [W/m2,K].
* K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 80.0 mm.

E2. Improving heat insulation of the upper floor -- U-value changed from 0.72 to 0.15 [W/m2,K].
* K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 132.0 mm.
* EKOLAB (λ=0.037 W/mK) insulation thickness needed is around 196.0 mm.

H2. Solar collector as an auxiliary hot water system, share target 40% -- Estimated annual solar radiation is 918.0 kWh/m2. Solar collector (efficiency: 38.0% , system loss:14.0%, directed: south, slope: local latitude) needed to reach the target is around 11.0 m²

N2. Installation of pv panels, production target 50% -- Estimated areas for PV panels to cover the target.
Appliance electricity, local production is 4092.0 kWh/a.
* PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 918.0 kWh/m2. Area needed to reach the target is around 28.0 m².
* PV wall panels (efficiency: 14.0 % , system loss:14.0%, directed: south, slope: 90 degrees). Estimated annual solar radiation is 648.0 kWh/m2. Area needed to reach the target is around 53.0 m².

All delivered electricity, production target is 4092.0 kWh/a.
* PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 918.0 kWh/m2. Area needed to reach the target is around 28.0 m².
* PV wall panels (efficiency: 14.0 % , system loss:14.0%, directed: south, slope: 90 degrees). Estimated annual solar radiation is 648.0 kWh/m2. Area needed to reach the target is around 53.0 m².

O2. Insulating hot water heating system pipes -- Hot water circulation pipe losses from 10.0 to 5.0 kWh/m²,a

Figure 26: Polish scenario 1 energy consumption estimation results and installed renovation options.

7.3.4 Comparison between Polish scenarios

All three Polish scenarios main results are collected to on table 6. Comparison shows that scenario 3 is saving energy most of the three scenarios.

Table 6: Three Polish scenarios main results. 'Before' refers to calculation results without any renovation actions.

Space heating						
	Scenario 1		**Scenario 2**		**Scenario 3**	
	Delivered kWh/a	Local production	Delivered kWh/a	Local production	Delivered kWh/a	Local production
Before	76759	0	76759	0	76759	0
After	23925	0	23925	0	21619	0
Savings	**52834**		**52834**		**55140**	

Hot water						
	Scenario 1		**Scenario 2**		**Scenario 3**	
	Delivered kWh/a	Local production	Delivered kWh/a	Local production	Delivered kWh/a	Local production
Before	17546	0	17546	0	17546	0
After	8980	0	8980	0	8980	0
Savings	**5998**		**9601**		**8566**	
Appliance electricity						
	Scenario 1		**Scenario 2**		**Scenario 3**	
	Delivered kWh/a	Local production	Delivered kWh/a	Local production	Delivered kWh/a	Local production
Before	8183	0	8183	0	8183	0
After	8183	0	4091	4091	4091	4091
Savings	**0**		**4092**		**4092**	
Space cooling						
	Scenario 1		**Scenario 2**		**Scenario 3**	
	Delivered kWh/a	Local production	Delivered kWh/a	Local production	Delivered kWh/a	Local production
Before	0	0	0	0	0	0
After	0	0	0	0	0	0
Savings	**0**		**0**		**0**	

7.4 Results for the French scenarios

This section shows the results for the different French scenarios. A summary of the core results is given in the end of this section.

7.4.1 French scenario 1

Estimated energy consumption savings for French scenario 1. are compared to other scenarios in paragraph 7.4.4 Comparison between French scenarios.

Estimated results for French scenario 1 energy consumption estimation results with a list of installed renovation options are presented in the Figure 27.

Installed refurbishment measures and additional information for French scenario 1:

- Replacement of windows with improved thermal performance (U-value) – The U-value has changed from 2,0 to 0,9 [W/m^2,K]. Total estimated window area is 94,0 m^2.
- Replacement of windows with a new type (G-value). Window glazing has changed from DOUBLE to SELECTIVEDOUBLE. Total estimated window area is 94,0 m^2.
- Insulation of outside walls. U-value changed from 0,75 to 0,2 [W/m^2,K]
  VTT Digital Twin tool also calculated thickness values for the K-FLEX and EKOLAB products, if these products would be used to do this refurbishment measure
- Solar collector as an auxiliary hot water system, share target 60%. Estimated annual solar radiation is 1114,0 kWh/m^2. Solar collector (efficiency: 38,0 %, system loss:14,0%, direct: south, slope: local latitude) needed to reach the target is around 59,0 m^2.
- Main space heating, change of boiler to enable the use of oil. Annual delivered main space heating energy is 54,0% from the original.
- DHW, change of boiler to enable the use of oil. Annual delivered domestic hot water heating energy is 36,0% from the original.
- Insulating hot water heating system pipes. Hot water circulation pipe losses from 10,0 to 5,0 kWh/m^2,a

Done!
Please find the results of the applied refurbishment measures. The impact is listed by sub-system type and summarized as an impact on the operational costs and CO2-emissions.

	Space heating			Hot water			Appliance electricity			Space cooling		
Delivered/Local production	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a
Before	98802	64	0	59238	38	0	35299	23	0	0	0	0
After	52880	34	0	21099	14	27428	35299	23	0	0	0	0
Savings	45922	30		38139	24		0	0		0	0	

Installed refurbishmen measures:
B2. Replacement of windows with improved thermal performance (U-value) -- The U-value has changed from 2.0 to 0.9 [W/m2,K]. Total estimated window area is 94.0 m².
B5. Replacement of windows with a new type (G-value) -- Window glazing has changed from DOUBLE to SELECTIVEDOUBLE. Total estimated window area is 94.0 m².
C2. Insulation of outside walls -- U-value changed from 0.75 to 0.2 [W/m2,K]. * K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 92.0 mm. * EKOLAB (λ=0.037 W/mK) insulation thickness needed is around 136.0 mm.
H5. Solar collector as an auxiliary hot water system, share target 60% -- Estimated annual solar radiation is 1114.0 kWh/m2. Solar collector (efficiency: 38.0 % , system loss:14.0%, directed: south, slope: local latitude) needed to reach the target is around 59.0 m²
J14. Main space heating, change of boiler to enable the use of oil -- Annual delivered main space heating energy is 54.0 % from the original. Local production is -8.0 % from the demand of 48650.0 kWh. Auxiliary space heating demand is 0.0 kWh.
M14. DHW, change of boiler to enable the use of oil -- Annual delivered domestic hot water heating energy is 36.0 % from the original. Local production is -8.0 % from the demand of 19411.0 kWh. Auxiliary hot water heating demand is 29117.0 kWh.
O2. Insulating hot water heating system pipes -- Hot water circulation pipe losses from 10.0 to 5.0 kWh/m²,a

Figure 27: French scenario 1 energy consumption estimation results and installed renovation options.

7.4.2 French scenario 2

Estimated energy consumption savings for French scenario 1. are compared to other scenarios in paragraph 7.4.4 Comparison between French scenarios.

Estimated results for French scenario 2 energy consumption estimation results with a list of installed renovation options are presented in the Figure 28.

Installed refurbishment measures and additional information for French scenario 1:

- Replacement of windows with improved thermal performance (U-value) – The U-value has changed from 2,0 to 0,9 [W/m^2,K]. Total estimated window area is 94,0 m^2.
- Replacement of windows with a new type (G-value). Window glazing has changed from DOUBLE to SELECTIVEDOUBLE. Total estimated window area is 94,0 m^2.
- Insulation of outside walls. U-value changed from 0,75 to 0,2 [W/m^2,K]
  VTT Digital Twin tool also calculated thickness values for the K-FLEX and EKOLAB products, if these products would be used to do this refurbishment measure
- Improving heat insulation of the upper floor. U-value changed from 0,31 to 0,16

[W/m²,K]. VTT Digital Twin tool also calculated thickness values for the K-FLEX and EKOLAB products, if these products would be used to do this refurbishment measure

- Heat recovery for ventilation system. Efficiency has changed from 0,0 to 0,72.
- Main space heating, ground source heat pump. Annual delivered main space heating energy is 8,0% from the original.
- DHW, Ground source heat pump. Annual delivered domestic hot water heating energy is 36,0% from the original.
- Installation of PV panels, production target 50%. Estimated areas for PV panels to cover the target. Appliance electricity, local production is 17650,0 kWh/a.
    - PV roof panels (efficiency: 19,0%, system loss: 14,0%, direct: south, slope: local latitude). Estimated annual solar radiation is 1114,0 kWh/m^2. Area needed to reach the target is around 97,0 m^2.
    - PV wall panels (efficiency:14,0%, system loss: 14,0%, direct: south, slope: 90 degree). Estimated annual solar radiation is 792,0 kWh/m^2. Are needed to reach the target is around 186,0 m^2.
- Insulating hot water heating system pipes. Hot water circulation pipe losses from 10,0 to 5,0 kWh/m^2,a

Done!
Please find the results of the applied refurbishment measures. The impact is listed by sub-system type and summarized as an impact on the operational costs and CO2-emissions.

	Space heating			Hot water			Appliance electricity			Space cooling		
Delivered/Local production	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a
Before	98802	64	0	59238	38	0	35299	23	0	0	0	0
After	7684	5	17674	21099	14	27428	17649	11	17649	0	0	0
Savings	91118	59		38139	24		17650	12		0	0	

Installed refurbishmen measures:

B2. Replacement of windows with improved thermal performance (U-value) -- The U-value has changed from 2.0 to 0.9 [W/m2,K]. Total estimated window area is 94.0 m².

B5. Replacement of windows with a new type (G-value) -- Window glazing has changed from DOUBLE to SELECTIVEDOUBLE. Total estimated window area is 94.0 m².

C2. Insulation of outside walls -- U-value changed from 0.75 to 0.2 [W/m2,K].
* K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 92.0 mm.
* EKOLAB (λ=0.037 W/mK) insulation thickness needed is around 136.0 mm.

E2. Improving heat insulation of the upper floor -- U-value changed from 0.31 to 0.16 [W/m2,K].
* K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 76.0 mm.
* EKOLAB (λ=0.037 W/mK) insulation thickness needed is around 112.0 mm.

G2. Heat recovery for ventilation system -- Efficiency has changed from 0.0 to 0.72.

J5. Main space heating, ground source heat pump -- Annual delivered main space heating energy is 8.0 % from the original. Local production is 70.0 % from the demand of 25359.0 kWh. Auxiliary space heating demand is 0.0 kWh.

M5. DHW Ground source heat pump -- Annual delivered domestic hot water heating energy is 36.0 % from the original. Local production is 57.0 % from the demand of 48528.0 kWh. Auxiliary hot water heating demand is 0.0 kWh.

N2. Installation of pv panels, production target 50% -- Estimated areas for PV panels to cover the target.
Appliance electricity, local production is 17650.0 kWh/a.
* PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 1114.0 kWh/m2. Area needed to reach the target is around 97.0 m².
* PV wall panels (efficiency: 14.0 % , system loss:14.0%, directed: south, slope: 90 degrees). Estimated annual solar radiation is 792.0 kWh/m2. Area needed to reach the target is around 186.0 m².
All delivered electricity, production target is 32041.0 kWh/a.
* PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 1114.0 kWh/m2. Area needed to reach the target is around 177.0 m².
* PV wall panels (efficiency: 14.0 % , system loss:14.0%, directed: south, slope: 90 degrees). Estimated annual solar radiation is 792.0 kWh/m2. Area needed to reach the target is around 337.0 m².

O2. Insulating hot water heating system pipes -- Hot water circulation pipe losses from 10.0 to 5.0 kWh/m²,a

Figure 28: French scenario 2 energy consumption estimation results and installed renovation options.

7.4.3 French scenario 3

Estimated energy consumption savings for French scenario 1. are compared to other scenarios in paragraph 7.4.4 Comparison between French scenarios.

Estimated results for French scenario 3 energy consumption estimation results with a list of installed renovation options are presented in the Figure 29.

Installed refurbishment measures and additional information for French scenario 1:

- Replacement of windows with improved thermal performance (U-value) – The U-value has changed from 2,0 to 0,9 [W/m²,K]. Total estimated window area is 94,0 m².
- Replacement of windows with a new type (G-value). Window glazing has changed

from DOUBLE to SELECTIVEDOUBLE. Total estimated window area is 94,0 m^2.

- Insulation of outside walls. U-value changed from 0,75 to 0,2 [W/m^2,K]
  VTT Digital Twin tool also calculated thickness values for the K-FLEX and EKOLAB products, if these products would be used to do this refurbishment measure
- Improving heat insulation of the upper floor. U-value changed from 0,31 to 0,16 [W/m^2,K]. VTT Digital Twin tool also calculated thickness values for the K-FLEX and EKOLAB products, if these products would be used to do this refurbishment measure
- Heat recovery for ventilation system. Efficiency has changed from 0,0 to 0,72.
- Solar collector as an auxiliary hot water system, share target 60%. Estimated annual solar radiation is 1114,0 kWh/m^2. Solar collector (efficiency: 38,0 %, system loss:14,0%, direct: south, slope: local latitude) needed to reach the target is around 59,0 m^2.
- Main space heating, change of boiler to enable the use of oil. Annual delivered main space heating energy is 25,0% from the original.
- DHW, change of boiler to enable the use of oil. Annual delivered main space heating energy is 25,0% from the original.
- Insulating hot water heating system pipes. Hot water circulation pipe losses from 10,0 to 5,0 kWh/m^2,a

Done!
Please find the results of the applied refurbishment measures. The impact is listed by sub-system type and summarized as an impact on the operational costs and CO2-emissions.

	Space heating			Hot water			Appliance electricity			Space cooling		
Delivered/Local production	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a	Delivered kWh/a	Delivered kWh/m2,a	Local_prod. kWh/a
Before	98802	64	0	59238	38	0	35299	23	0	0	0	0
After	24305	16	0	21099	14	27428	35299	23	0	0	0	0
Savings	74497	48		38139	24		0	0		0	0	

Installed refurbishmen measures:

B2. Replacement of windows with improved thermal performance (U-value) -- The U-value has changed from 2.0 to 0.9 [W/m2,K]. Total estimated window area is 94.0 m².

B5. Replacement of windows with a new type (G-value) -- Window glazing has changed from DOUBLE to SELECTIVEDOUBLE. Total estimated window area is 94.0 m².

C5. Insulation of outside walls -- U-value changed from 0.75 to 0.15 [W/m2,K].
* K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 134.0 mm.
* EKOLAB (λ=0.037 W/mK) insulation thickness needed is around 198.0 mm.

E2. Improving heat insulation of the upper floor -- U-value changed from 0.31 to 0.16 [W/m2,K].
* K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 76.0 mm.
* EKOLAB (λ=0.037 W/mK) insulation thickness needed is around 112.0 mm.

G2. Heat recovery for ventilation system -- Efficiency has changed from 0.0 to 0.72.

H5. Solar collector as an auxiliary hot water system, share target 60% -- Estimated annual solar radiation is 1114.0 kWh/m2. Solar collector (efficiency: 38.0 % , system loss:14.0%, directed: south, slope: local latitude) needed to reach the target is around 59.0 m²

J14. Main space heating, change of boiler to enable the use of oil -- Annual delivered main space heating energy is 25.0 % from the original. Local production is -8.0 % from the demand of 22361.0 kWh. Auxiliary space heating demand is 0.0 kWh.

M14. DHW, change of boiler to enable the use of oil -- Annual delivered domestic hot water heating energy is 36.0 % from the original. Local production is -8.0 % from the demand of 19411.0 kWh. Auxiliary hot water heating demand is 29117.0 kWh.

O2. Insulating hot water heating system pipes -- Hot water circulation pipe losses from 10.0 to 5.0 kWh/m²,a

Figure 29: French scenario 3 energy consumption estimation results and installed renovation options.

7.4.4 Comparison between French scenarios

All three French scenarios main results are collected to on table 7. Comparison shows that estimation suggests that scenario 2 is saving most of the energy of the three scenarios.

Table 7: Three French scenarios main results

Space heating						
	Scenario 1		**Scenario 2**		**Scenario 3**	
	Delivered kWh/a	Local production	Delivered kWh/a	Local production	Delivered kWh/a	Local production
Before	98802	0	98802	0	98802	0
After	52880	0	7684	17674	24305	0
Savings	**45922**		**91118**		**74497**	
Hot water						
	Scenario 1		**Scenario 2**		**Scenario 3**	

	Delivered kWh/a	Local production	Delivered kWh/a	Local production	Delivered kWh/a	Local production
Before	59238	0	59238	0	59238	0
After	21099	27428	21099	27428	21099	27428
Savings	**38139**		**38139**		**38139**	
Appliance electricity						
	Scenario 1		**Scenario 2**		**Scenario 3**	
	Delivered kWh/a	Local production	Delivered kWh/a	Local production	Delivered kWh/a	Local production
Before	35299	0	35299	0	35299	0
After	35299	0	17649	17649	35299	0
Savings	**0**		**17650**		**0**	
Space cooling						
	Scenario 1		**Scenario 2**		**Scenario 3**	
	Delivered kWh/a	Local production	Delivered kWh/a	Local production	Delivered kWh/a	Local production
Before	0	0	0	0	0	0
After	0	0	0	0	0	0
Savings	**0**		**0**		**0**	

8 Added value to the renovation process

Within the RINNO project, VTT upgraded the existing VTT Digital Twin -toolkit to be able to provide the competency to support quick and easy building energy renovation scenarios modelling. The advanced Digital Twin -tool is quick and easy to use by non-expert and provide reliable estimations for different energy renovation scenarios. The tool can be used to easily test the effect of various renovation measures on a building's energy consumption. Digital Twin toolkit enables also some more detailed data to be entered to the tool to provide more accurate estimations of various renovation measures on a building's energy consumption. Validation and verification will be reported in the next version of the deliverable. The E-Pass tool has been validated on Finnish weather data (Biström and Shemeikka, 2007; Ketomäki, 2015; Tuomisto, n.d.)

The calculations are based on existing standards.

9 Conclusions and next steps

This report described the development work done for the digital twin tool of the RINNO project. The development was done building on the existing E-PASS tool which is meant for initial assessment of different renovation alternatives. The E-pass tool was substantially modified and upscaled for RINNO. The new modifications/calculations included:

- Adding support and connectivity to Rinno renovation process toolkit
- Adding support for climate data in different geographic climates
- Adding support and connectivity to Rinno demo building solutions and technologies
- Estimated annual mechanical air flow change from original mechanical air flow before renovation
- Estimated annual infiltration air flow change from original infiltration air flow before renovation
- The U-value and total window area change from original U-value and total window area
- Total estimated windows are after replacement of windows
- The U-value changes of walls after renovations and estimation of RINNO project participants K-FLEX and EKOLAB insulation thickness if used in the renovation
- Base floor U-value change estimation after renovation and estimation of RINNO project participant K-FLEX insulation thickness if used in the renovation
- The U-value change of upper floor after renovations and estimation of RINNO project participants K-FLEX and EKOLAB insulation thickness if used in the renovation
- Efficiency estimation of heat recovery for ventilation system after renovation
- Solar collector estimation of efficiency, system loss and area targets estimations after renovation
- Main space heating estimation of delivered energy demand after renovation
- Domestic hot water estimation of delivered heating energy after renovation
- Air-to-air heat pump estimation of delivered heating energy after renovation
- Local production and solar radiation estimation of PV panels after renovation

Furthermore, the new digital twin tool was tested in the RINNO demonstration buildings with the scenarios defined earlier in the project.

Potential updates to the second version of the tool (to be reported in Deliverable D3.4):

- Modifications needed by the updated renovation scenarios
- Updated calculations for the updated scenarios
- Preliminary cost analyses of the scenarios

- Collecting relevant information from BIM models to support renovation decision making
- Utilization of hourly measured data
- Capability of setting required level of solar energy production target (kWh production) and calculating expected PV panel requirements/area
- Validation/verification of results compared to results received with other tools. Detailed simulations will be done with the Certh tool in another task.
- Renaming the tool in the user interface
- Including primary energy calculations to the tool

10 References

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ABOUT RINNO

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