RINNO PROJECT

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

Deliverable D3.4: Renovation Digital Twining tool and Scenarios definition (V2)
Work Package 3: RINNO Toolkits for Improving the Building Renovation Planning & Design Phase

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3.1	VTTers	2023-02-08	Calculated more renovation scenarios.
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3.3	VTTers	2023-05-15	Updated renovation scenario calculations

Executive Summary

This Deliverable 3.4 is the second 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.

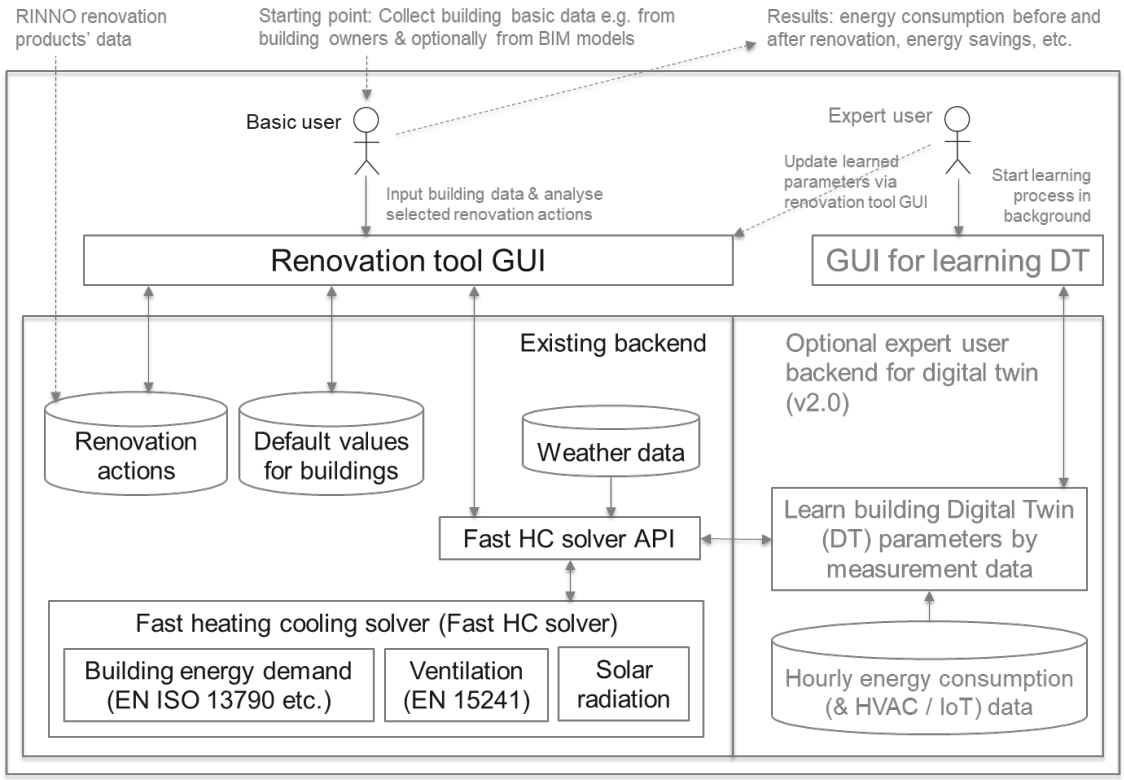

Figure 1: VTT Digital Twin tool in RINNO architecture

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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=

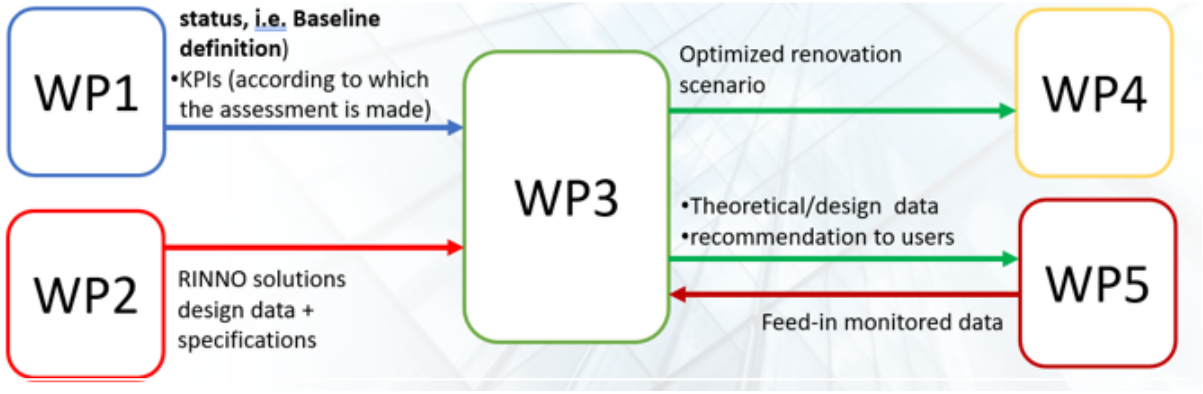

Figure 2: Overall illustration of WP3 relations to other WPs and Tasks, not describing individual products.

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.

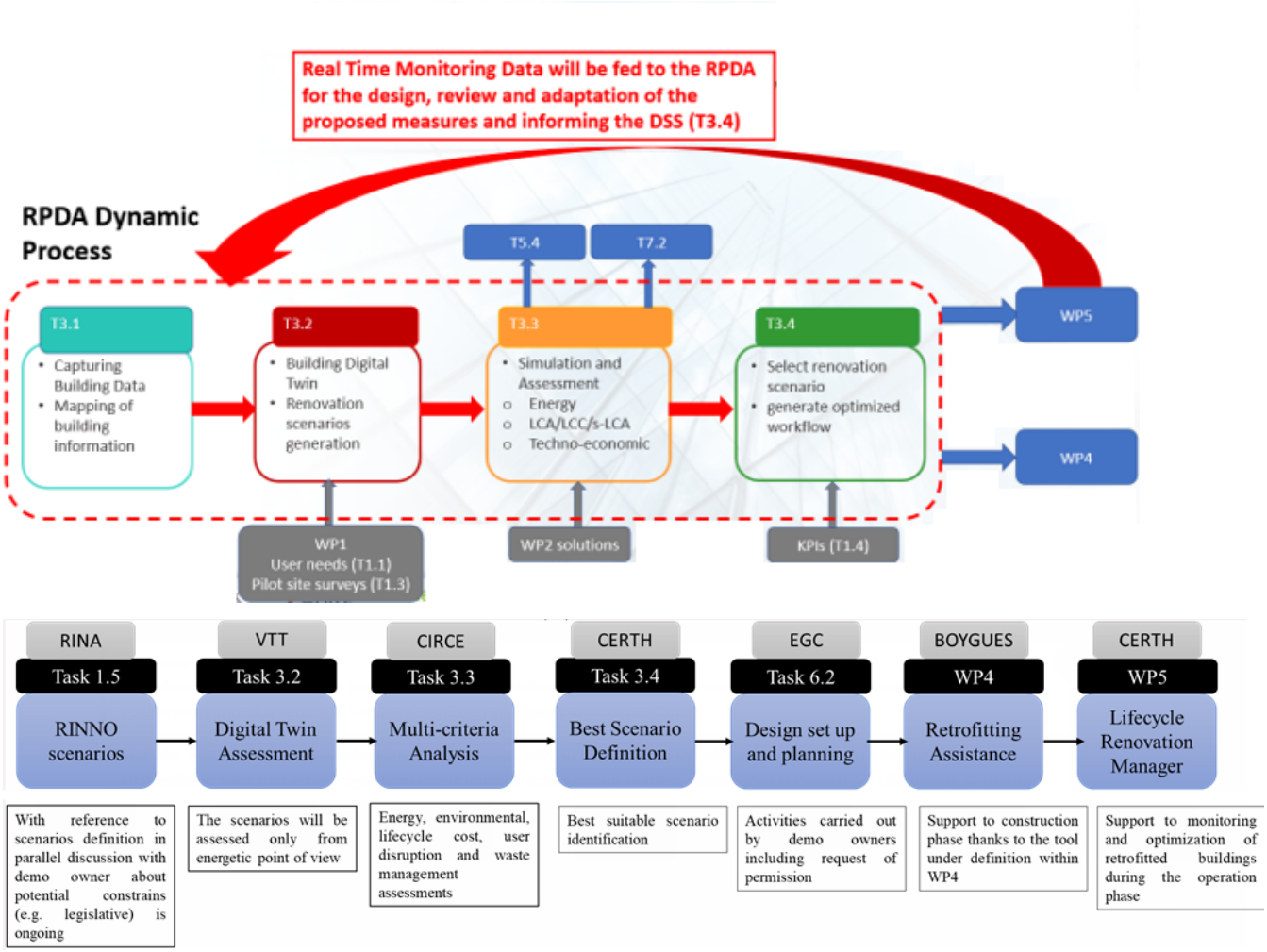

Figure 3: T3.2 relations to other Tasks and WPs.

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

[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/

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 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.

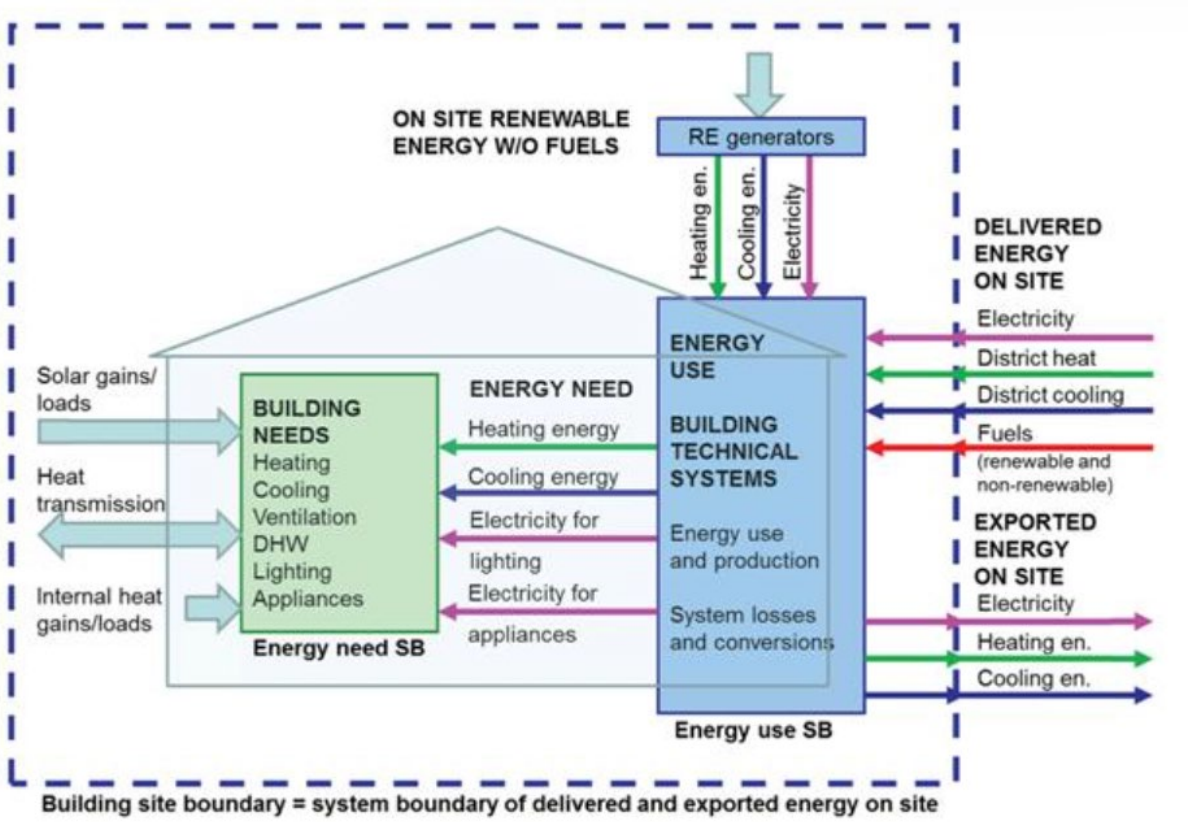

Figure 4: E-PASS was created to provide rough estimation about these energy flows. Figure from (Kurnitski, 2013).

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 M36

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., 2013; Paiho, Pinto Seppä, et al., 2015) 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., 2014; Paiho, Abdurafikov, & Hoang, 2015; Paiho, Abdurafikov, Hoang, et al., 2015).

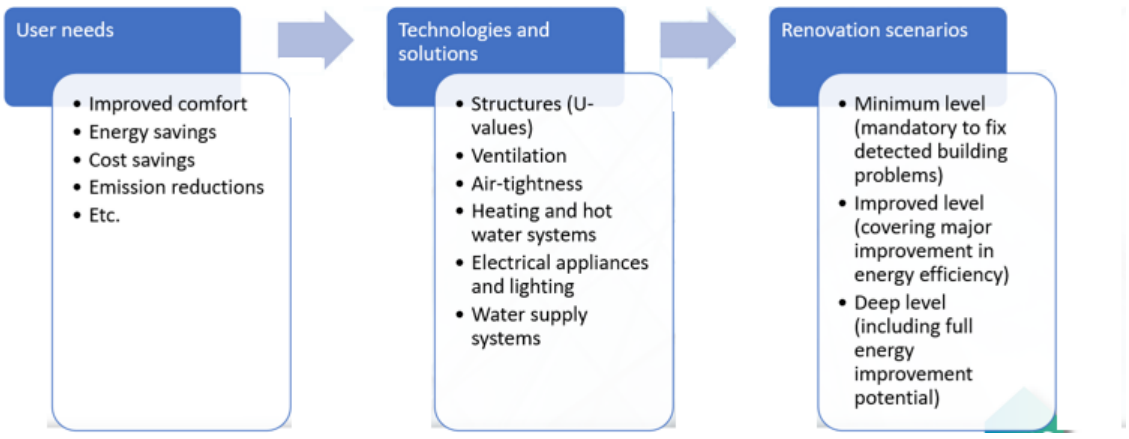

Figure 5: A common approach of defining energy renovation scenarios.

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.

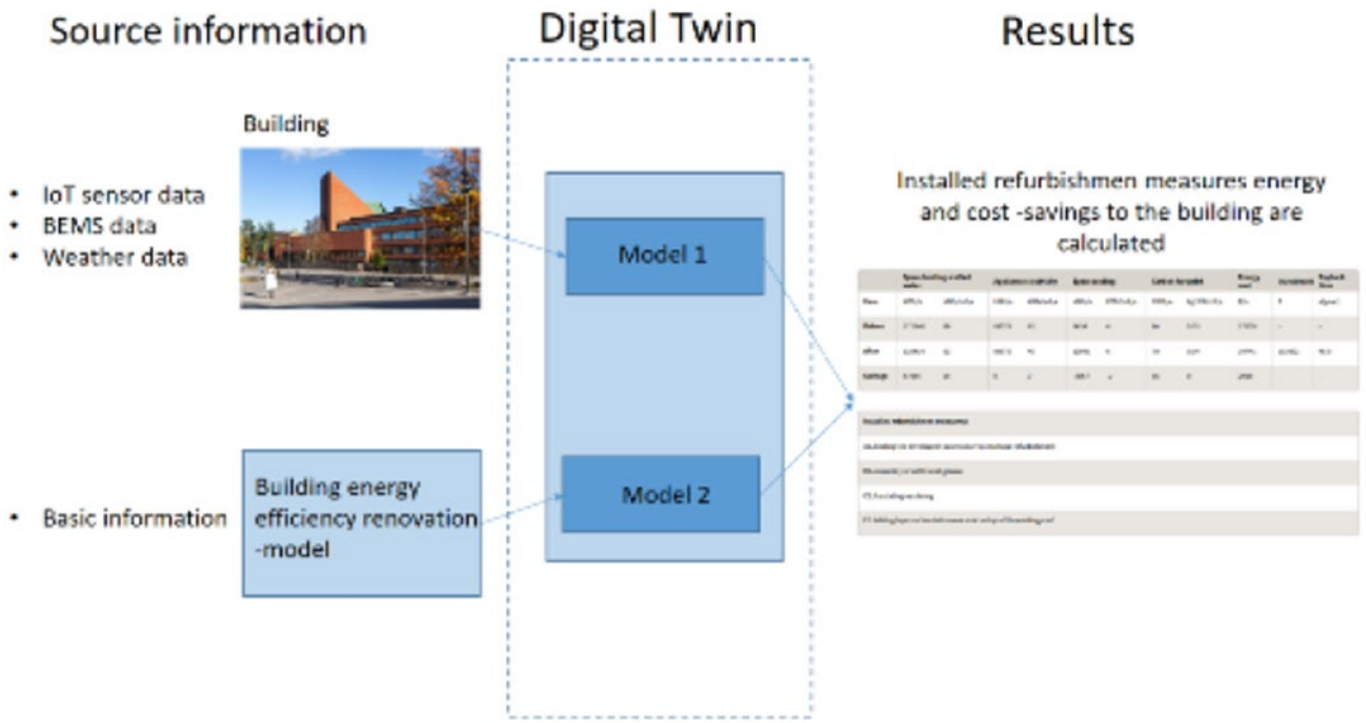

Figure 6: The original plan of VTT Digital Tool for RINNO.

Since the needed hourly measurement and weather data was not available from the RINNO demonstration buildings, the AI based learning of digital twin parameters could not be realized using RINNO pilot building data. But if such hourly data for a minimum of one year is available later, this feature of VTT Digital Twin toolkit is ready to be used.

An example of the VTT Digital Twin toolkit parameters learning process progression is

shown in figure 7. The basic idea is to find those building model parameters which minimize the building heating, cooling and electricity consumption errors between measured and simulated values. The learning is done using one-year hourly data.

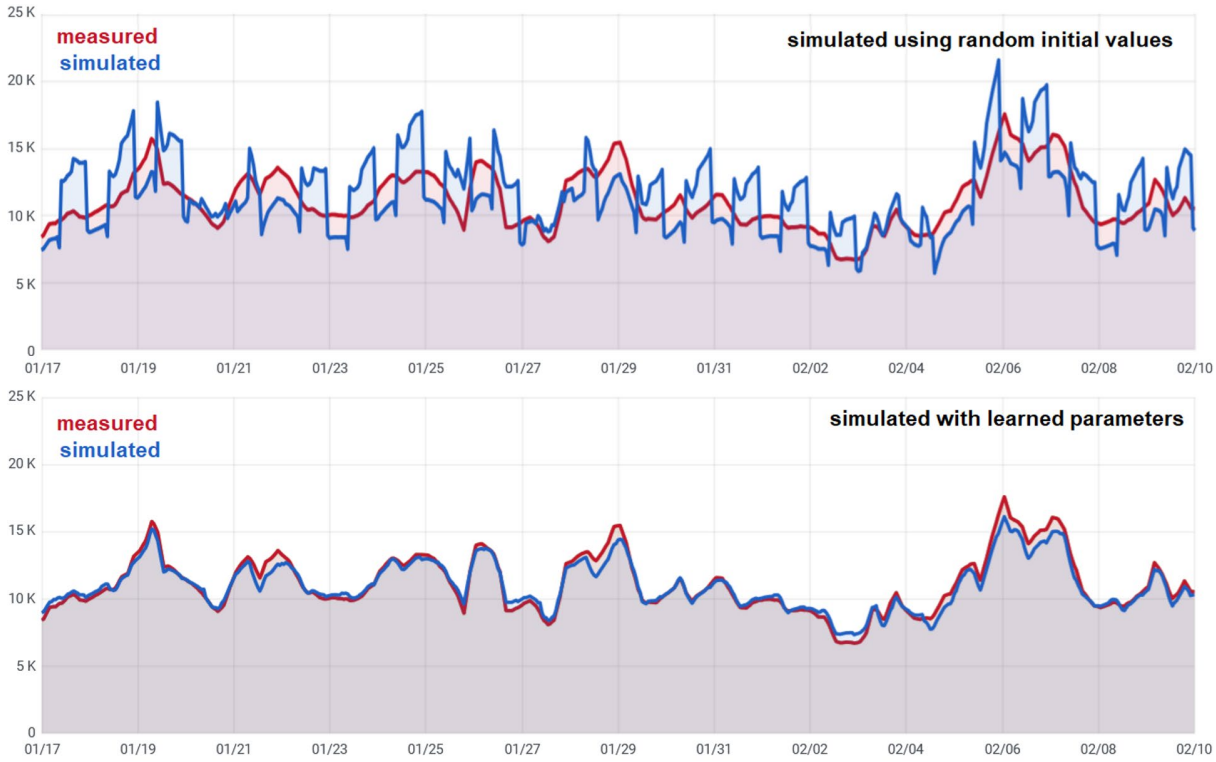

Figure 7: An example of the progression of the AI based learning building digital twin parameters by measured energy and weather data (Piira et al., 2022).

The upper part of the digital twin parameters learning process figure shows the difference between reference space heating energy consumption and related values using initial building values and the lower part of the figure describes the situation when stopping criteria for the learning process are met. The building digital twin parameters which this AI based learning can learn from measurement data are e.g. external walls U-values, heat recovery efficient of ventilation, air handling schedules, air tightness n50 (air change rates at 50Pa pressure difference), building heat capacity, windows parameters (U-values, area & share facing south) and domestic hot water (consumption per person & share of hot water. This AI based learning process is described more detailed in journal paper (Piira et al., 2022).

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

The new plan to implement VTT Digital Twin -toolkit to the RINNO platform is shown in

the Figure 7.

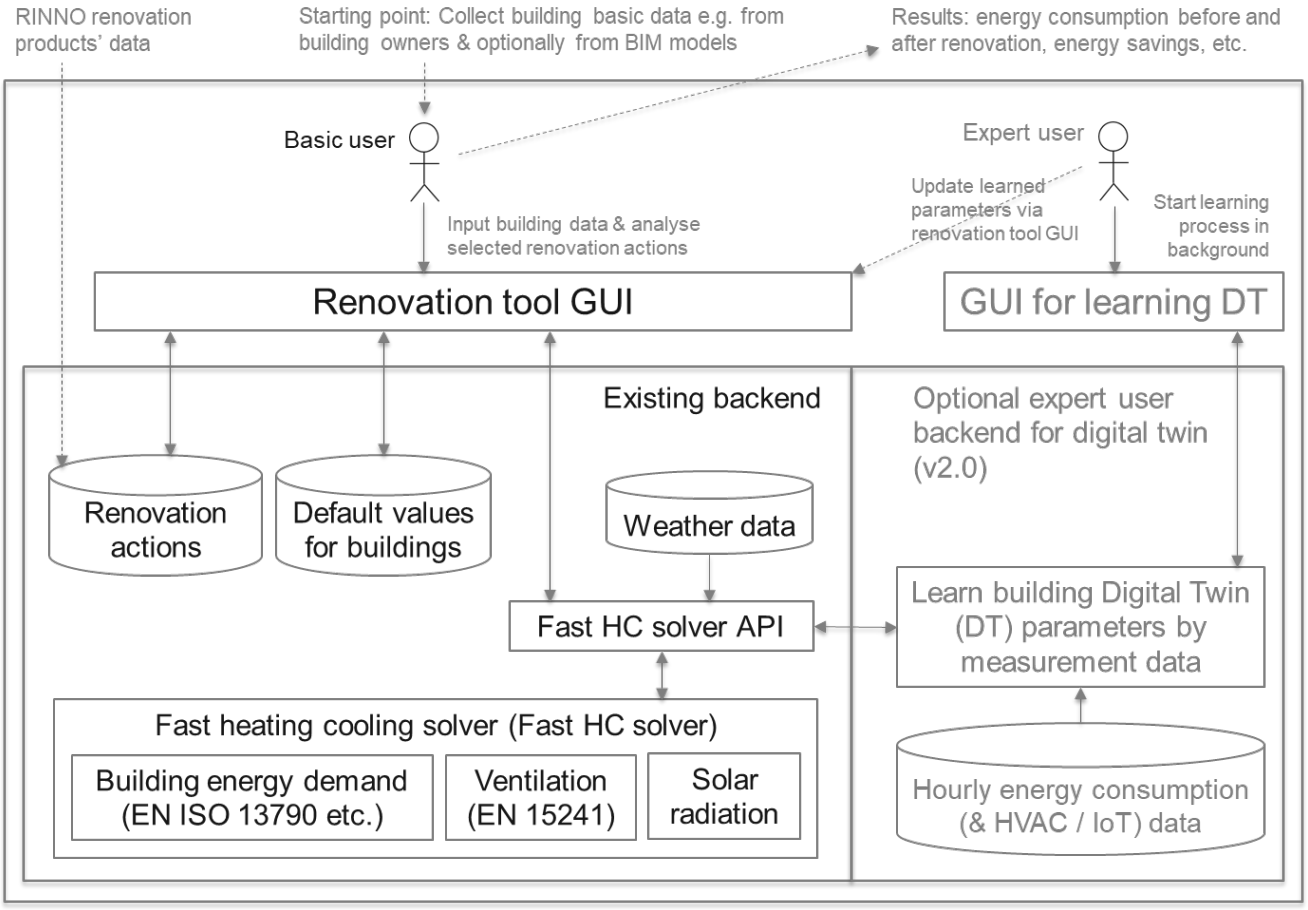

Figure 8: Architecture of the VTTs Digital Twin toolkit

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 Utilizing BIM models in VTT Digital Twin toolkit

The original plan was to read available VTT Renovation Tool input values via BIM related API's from the BIM models. From implementation point of view, the challenge is that the available pilot building BIM models lack some needed information, and the BIM models were not done in a harmonized way. This means that the data queries should have done in different way for each pilot buildings. This challenge was solved so that the end user reads the available values from the BIM models using free BIM software (e.g. BIMvision, https://bimvision.eu/) and set available information manually as Renovation Tool input values via Renovation Tool web based graphical user interface (see figure 9).

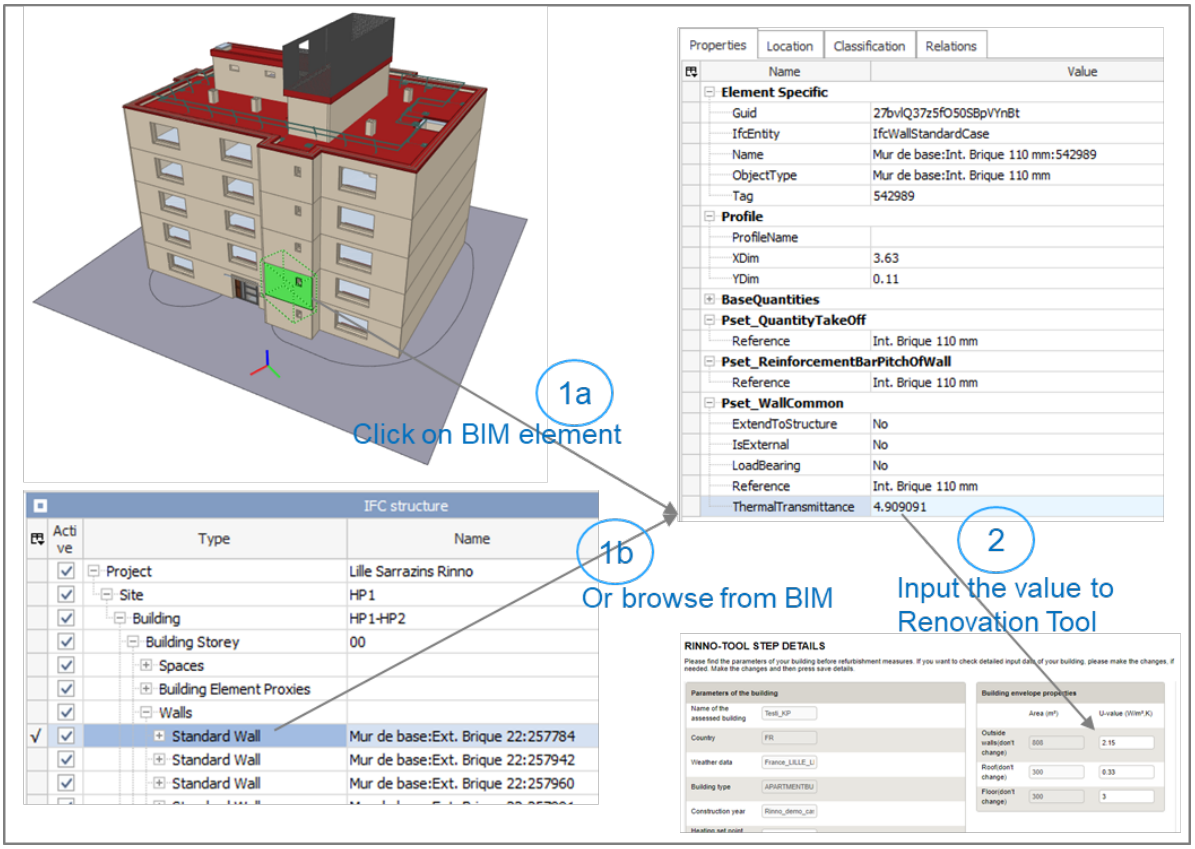

Figure 9: An example for manual reading the data from BIM model to VTT Renovation Tool.

The basic idea for manual reading of the data from the BIM models to the VTT Renovation Tool can be done using two different ways. The first way to read data is to click the BIM application related BIM model element (see figure step 1a) and check if available information is available e.g. in properties fields (here thermal transmittance which is same as U-value). An alternative way is to browse an interested BIM element from the IFC model (see figure step 1b). When the searched

information is found it can be set manually via Renovation Tool GUI (see figure step 2) as shown in figure above.

3.2.8 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
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- 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

Renovation Demo Site #1: Multi-family dwelling, GREECE	
	completion the building will be certified as the first 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.

Renovation Demo Site #1: Multi-family dwelling, GREECE	
	Included in renovation planning: Triple glazing Low-e 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	14

Renovation Demo Site #1: Multi-family dwelling, GREECE		
residents (-):		
Window information		
Window type	Single	
Windows U-value ($W/m^2,k$)	4,85	
Share of window area to south	0,35	
Share of window area of the floor area	0,35	
Building envelope properties		
	Area (m^2)	U-value (W/m^2K)
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/m^2)	2	
Appliances (W/m^2)	2,4	
Lighting (W/m^2)	3	

Renovation Demo Site #1: Multi-family dwelling, GREECE	
Hot water system	
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 10: 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)

Renovation Demo Site #2: Multi-family dwelling, FRANCE	
	Roof area is around 400m^2. blind façade area is 300 m^2 and facades with opening of a total surface of 1,359 m^2 Construction date: 1970 // No BIM available.
Gross Surface Area (GSA):	2,000m^2
Pilot Renovation Area (PRA)	2,000m^2
Purpose / Scope of Renovation:	The users' association representative decided to renovate this building in order to reduce the energy bill and to valorize 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/m^2/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

Renovation Demo Site #2: Multi-family dwelling, FRANCE	
	centralized extraction fan with heat recovery devices will 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	

Renovation Demo Site #2: Multi-family dwelling, FRANCE		
area (m^2):		
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 11: 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

Renovation Demo Site #3: Multi-family dwelling, Poland	
	fired stove, there is no walls insulation (brick walls) // 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).

Renovation Demo Site #3: Multi-family dwelling, Poland	
	Included in renovation planning: Double glazing (U=0.9 W/ m^2K).
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 (m^2):	257,8
Number of floors:	3
Floor height (m):	2,80
Number of residents (-):	12

Renovation Demo Site #3: Multi-family dwelling, Poland		
Window information		
Window type	Double	
Windows U-value ($W/m^2,k$)	1,7	
Share of window area to south	0,150	
Share of window area of the floor area	0,157	
Building envelope properties		
	Area (m^2)	U-value (W/m^2K)
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/m^2)	2,11	
Appliances (W/m^2)	5,59	
Lighting (W/m^2)	2,67	
Hot water system		

Renovation Demo Site #3: Multi-family dwelling, Poland	
Total water consumption (l/person, day)	90
Share of hot water (-)	0,4
Hot water circulation pipe losses (kWh/m^2,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 12: 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.

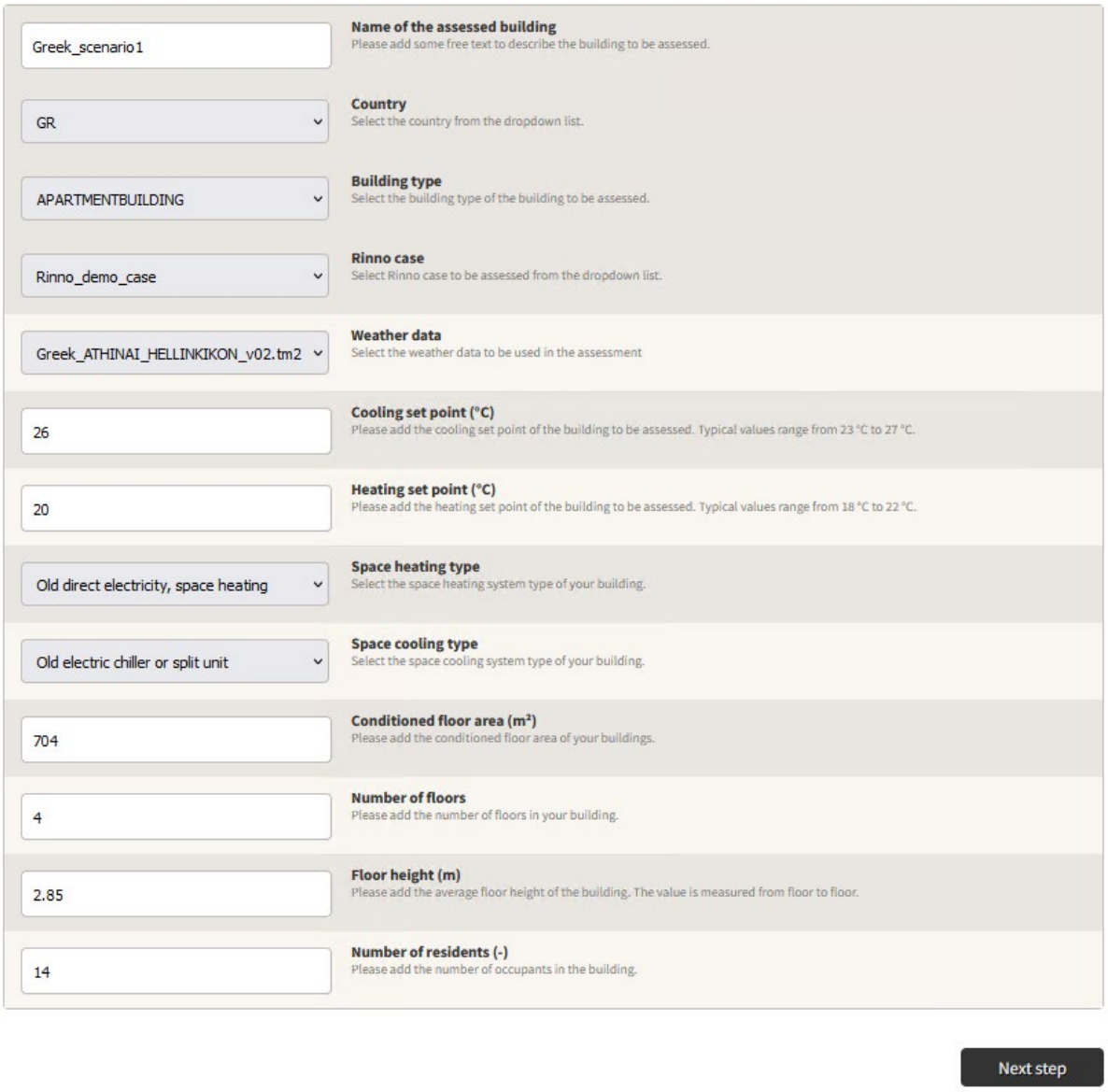


Figure 13: Greek demo case basic information in VTT Digital Twin toolkit

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_HELLINIKON_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 14: 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 m²
- Number of floors: 4
- Floor height: 2,85 m
- Number of residents: 14
- Window type: Single
- Window U-value: 4.,5 W/m², k
- Share of window area to south: 0,35
- Share of window area of the floor area: 0,35
- Outside walls: 560 m²
- Roof: 176 m²
- Floor: 176 m²
- Air change: 2 1/h
- Heat recovery efficiency: 0
- Leakage air value: 8 n50 Pa (1/h)
- Occupants: 2 W/m²
- Appliances. Used 60% of commonly used Finnish values here, because it seemed the best estimation for the demo building: 2,4 W/m²
- Lighting: Used 60% of commonly used values here, because it seemed the best estimation for the demo building: 3 W/m²

- 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 (m^2)	704
Number of floors	4
Floor height (m)	2.85
Number of residents	14
Window type	SINGLE
Windows U-value ($W/m^2,k$)	4.85
Share of window area to south	0.35

Building envelope properties

	Area (m^2)	U-value ($W/m^2,K$)
Outside walls(don't change)	361.6	2.4
Roof(don't change)	176	3.85
Floor(don't change)	176	4.2

Figure 15: (1/3) Greek demo case detailed information in VTTs Digital Twin toolkit

area to south	0.35
Share of window area of the floor area	0.35

Windows

Orientation	Area (m²)	U-value (W/m²,K)	g-value (-)	Curtain factor (-)	Frame factor (-)	Horisontal shading (degrees)
South	86.24	4.85	0.7	0.7	0.1	15
West	55.44	4.85	0.7	0.7	0.1	15
North	49.28	4.85	0.7	0.7	0.1	15
East	55.44	4.85	0.7	0.7	0.1	15

Ventilation and infiltration

Mechanical ventilation system	
Air change (1/h)	2
Heat recovery efficiency (-)	0

Schedule	Begin	End	On factor	Other time factor
Workdays	0	24	1	0
Saturday	0	24	1	0
Sunday	0	24	1	0

Air tightness of the building

Leakage air value n50 Pa (1/h)	2

User profiles and internal gains

Occupants (W/m²)	2

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

Figure 16: (2/3) Greek demo case detailed information in VTTs Digital Twin toolkit

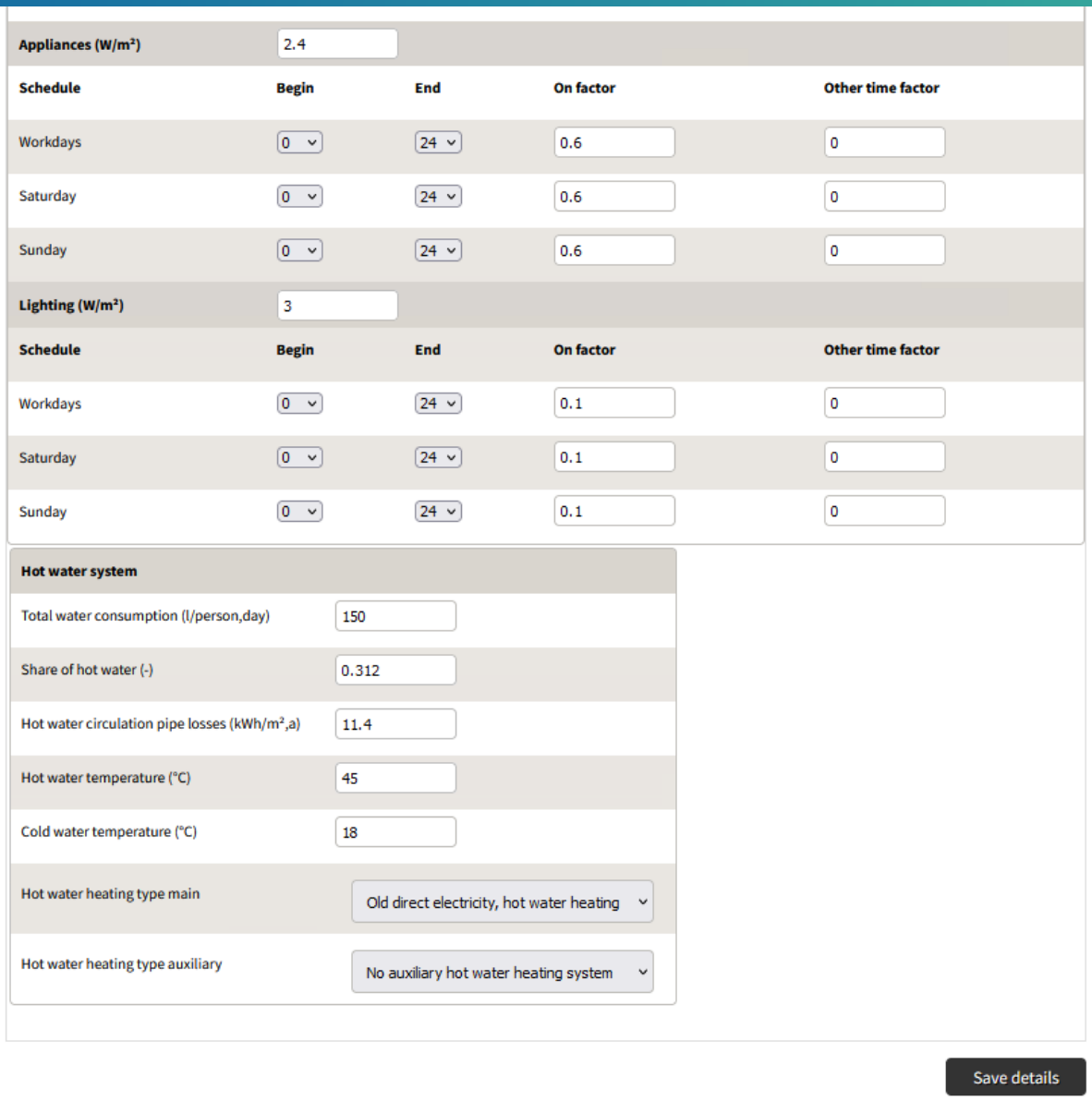


Figure 17: (3/3) Greek demo case detailed information in VTTs Digital Twin toolkit

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 (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 18: 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.

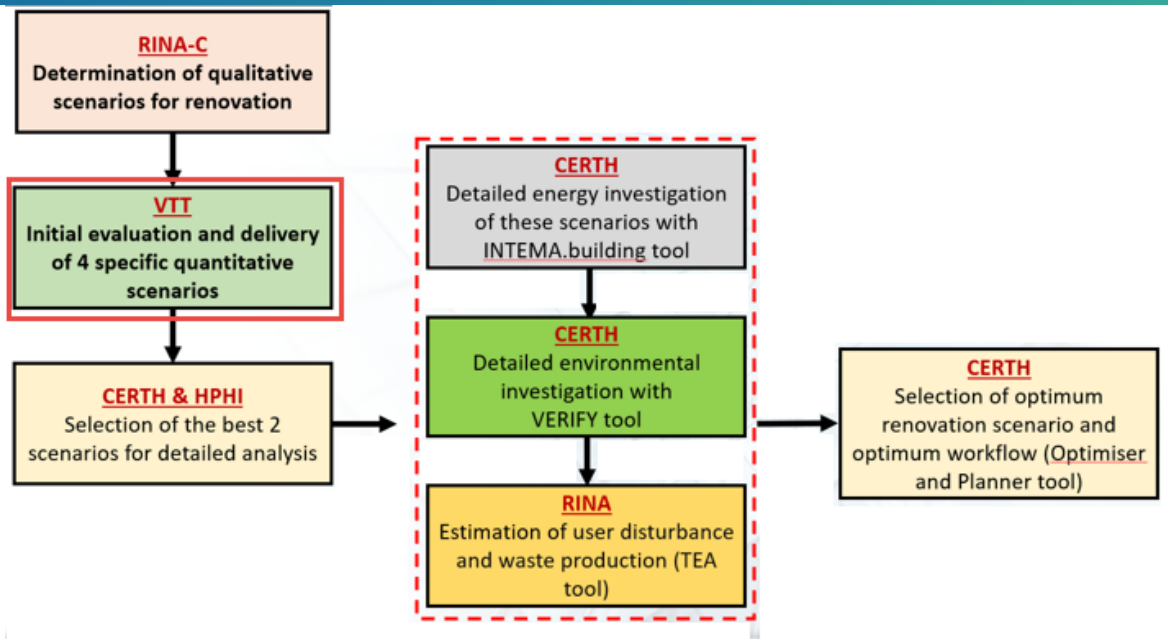


Figure 19. Use of the VTTs Digital Twin toolkit in red square

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 four 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 four Greek scenarios and interventions of scenarios are presented below.

7.1.1.1 Greek Renovation Scenario 1

This scenario is a simplistic one that aims to improve the building energy performance by incorporating a restricted number of renovation actions. Below, the applied retrofitting techniques of the new building are listed:

A) External Insulation
Goal: Reduce the thermal losses, reduce the U-value, reduce the absorbance of solar irradiation.
- **External walls:** Addition of 12 cm EPS insulation with k=0.034 W/mK; the new U-value is 0.25 W/m^{2}K.
- **Roof**: Addition of 20 cm EPS insulation with k=0.032 W/mK; the new U-value is 0.16 W/m^{2}K.
- **Elimination of the thermal bridges**.

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

- Use of thermochromic windows in the south-west direction for the 2nd and 3rd floors. Window U-value=0.6 W/m²K, frame U-value= 1 W/m²K, g-value=0.37.
- Use of triple-glazed low-e aluminium/pvc windows in the remaining cases. Window U-value=0.6 W/m²K, frame U-value= 1 W/m²K, g-value=0.37.

The airtightness of the envelope will be reduced from 2 air changes per hour to 1 air change per hour.

C) Installation of decentralized air to air Heat Pumps

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

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

D) Installation of PV panels

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

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

7.1.1.2 Greek Renovation Scenario 2

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

A) External Insulation (K-FLEX)

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

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

B) Windows replacement

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

- Use of thermochromic windows in the south-west direction for the 2nd and 3rd floors. Window U-value=0.6 W/m²K, frame U-value= 1 W/m²K, g-value=0.37.
- Use of triple-glazed low-e aluminium/pvc windows in the remaining cases. Window U-value=0.6 W/m²K, frame U-value= 1 W/m²K, g-value=0.37.

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

C) Installation of decentralized air to air Heat Pumps

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

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

D) Solar thermal collectors coupled to storage tanks

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

Use of an integrated solar thermal system in every apartment separately. Highly efficient selective solar thermal collectors of 2.0 m^2 coupled to a storage tank of 120 L, are selected. The collectors are located in the south direction with an inclination angle of 55°. The system includes auxiliary electrical resistance.

E) Installation of PV panels

Goal: Electricity production from solar irradiation.

- Installation of highly efficient PV panels (Polycrystalline silicon) in the roof with a 0° inclination. Totally, the PV area is 82.4 m^2 which includes 50 modules of 1.65 m^2 of each module. The maximum efficiency of the panel is 24%.
- Installation of vertical BIPV in the southeast direction (GREENSTRUCT). Totally 4 panels were selected to be installed on the 3rd floor. Every panel has dimensions of 2.45 m x 1.25 m, a total area of 3.06 m^2 and maximum efficiency of 5.8%.

F) Improvement of the lighting installation

Goal: Partial reduction of the electricity demand.

Replacement of the lighting equipment with energy-efficient systems. The nominal specific lighting power becomes equal to 1 W/m^2 with an operating fraction of 10%, while the appliances operating fraction is 40% and the specific power remains at 4 W/m^2.

7.1.1.3 Greek Renovation Scenario 3

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

A) External Insulation (K-FLEX)

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

- External walls: Addition of 8 cm insulation (K-FLEX) with k=0.027 W/mK; the new U-value is 0.293 W/m^2K.

- Roof: Addition of 20 cm insulation (EPS 200 White) with k=0.033 W/mK; the new U-value is 0.156 W/m^2K.

- Basement ceiling: Addition of 3 cm insulation (EPS 100 White) with k=0.034 W/mK; the new U-value is 0.831 W/m^{2}K.
- Cool paint for reflecting solar irradiation
- Elimination of the thermal bridges.

B) Windows replacement
Goal: Reduce the thermal losses, reduce the infiltration rate and manage properly the solar irradiation.
- Use of thermochromic windows in the south-west direction for the 2nd and 3rd floors. Window U-value=0.6 W/m^{2}K, frame U-value= 1 W/m^{2}K, g-value=0.37.
- Use of triple-glazed low-e aluminium/pvc windows in the remaining cases. Window U-value=0.6 W/m^{2}K, frame U-value= 1 W/m^{2}K, g-value=0.37.
The airtightness of the envelope will be reduced from 2 air changes per hour to 0.4 air changes per hour.

C) Decentralized Mechanical Ventilation with heat recovery
Goal: Provide the proper fresh air by reducing the load due to the use of heat recovery.
Addition of the proper mechanical ventilation systems in every apartment. The flow rate is about 100 m^3/h, which corresponds to 0.4 air changes per hour. The systems include a heat recovery heat exchanger with an effectiveness of 80 %.

D) Installation of decentralized air to air Heat Pumps
Goal: Cover the heating and cooling loads with relatively low energy demand.
Use of decentralized highly efficient reversible air-to-air heat pumps in all the apartments in order to cover the heating loads during winter and the cooling loads during summer. These heat pumps present a SEER=6.0 and a SCOP=3.31, values provided by the Hellenic Institute of Passive Buildings.

E) Solar thermal collectors coupled to storage tanks
Goal: Provide domestic hot water by exploiting solar irradiation and avoiding electricity demand.
Use of an integrated solar thermal system in every apartment separately. Highly efficient selective solar thermal collectors of 2.0 m^2 coupled to a storage tank of 120 L, are selected. The collectors are located in the south direction with an inclination angle of 55°. The system includes auxiliary electrical resistance.

F) Installation of PV panels
Goal: Electricity production from solar irradiation.
- Installation of highly efficient PV panels (Polycrystalline silicon) in the roof with a 0° inclination. Totally, the PV area is 82.4 m^2 which includes 50 modules of 1.65 m^2 of each module. The maximum efficiency of the panel is 24%.
- Installation of vertical BIPV in the southeast direction (GREENSTRUCT). Totally 4 panels were selected to be installed on the 3rd floor. Every panel has dimensions of 2.45 m x 1.25 m, a total area of 3.06 m^2 and maximum efficiency of 5.8%.

G) Improvement of the lighting installation
Goal: Partial reduction of the electricity demand.
Replacement of the lighting equipment with energy-efficient systems. The nominal specific lighting power becomes equal to 1 W/m^2 with an operating fraction of 10%, while the appliances operating fraction is 40% and the specific power remains at 4 W/m^2.

7.1.1.4 Greek Renovation Scenario 4

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

A) External Insulation
Goal: Reduce the thermal losses, reduce the U-value, reduce the absorbance of solar irradiation.
- **External walls:** Addition of 12 cm insulation with k=0.034 W/mK; the new U-value is 0.25 W/m^{2}K.
- **Roof**: Addition of 20 cm EPS insulation with k=0.032 W/mK; the new U-value is 0.16 W/m^{2}K.
- **Basement ceiling:** Addition of 3 cm EPS insulation with k=0.032 W/mK; the new U-value is 0.86 W/m^{2}K.
- **Cool paint** for reflecting solar irradiation.
- **Elimination of the thermal bridges**.

B) Windows replacement
Goal: Reduce the thermal losses, reduce the infiltration rate and manage properly the solar irradiation.
Use of triple-glazed low-e aluminium/pvc windows. Window U-value=0.6 W/m^{2}K, frame U-value= 1 W/m^{2}K, g-value=0.37. The airtightness of the envelope will be reduced from 2 air changes per hour to 0.4 air changes per hour.

C) Decentralized Mechanical Ventilation with heat recovery
Goal: Provide the proper fresh air by reducing the load due to the use of heat recovery.
Addition of the proper mechanical ventilation systems in every apartment. The flow rate is about 100 m^3/h, which corresponds to 0.45 air changes per hour. The systems include a heat recovery heat exchanger with an effectiveness of 72 % (a typical system was used as per the recommendations from HPHI).

D) Installation of decentralized air to air Heat Pumps
Goal: Cover the heating and cooling loads with relatively low energy demand.
Use of decentralized highly efficient reversible air-to-air heat pumps in all the apartments in order to cover the heating loads during winter and the cooling loads during summer. These heat pumps present a SEER=5 and a SCOP=3, values provided by the Hellenic Institute of Passive Buildings.

E) Solar thermal collectors coupled to storage tanks
Goal: Provide domestic hot water by exploiting solar irradiation and avoiding electricity demand.
Use of an integrated solar thermal system in every apartment separately. Selective solar thermal collectors of 2.5 m^2 coupled to a storage tank of 160 L, are selected. The system includes auxiliary electrical resistance.

F) Installation of PV panels
Goal: Electricity production from solar irradiation.
- Installation of highly efficient PV panels in the roof with a 30° inclination towards the south direction (Aleo-Solar panel).

- Installation of highly efficient PV façade panels in the southwest direction (vertical panels – Aleo Solar panels).

G) Improvement of the lighting installation
Goal: Partial reduction of the electricity demand.
Replacement of the lighting equipment with energy-efficient systems. The nominal specific lighting power becomes equal to 3 W/m^2.

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 below

7.1.3 Scenarios for French demo building

In this paragraph two 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 below.

7.1.3.1 French Renovation Scenario 1

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

A) Adding Insulation mineral insulation
Goal: Reduce the thermal losses, reduce the U-value, reduce the absorbance of solar irradiation.
External walls: Addition of 20 cm insulation with k=0.035 W/mK; the new U-value is around 0.18 W/m^{2}K.

B) Windows replacement
Goal: Reduce the thermal losses, reduce the infiltration rate and manage properly the solar irradiation.
Use of advanced double windows. Window with total U-value=1.4 W/m^{2}K (75% glass and 25% frame) and g-value=0.7. The airtightness of the envelope (infiltration - N50 = 5 ACH) will be reduced from 0.4 air changes per hour to 0.25 air changes per hour (infiltration).

C) Piping insulation (K-FLEX)

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

D) Electrical air-to-water heat pump
Goal: Cover the heating and DHW needs with an efficient energy system.
The highly efficient electric heat pump (PAC 2xHRC70) with 60 kW capacity is used. This heat pump produces space heating at a temperature level close to 40°C and DHW at a temperature level close to 60°C. The COP in the heating mode is around 3.02 and for the DHW mode around 2.6 according to the manufacturer brochure. Especially, for the DHW thermal losses of 75% due to distribution and regulation are selected.

E) Centralized double coil heat storage tank
Goal: Store the hot water from the heat pump in a proper storage device.
Use of an insulated storage tank with two coil heat exchangers with a total volume of 1 m^3 for covering the space heating and the DHW needs.

F) Installation of PV panels
Goal: Electricity production from solar irradiation in order to cover all the possible needs and be positive.
Installation of around 38 m^2 of highly efficient PV panels on the roof. These panels will be located with a slope of around 10° and 75% will be in the south-west direction, while the other 25% to the north-east direction. Every panel has an area of 1.92 m^2, maximum power of around 400 W and maximum efficiency of 20.8% (TRINA SOLAR).

G) Installation of motion detector for the lighting in the common spaces
Goal: Reduction of the electricity demand in the common spaces
A typical motion detector is selected which reduces the electricity demand by around 40%. This detector regards the common spaces with an area of around 157 m^2.

7.1.3.2 French Renovation Scenario 2

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

A) Adding Insulation mineral insulation
Goal: Reduce the thermal losses, reduce the U-value, reduce the absorbance of solar irradiation.
- External walls: Addition of 20 cm insulation with k=0.035 W/mK; the new U-value is around 0.18 W/m^2K.
- Roof: Addition of 21 cm Isocell insulation with k=0.037 W/mK; the new U-value is 0.15 W/m^2K.

B) Windows replacement
Goal: Reduce the thermal losses, reduce the infiltration rate and manage properly the solar irradiation.
Use of advanced double windows. Window with total U-value=1.4 W/m^2K (75% glass and 25% frame) and g-value=0.7. The airtightness of the envelope (infiltration - N50 = 5 ACH) will be reduced from 0.4 air changes per hour to 0.25 air changes per hour (infiltration).

C) Piping insulation (K-FLEX)
Goal: Reduction of the distribution of thermal losses.
Use of Bio-based pipes insulation and K-BOX units to insulate the pipe network and vanes with low

thermal conductivity of 0.038 W/mK.

D) Electrical air-to-water heat pump
Goal: Cover the heating and DHW needs with an efficient energy system.
The highly efficient electric heat pump (PAC 2xHRC70) with 60 kW capacity is used. This heat pump produces space heating at a temperature level close to 40°C and DHW at a temperature level close to 60°C. The COP in the heating mode is around 3.02 and for the DHW mode around 2.6 according to the manufacturer brochure. Especially, for the DHW thermal losses of 75% due to distribution and regulation are selected.

E) Centralized double coil heat storage tank
Goal: Store the hot water from the heat pump in a proper storage device.
Use of an insulated storage tank with two coil heat exchangers with a total volume of 1 m^3 for covering the space heating and the DHW needs.

F) Installation of PV panels
Goal: Electricity production from solar irradiation in order to cover all the possible needs and be positive.
Installation of around 38 m^2 of highly efficient PV panels on the roof. These panels will be located with a slope of around 10° and 75% will be in the south-west direction, while the other 25% to the north-east direction. Every panel has an area of 1.92 m^2, maximum power of around 400 W and maximum efficiency of 20.8% (TRINA SOLAR).

G) Installation of motion detector for the lighting in the common spaces
Goal: Reduction of the electricity demand in the common spaces
A typical motion detector is selected which reduces the electricity demand by around 40%. This detector regards the common spaces with an area of around 157 m^2.

7.1.3.3 French Renovation Scenario 3

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

A) Adding Insulation mineral insulation
Goal: Reduce the thermal losses, reduce the U-value, reduce the absorbance of solar irradiation.
External walls: Addition of 20 cm insulation with k=0.035 W/mK; the new U-value is around 0.18 W/m^2K.

B) Windows replacement
Goal: Reduce the thermal losses, reduce the infiltration rate and manage properly the solar irradiation.
Use of advanced double windows. Window with total U-value=1.4 W/m^2K (75% glass and 25% frame) and g-value=0.7. The airtightness of the envelope (infiltration - N50 = 5 ACH) will be reduced from 0.4 air changes per hour to 0.25 air changes per hour (infiltration).

C) Piping and vanes insulation (K-FLEX)
Goal: Reduction of the distribution of thermal losses.
Use of Bio-based pipes insulation and K-BOX units to insulate the pipe network and vanes with low thermal conductivity of 0.038 W/mK.

D) Decentralized Mechanical Ventilation with heat recovery (EKOLAB)
Goal: Provide the proper fresh air by reducing the load due to the use of heat recovery.
Addition of the proper mechanical ventilation systems in every apartment. 8 apartments will use a heat recovery system with high efficiency, while the other apartments will use a typical upgraded ventilation system. In order to take into account this situation, the equivalent recovery efficiency of 55% was selected for all the ventilation quantities, after a suitable analysis.

E) Electrical air-to-water heat pump
Goal: Cover the heating and DHW needs with an efficient energy system.
The highly efficient electric heat pump (PAC 2xHRC70) with 60 kW capacity is used. This heat pump produces space heating at a temperature level close to 40°C and DHW at a temperature level close to 60°C. The COP in the heating mode is around 3.02 and for the DHW mode around 2.6 according to the manufacturer brochure. Especially, for the DHW thermal losses of 75% due to distribution and regulation are selected.

F) Centralized double coil heat storage tank
Goal: Store the hot water from the heat pump in a proper storage device.
Use of an insulated storage tank with two coil heat exchangers with a total volume of 1 m^3 for covering the space heating and the DHW needs.

G) Installation of PV panels
Goal: Electricity production from solar irradiation in order to cover all the possible needs and be positive.
Installation of around 38 m^2 of highly efficient PV panels on the roof. These panels will be located with a slope of around 10° and 75% will be in the south-west direction, while the other 25% to the north-east direction. Every panel has an area of 1.92 m^2, maximum power of around 400 W and maximum efficiency of 20.8% (TRINA SOLAR).

H) Installation of motion detector for the lighting in the common spaces
Goal: Reduction of the electricity demand in the common spaces

7.1.4 Scenarios for Danish demo building

In this paragraph two Danish 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 two Danish scenarios and interventions of scenarios are presented below.

7.1.4.1 Danish Renovation Scenario 1

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

A) Windows replacement
Goal: Reduction of the thermal losses, reduction of the infiltration rate and proper management of the solar irradiation.
Use of advanced triple-glazed windows. Windows with total U-value=0.9 W/m^{2}K (75% glass and 25% frame) and g-value=0.65. The airtightness of the envelope (infiltration) will be reduced from 0.4 air changes per hour to 0.3 air changes per hour.

B) Piping insulation (K-FLEX)
Goal: Reduction of the distribution of thermal losses.
Use of bio-based pipes insulation with low thermal conductivity of 0.038 W/mK. The thermal losses will be reduced by 22% for the DHW and by 27% for the space heating system, compared to the baseline scenario. More specifically, the heating thermal losses are reduced from 2.80% to 2.04%, while the DHW thermal losses are from 45% to 35.1%.

C) Decentralized Mechanical Ventilation with heat recovery (EKOLAB)
Goal: Provide the proper fresh air by reducing the load due to the use of heat recovery.
Retrofitting of the mechanical ventilation system in every apartment (MicroVent – EKOLAB). The total mechanical ventilation rate will be around 0.8 air changes per hour with a heat recovery efficiency of 90%, while the baseline scenario included a system with 0.55 ACH and 55% heat recovery. Also, the retrofitting of the ventilation system leads to 32% lower electricity consumption in the common spaces because the new system consumes 300 J/m^3, while the old system consumed 2000 J/m^3.

D) Installation of PV panels (ZAPPA)
Goal: Electricity production from solar irradiation in order to cover all the possible needs and be positive.
Installation of around 166 m^2 of ZAPPA with a PV area of 107 m^2. More specifically, the vertical PVs area located in the south is 72 m^2 and in the west direction 35 m^2.

7.1.4.2 Danish Renovation Scenario 2

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

A) Adding Isocell Cellulose Insulation in the south and west external walls (EKOLAB)
Goal: Reduction of the thermal losses, reduction of the U-value, reduction of the absorbance of solar irradiation.
External walls: Addition of 10 cm Isocell insulation with k=0.035 W/mK.

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

Use of advanced triple-glazed windows. Windows with total U-value=0.9 W/m^{2}K (75% glass and 25% frame) and g-value=0.65. The airtightness of the envelope (infiltration) will be reduced from 0.4 air changes per hour to 0.3 air changes per hour.

C) Piping insulation (K-FLEX)
Goal: Reduction of the distribution of thermal losses.
Use of bio-based pipes insulation with low thermal conductivity of 0.038 W/mK. The thermal losses will be reduced by 22% for the DHW and by 27% for the space heating system, compared to the baseline scenario. More specifically, the heating thermal losses are reduced from 2.80% to 2.04%, while the DHW thermal losses are from 45% to 35.1%.

D) Decentralized Mechanical Ventilation with heat recovery (EKOLAB)
Goal: Provide the proper fresh air by reducing the load due to the use of heat recovery.
Retrofitting of the mechanical ventilation system in every apartment (MicroVent – EKOLAB). The total mechanical ventilation rate will be around 0.8 air changes per hour with a heat recovery efficiency of 90%, while the baseline scenario included a system with 0.55 ACH and 55% heat recovery. Also, the retrofitting of the ventilation system leads to 32% lower electricity consumption in the common spaces because the new system consumes 300 J/m^3, while the old system consumed 2000 J/m^3.

E) Installation of PV panels (ZAPPA)
Goal: Electricity production from solar irradiation in order to cover all the possible needs and be positive.
Installation of around 166 m^2 of ZAPPA with a PV area of 107 m^2. More specifically, the vertical PVs area located in the south is 72 m^2 and in the west direction 35 m^2.

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 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 4,8 to 0,65 [W/ m^2,K]. Total estimated window area is 175,0 m^2.

- Replacement of windows with a new type (G-value). Window glazing has changed from SINGLE to SELECTIVEQUADRUPLE. Total estimated window area is 175,0 m^2.
- Insulation of outside walls. U-value changed from 3,45 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 4,0 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, air to water heat pump. Annual delivered main space heating energy is 13,0 % from the original. Local production is 67,0% from the demand of 10925,0 kWh.
- Air-to-air heat pump as an auxiliar space heating system. Annual delivered auxiliar space heating energy is 13,0% from the original. Local production is 67,0% from the demand of 10925,0 kWh. Main space heating demand is 0,0 kWh.
- New cooling device. Annual delivered space cooling energy is 17,0 % from the original. Local production is 80,0% from the demand of 17793,0 kWh.
- Installation of PV panels, production target 75%. 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 2047,0 kWh/m^2. Area needed to reach the target is around 66,0 m^2.
    - PV wall panels (efficiency:14,0%, system loss: 14,0%, direct: south, slope: 90 degree). Estimated annual solar radiation is 1272,0 kWh/m^2. Are needed to reach the target is around 145,0 m^2.
- Heating demand is 10925 kWh
- Cooling demand is 17792 kWh
- Domestic hot water demand is 8020 kWh
- Electricity demand for appliances/lighting is 33109 kWh

RINNO-TOOL RESULTS

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			Appliances and lighting 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	63926	91	31612	4910	7	3110	33109	47	0	22147	32	22147
After	3642	5	7283	4910	7	3110	11036	16	22073	3558	5	14234
Savings	60284	86		0	0		22073	31		18589	27	

Primary energy analysis			
	Baseline kWh/a	After renovation kWh/a	Savings kWh/a
Delivered primary energy for heating:	134808	10560	124248
Delivered primary energy for cooling:	64225	10319	53906
Delivered primary energy for hot water:	14240	14240	0
Delivered primary energy for appliances/lighting:	96016	32005	64011
Total delivered primary energy:	309289	67124	242165

Installed refurbishmen measures:

A2. Installing new ventilation system -- Estimated annual mechanical air flow is 67.0 % from original

Installed refurbishmen measures:

A2. Installing new ventilation system -- Estimated annual mechanical air flow is 67.0 % from original.

A5. Sealing the envelope -- Estimated annual Infiltration air flow is 4.0 % from original.

B2. Replacement of windows with improved thermal performance (U-value) -- The U-value has changed from 4.8 to 0.65 [W/m2,K]. Total estimated window area is 175.0 m².

B5. Replacement of windows with a new type (G-value) -- Window glazing has changed from SINGLE to SELECTIVEQUADRUPLE. Total estimated window area is 175.0 m².

C2. Insulation of outside walls -- U-value changed from 3.45 to 0.25 [W/m2,K].
* K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 93.0 mm.
* EKOLAB (λ=0.037 W/mK) insulation thickness needed is around 138.0 mm.

E2. Improving heat insulation of the upper floor -- U-value changed from 4.0 to 0.16 [W/m2,K].
* K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 151.0 mm.
* EKOLAB (λ=0.037 W/mK) insulation thickness needed is around 222.0 mm.

K5. Air-to-air heat pump as an auxiliary space heating system -- Annual delivered auxiliary space heating energy is 13.0 % from the original. Local production is 67.0 % from the demand of 10925.0 kWh. Main space heating demand is 0.0 kWh.

L2. New cooling device -- Annual delivered space cooling energy is 17.0 % from the original. Local production is 80.0 % from the demand of 17793.0 kWh.

N5. Installation of pv panels, production target 75% -- Estimated areas for PV panels to cover the target.
Appliance electricity, local production is 22073.0 kWh/a.
* PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 2047.0 kWh/m2. Area needed to reach the target is around 66.0 m².
* PV wall panels (efficiency: 14.0 % , system loss:14.0%, directed: south, slope: 90 degrees). Estimated annual solar radiation is 1272.0 kWh/m2. Area needed to reach the target is around 145.0 m².
All delivered electricity, production target is 31156.0 kWh/a.
* PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 2047.0 kWh/m2. Area needed to reach the target is around 94.0 m².
* PV wall panels (efficiency: 14.0 % , system loss:14.0%, directed: south, slope: 90 degrees). Estimated annual solar radiation is 1272.0 kWh/m2. Area needed to reach the target is around 204.0 m².

Figure 20: 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 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 0,65 [W/m^2,K]. Total estimated window area is 175,0 m^2.
- Replacement of windows with a new type (G-value). Window glazing has changed from SINGLE to SELECTIVEQUADRUPLE. Total estimated window area is 175,0 m^2.
- Insulation of outside walls. U-value changed from 3,45 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.
- Adding layers of insulation material on top of the base floor. U-value changed from 4,2 to 0,83 [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 4,0 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.
- Solar collector as an auxiliary hot water system, share target high.
- Air-to-air heat pump as an auxiliar space heating system. Annual delivered auxiliar space heating energy is 15,0% from the original. Local production is 67,0% from the demand of 12372,0 kWh. Main space heating demand is 0,0 kWh.
- New cooling device. Annual delivered space cooling energy is 23,0 % from the original. Local production is 80,0% from the demand of 25269,0 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 2047,0 kWh/m^2. Area needed to reach the target is around 36,0 m^2.
    - PV wall panels (efficiency:14,0%, system loss: 14,0%, direct: south, slope: 90 degree). Estimated annual solar radiation is 1272,0 kWh/m^2. Are needed to

reach the target is around 79,0 m².

RINNO-TOOL RESULTS

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			Appliances and lighting 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	63926	91	31612	4910	7	3110	33109	47	0	22147	32	22147
After	4124	6	8248	3274	5	4747	0	0	11956	5054	7	20215
Savings	59802	85		1636	2		33109	47		17093	25	

Primary energy analysis			
	Baseline kWh/a	After renovation kWh/a	Savings kWh/a
Delivered primary energy for heating:	134808	11959	122849
Delivered primary energy for cooling:	64225	14656	49569
Delivered primary energy for hot water:	14240	9493	4747
Delivered primary energy for appliances/lighting:	96016	0	96016
Total delivered primary energy:	309289	36108	273181

Total delivered primary energy:	309289	36108	273181

Installed refurbishmen measures:
A2. Installing new ventilation system -- Estimated annual mechanical air flow is 67.0 % from original.
A5. Sealing the envelope -- Estimated annual Infilatration air flow is 4.0 % from original.
B2. Replacement of windows with improved thermal performance (U-value) -- The U-value has changed from 4.8 to 0.65 [W/m2,K]. Total estimated window area is 175.0 m^2.
B5. Replacement of windows with a new type (G-value) -- Window glazing has changed from SINGLE to SELECTIVEQUADRUPLE. Total estimated window area is 175.0 m^2.
C2. Insulation of outside walls -- U-value changed from 3.45 to 0.25 [W/m2,K]. * K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 93.0 mm. * EKOLAB (λ=0.037 W/mK) insulation thickness needed is around 138.0 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 4.0 to 0.16 [W/m2,K]. * K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 151.0 mm. * EKOLAB (λ=0.037 W/mK) insulation thickness needed is around 222.0 mm.
H5. Solar collector as an auxiliary hot water system, share target high -- The share of auxiliary heating is 60.0 %. Estimated annual solar radiation is 2047.0 kWh/m2. Solar collector (efficiency: 38.0% , system loss:14.0%, directed: south, slope: local latitude) needed to reach the target is around 30.0 m^2
K5. Air-to-air heat pump as an auxiliary space heating system -- Annual delivered auxiliary space heating energy is 15.0 % from the original. Local production is 67.0 % from the demand of 12372.0 kWh. Main space heating demand is 0.0 kWh.
L2. New cooling device -- Annual delivered space cooling energy is 23.0 % from the original. Local production is 80.0 % from the demand of 25269.0 kWh.
N8. Installation of pv panels, production target 100% -- Estimated areas for PV panels to cover the target. **Appliance electricity**, local production is 11957.0 kWh/a. * PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 2047.0 kWh/m2. Area needed to reach the target is around 36.0 m^2. * PV wall panels (efficiency: 14.0 % , system loss:14.0%, directed: south, slope: 90 degrees). Estimated annual solar radiation is 1272.0 kWh/m2. Area needed to reach the target is around 79.0 m^2. **All delivered electricity**, production target is 24408.0 kWh/a. * PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 2047.0 kWh/m2. Area needed to reach the target is around 73.0 m^2. * PV wall panels (efficiency: 14.0 % , system loss:14.0%, directed: south, slope: 90 degrees). Estimated annual solar radiation is 1272.0 kWh/m2. Area needed to reach the target is around 160.0 m^2.
N14. Improvement of the lighting, reduce power (like led) -- Lighting power from 5.0 W/m2 to 1.25 W/m2.

Figure 21: 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 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 67,0% from original.
- Sealing the envelope. Estimated annual infiltration air flow is 4,0% from original.
- Replacement of windows with improved thermal performance (U-value) – The U-value has changed from 4,85 to 0,65 [W/m^2,K]. Total estimated window area is 175,0 m^2.

- Replacement of windows with a new type (G-value). Window glazing has changed from SINGLE to SELECTIVEQUADRUPLE Total estimated window area is 175,0 m^2.
- Insulation of outside walls. U-value changed from 3,45 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 4,2 to 0,83 [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 4,0 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 0,8.
- Solar collector as an auxiliary hot water system, share target 60%. Estimated annual solar radiation is 2047,0 kWh/m^2. Solar collector (efficiency: 38,0 %, system loss:14,0%, direct: south, slope: local latitude) needed to reach the target is around 30,0 m^2.
- 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 67,0% from the demand of 407,0 kWh. Main space heating demand is 0,0 kWh.
- New cooling device. Annual delivered space cooling energy is 28,0 % from the original. Local production is 80,0% from the demand of 30134,0 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 2047,0 kWh/m^2. Area needed to reach the target is around 36,0 m^2.
  - PV wall panels (efficiency:14,0%, system loss: 14,0%, direct: south, slope: 90 degree). Estimated annual solar radiation is 1272,0 kWh/m^2. Are needed to reach the target is around 140,0 m^2.
- Heating demand is 406 kWh
- Cooling demand is 30133 kWh
- Domestic hot water demand is 8020 kWh
- Electricity demand for appliances/lighting is 11956 kWh

RINNO-TOOL RESULTS

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			Appliances and lighting 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	63926	91	31612	4910	7	3110	33109	47	0	22147	32	22147
After	135	0	271	3274	5	4747	0	0	11956	6027	9	24107
Savings	63791	91		1636	2		33109	47		16120	23	

Primary energy analysis			
	Baseline kWh/a	After renovation kWh/a	Savings kWh/a
Delivered primary energy for heating:	134808	393	134415
Delivered primary energy for cooling:	64225	17477	46748
Delivered primary energy for hot water:	14240	9493	4747
Delivered primary energy for appliances/lighting:	96016	0	96016
Total delivered primary energy:	309289	27363	281926

Installed refurbishmen measures:

A2. Installing new ventilation system -- Estimated annual mechanical air flow is 67.0 % from original.

A5. Sealing the envelope -- Estimated annual Infilatration air flow is 4.0 % from original.

B2. Replacement of windows with improved thermal performance (U-value) -- The U-value has changed from 4.8 to 0.65 [W/m2,K]. Total estimated window area is 175.0 m².

B5. Replacement of windows with a new type (G-value) -- Window glazing has changed from SINGLE to SELECTIVEQUADRUPLE. Total estimated window area is 175.0 m².

C2. Insulation of outside walls -- U-value changed from 3.45 to 0.25 [W/m2,K].
* K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 93.0 mm.
* EKOLAB (λ=0.037 W/mK) insulation thickness needed is around 138.0 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 4.0 to 0.16 [W/m2,K].
* K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 151.0 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 0.8.

H5. Solar collector as an auxiliary hot water system, share target high -- The share of auxiliary heating is 60.0 %. Estimated annual solar radiation is 2047.0 kWh/m2. Solar collector (efficiency: 38.0% , system loss:14.0%, directed: south, slope: local latitude) needed to reach the target is around 30.0 m²

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 407.0 kWh. Main space heating demand is 0.0 kWh.

L2. New cooling device -- Annual delivered space cooling energy is 28.0 % from the original. Local production is 80.0 % from the demand of 30134.0 kWh.

N8. Installation of pv panels, production target 100% -- Estimated areas for PV panels to cover the target.
Appliance electricity, local production is 11957.0 kWh/a.
* PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 2047.0 kWh/m2. Area needed to reach the target is around 36.0 m².
* PV wall panels (efficiency: 14.0 % , system loss:14.0%, directed: south, slope: 90 degrees). Estimated annual solar radiation is 1272.0 kWh/m2. Area needed to reach the target is around 79.0 m².
All delivered electricity, production target is 21392.0 kWh/a.
* PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 2047.0 kWh/m2. Area needed to reach the target is around 64.0 m².
* PV wall panels (efficiency: 14.0 % , system loss:14.0%, directed: south, slope: 90 degrees). Estimated annual solar radiation is 1272.0 kWh/m2. Area needed to reach the target is around 140.0 m².

N14. Improvement of the lighting, reduce power (like led) -- Lighting power from 5.0 W/m2 to 1.25 W/m2.

N17. Improvement of the appliances, reduce power -- Appliance power from 4.0 W/m2 to 2.0 W/m2.

Figure 22: Greek scenario 3 energy consumption estimation results and installed renovation options.

7.2.4 Greek scenario 4

Estimated energy consumption savings for Greek scenario 4 and are compared to other scenarios in paragraph 7.2.4 Comparison between Greek scenarios.

Estimated results for Greek scenario 4 energy consumption 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 67,0% from original.
- Sealing the envelope. Estimated annual infiltration air flow is 4,0% from original.
- Replacement of windows with improved thermal performance (U-value) – The U-value has changed from 4,85 to 0,65 [W/m^2,K]. Total estimated window area is 175,0 m^2.
- Replacement of windows with a new type (G-value). Window glazing has changed from SINGLE to SELECTIVEQUADRUPLE Total estimated window area is 175,0 m^2.
- Insulation of outside walls. U-value changed from 3,45 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.
- Adding layers of insulation material on top of the base floor. U-value changed from 4,2 to 0,83 [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 4,0 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 0,8.
- Solar collector as an auxiliary hot water system, share target 60%. Estimated annual solar radiation is 2047,0 kWh/m^2. Solar collector (efficiency: 38,0 %, system loss:14,0%, direct: south, slope: local latitude) needed to reach the target is around 30,0 m^2.
- 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 67,0% from the demand of 141,0 kWh. Main space heating demand is 0,0 kWh.

- New cooling device. Annual delivered space cooling energy is 37,0 % from the original. Local production is 80,0% from the demand of 40005,0 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 2047,0 kWh/m^2. Area needed to reach the target is around 77,0 m^2.
    - PV wall panels (efficiency:14,0%, system loss: 14,0%, direct: south, slope: 90 degree). Estimated annual solar radiation is 1272,0 kWh/m^2. Are needed to reach the target is around 169,0 m^2.
- Heating demand is 140 kWh
- Cooling demand is 40005 kWh
- Domestic hot water demand is 8020 kWh
- Electricity demand for appliances/lighting is 25751 kWh

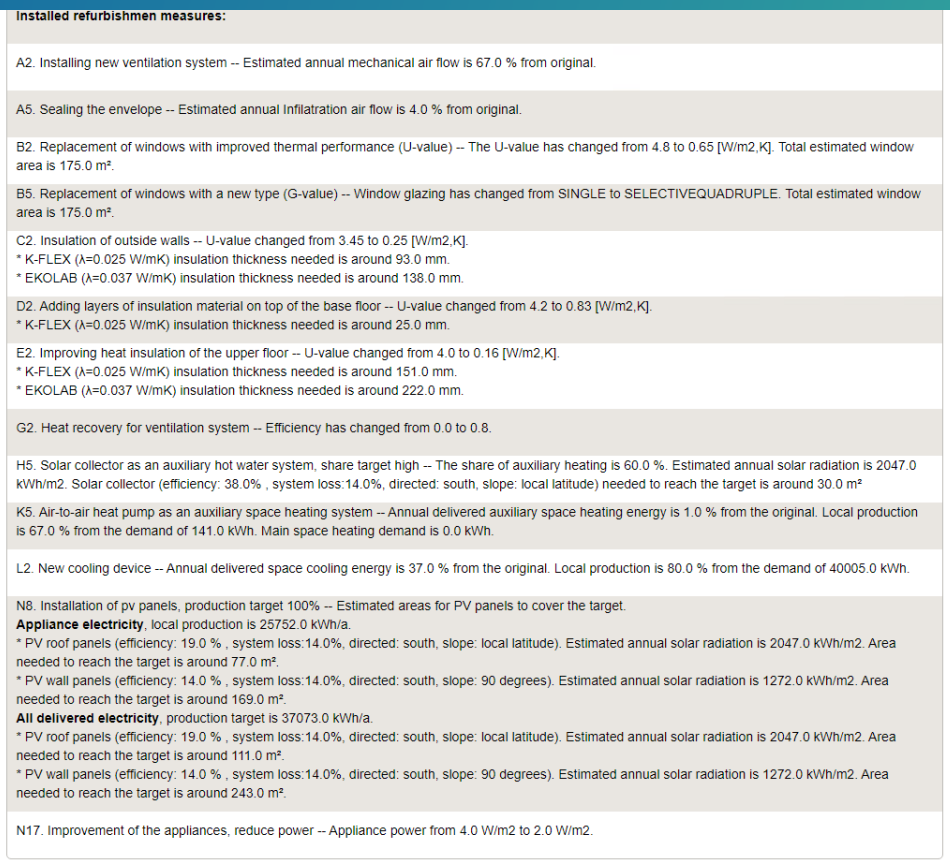
RINNO-TOOL RESULTS

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			Appliances and lighting 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	63926	91	31612	4910	7	3110	33109	47	0	22147	32	22147
After	47	0	94	3274	5	4747	0	0	25751	8001	11	32004
Savings	63879	91		1636	2		33109	47		14146	21	

Primary energy analysis			
	Baseline kWh/a	After renovation kWh/a	Savings kWh/a
Delivered primary energy for heating:	134808	136	134672
Delivered primary energy for cooling:	64225	23203	41022
Delivered primary energy for hot water:	14240	9493	4747
Delivered primary energy for appliances/lighting:	96016	0	96016
Total delivered primary energy:	309289	32832	276457

Installed refurbishmen measures:



Installed refurbishmen measures:

A2. Installing new ventilation system -- Estimated annual mechanical air flow is 67.0 % from original.

A5. Sealing the envelope -- Estimated annual Infilatration air flow is 4.0 % from original.

B2. Replacement of windows with improved thermal performance (U-value) -- The U-value has changed from 4.8 to 0.65 [W/m2,K]. Total estimated window area is 175.0 m².

B5. Replacement of windows with a new type (G-value) -- Window glazing has changed from SINGLE to SELECTIVEQUADRUPLE. Total estimated window area is 175.0 m².

C2. Insulation of outside walls -- U-value changed from 3.45 to 0.25 [W/m2,K].
* K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 93.0 mm.
* EKOLAB (λ=0.037 W/mK) insulation thickness needed is around 138.0 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 4.0 to 0.16 [W/m2,K].
* K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 151.0 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 0.8.

H5. Solar collector as an auxiliary hot water system, share target high -- The share of auxiliary heating is 60.0 %. Estimated annual solar radiation is 2047.0 kWh/m2. Solar collector (efficiency: 38.0% , system loss:14.0%, directed: south, slope: local latitude) needed to reach the target is around 30.0 m²

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 141.0 kWh. Main space heating demand is 0.0 kWh.

L2. New cooling device -- Annual delivered space cooling energy is 37.0 % from the original. Local production is 80.0 % from the demand of 40005.0 kWh.

N8. Installation of pv panels, production target 100% -- Estimated areas for PV panels to cover the target.
Appliance electricity, local production is 25752.0 kWh/a.
* PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 2047.0 kWh/m2. Area needed to reach the target is around 77.0 m².
* PV wall panels (efficiency: 14.0 % , system loss:14.0%, directed: south, slope: 90 degrees). Estimated annual solar radiation is 1272.0 kWh/m2. Area needed to reach the target is around 169.0 m².
All delivered electricity, production target is 37073.0 kWh/a.
* PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 2047.0 kWh/m2. Area needed to reach the target is around 111.0 m².
* PV wall panels (efficiency: 14.0 % , system loss:14.0%, directed: south, slope: 90 degrees). Estimated annual solar radiation is 1272.0 kWh/m2. Area needed to reach the target is around 243.0 m².

N17. Improvement of the appliances, reduce power -- Appliance power from 4.0 W/m2 to 2.0 W/m2.

Figure 23: Greek scenario 4 energy consumption estimation results and installed renovation options.

7.2.5 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 and 4 are saving energy most of the four scenarios.

Table 5: Four Greek scenarios main results

Space heating								
	Scenario 1		**Scenario 2**		**Scenario 3**		**Scenario 4**	
	Delivered kWh/a	Local production	Delivered kWh/a	Local production	Delivered kWh/a	Local production	Delivered kWh/a	Local production
Before	63926	31612	63926	31612	63926	33612	63926	33612
After	3642	7283	4124	8248	135	271	47	94
Savings	**60284**		**59802**		**63791**		**63879**	
Hot water								

	Scenario 1		**Scenario 2**		**Scenario 3**		**Scenario 4**	
	Delivered kWh/a	Local production	Delivered kWh/a	Local production	Delivered kWh/a	Local production	Delivered kWh/a	Local production
Before	4910	3110	4910	3110	4910	3110	4910	3110
After	4910	3110	3274	4747	3274	4747	3274	4747
Savings	**0**		**1636**		**1636**		**1636**	
Appliance electricity								
	Scenario 1		**Scenario 2**		**Scenario 3**		**Scenario 4**	
	Delivered kWh/a	Local production	Delivered kWh/a	Local production	Delivered kWh/a	Local production	Delivered kWh/a	Local production
Before	33109	0	33109	0	33109	0	33109	0
After	0	133109	0	11956	0	11956	0	25751
Savings	**33109**		**33109**		**33109**		**33109**	
Space cooling								
	Scenario 1		**Scenario 2**		**Scenario 3**		**Scenario 4**	
	Delivered kWh/a	Local production	Delivered kWh/a	Local production	Delivered kWh/a	Local production	Delivered kWh/a	Local production
Before	22147	22147	22147	22147	22147	22147	22147	22147
After	3558	14234	5054	20215	6027	24107	8001	32004
Savings	**18589**		**17093**		**16120**		**14146**	

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 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 14,0 to 0,9 [W/m^2,K]. Total estimated window area is 26,0 m^2.
- Replacement of windows with a new type (G-value). Window glazing has changed from DOUBLE to SELECTIVEDOUBLE. Total estimated window area is 26,0 m^2.
- Insulation of outside walls. U-value changed from 1,73 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 upper floor. U-value changed from 0,4 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 60%. Estimated annual solar radiation is 1164,0 kWh/m^2. Solar collector (efficiency: 38,0 %, system loss:14,0%, direct: south, slope: local latitude) needed to reach the target is around 18,0 m^2.
- Main space heating, change of boiler to enable the use of gas.
- DHW, change of boiler to enable the use of gas
- Installation of PV panels, production target 25%. 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 1164,0 kWh/m^2. Area needed to reach the target is around 15,0 m^2.
  - PV wall panels (efficiency:14,0%, system loss: 14,0%, direct: south, slope: 90 degree). Estimated annual solar radiation is 832,0 kWh/m^2. Are needed to reach the target is around 28,0 m^2.

RINNO-TOOL RESULTS

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			Appliances and lighting 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	127947	457	0	20644	74	0	11036	39	0	0	0	0
After	21546	77	0	6072	22	4250	8298	30	2738	0	0	0
Savings	106401	380		14572	52		2738	9		0	0	

Primary energy analysis			
	Baseline kWh/a	After renovation kWh/a	Savings kWh/a
Delivered primary energy for heating:	140741	23701	117040
Delivered primary energy for cooling:	0	0	0
Delivered primary energy for hot water:	22708	6679	16029
Delivered primary energy for appliances/lighting:	33109	24894	8215
Total delivered primary energy:	196558	55274	141284

Installed refurbishmen measures:

Installed refurbishmen measures:

A2. Installing new ventilation system -- Estimated annual mechanical air flow is 90.0 % from original.

A5. Sealing the envelope -- Estimated annual Infilatration air flow is 70.0 % from original.

B2. Replacement of windows with improved thermal performance (U-value) -- The U-value has changed from 4.0 to 0.9 [W/m2,K]. Total estimated window area is 26.0 m^2.

B5. Replacement of windows with a new type (G-value) -- Window glazing has changed from SINGLE to SELECTIVEDOUBLE. Total estimated window area is 26.0 m^2.

C2. Insulation of outside walls -- U-value changed from 1.73 to 0.2 [W/m2,K].
* K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 111.0 mm.
* EKOLAB (λ=0.037 W/mK) insulation thickness needed is around 164.0 mm.

E2. Improving heat insulation of the upper floor -- U-value changed from 0.4 to 0.15 [W/m2,K].
* K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 105.0 mm.
* EKOLAB (λ=0.037 W/mK) insulation thickness needed is around 155.0 mm.

H5. Solar collector as an auxiliary hot water system, share target high -- The share of auxiliary heating is 60.0 %. Estimated annual solar radiation is 1164.0 kWh/m2. Solar collector (efficiency: 38.0% , system loss:14.0%, directed: south, slope: local latitude) needed to reach the target is around 18.0 m^2

J14. Main space heating, change of boiler to enable the use of gas -- Annual delivered main space heating energy is 17.0 % from the original. Local production is -20.0 % from the demand of 17884.0 kWh. Auxiliary space heating demand is 0.0 kWh.

M14. DHW, change of boiler to enable the use of gas -- Annual delivered domestic hot water heating energy is 30.0 % from the original. Local production is -47.0 % from the demand of 4129.0 kWh. Auxiliary hot water heating demand is 6194.0 kWh.

N11. Installation of pv panels, production target 25% -- Estimated areas for PV panels to cover the target.
Appliance electricity, local production is 2739.0 kWh/a.
* PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 1164.0 kWh/m2. Area needed to reach the target is around 15.0 m^2.
* PV wall panels (efficiency: 14.0 % , system loss:14.0%, directed: south, slope: 90 degrees). Estimated annual solar radiation is 832.0 kWh/m2. Area needed to reach the target is around 28.0 m^2.
All delivered electricity, production target is 2739.0 kWh/a.
* PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 1164.0 kWh/m2. Area needed to reach the target is around 15.0 m^2.
* PV wall panels (efficiency: 14.0 % , system loss:14.0%, directed: south, slope: 90 degrees). Estimated annual solar radiation is 832.0 kWh/m2. Area needed to reach the target is around 28.0 m^2.

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 4,0 to 0,9 [W/m^2,K]. Total estimated window area is 26,0 m^2.
- Replacement of windows with a new type (G-value). Window glazing has changed from DOUBLE to SELECTIVEDOUBLE. Total estimated window area is 26,0 m^2.
- Insulation of outside walls. U-value changed from 1,73 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, when share target is 60%. Estimated annual solar radiation is 1164,0 kWh/m^2. Solar collector (efficiency: 38,0 %, system loss:14,0%, direct: south, slope: local latitude) needed to reach the target is around 18,0 m^2.
- Main space heating, change of boiler to enable the use of gas.
- DHW, change of boiler to enable the use of gas
- Installation of PV panels, production target 25%. 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 1164,0 kWh/m^2. Area needed to reach the target is around 15,0 m^2.
  - PV wall panels (efficiency:14,0%, system loss: 14,0%, direct: south, slope: 90 degree). Estimated annual solar radiation is 832,0 kWh/m^2. Are needed to reach the target is around 28,0 m^2.
- Heating demand is 10814 kWh
- Domestic hot water demand is 10322 kWh
- Electricity demand for appliances/lighting is 11036 kWh

RINNO-TOOL RESULTS

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			Appliances and lighting 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	127947	457	0	20644	74	0	11036	39	0	0	0	0
After	24890	89	0	6072	22	4250	8298	30	2738	0	0	0
Savings	103057	368		14572	52		2738	9		0	0	

Primary energy analysis			
	Baseline kWh/a	After renovation kWh/a	Savings kWh/a
Delivered primary energy for heating:	140741	27379	113362
Delivered primary energy for cooling:	0	0	0
Delivered primary energy for hot water:	22708	6679	16029
Delivered primary energy for appliances/lighting:	33109	24894	8215
Total delivered primary energy:	196558	58952	137606

Installed refurbishmen measures:

Installed refurbishmen measures:

A2. Installing new ventilation system -- Estimated annual mechanical air flow is 90.0 % from original.

A5. Sealing the envelope -- Estimated annual Infilatration air flow is 70.0 % from original.

B2. Replacement of windows with improved thermal performance (U-value) -- The U-value has changed from 4.0 to 0.9 [W/m2,K]. Total estimated window area is 26.0 m².

B5. Replacement of windows with a new type (G-value) -- Window glazing has changed from SINGLE to SELECTIVEDOUBLE. Total estimated window area is 26.0 m².

C2. Insulation of outside walls -- U-value changed from 1.73 to 0.2 [W/m2,K].
* K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 111.0 mm.
* EKOLAB (λ=0.037 W/mK) insulation thickness needed is around 164.0 mm.

H5. Solar collector as an auxiliary hot water system, share target high -- The share of auxiliary heating is 60.0 %. Estimated annual solar radiation is 1164.0 kWh/m2. Solar collector (efficiency: 38.0% , system loss:14.0%, directed: south, slope: local latitude) needed to reach the target is around 18.0 m²

J14. Main space heating, change of boiler to enable the use of gas -- Annual delivered main space heating energy is 20.0 % from the original. Local production is -20.0 % from the demand of 20659.0 kWh. Auxiliary space heating demand is 0.0 kWh.

M14. DHW, change of boiler to enable the use of gas -- Annual delivered domestic hot water heating energy is 30.0 % from the original. Local production is -47.0 % from the demand of 4129.0 kWh. Auxiliary hot water heating demand is 6194.0 kWh.

N11. Installation of pv panels, production target 25% -- Estimated areas for PV panels to cover the target.
Appliance electricity, local production is 2739.0 kWh/a.
* PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 1164.0 kWh/m2. Area needed to reach the target is around 15.0 m².
* PV wall panels (efficiency: 14.0 % , system loss:14.0%, directed: south, slope: 90 degrees). Estimated annual solar radiation is 832.0 kWh/m2. Area needed to reach the target is around 28.0 m².
All delivered electricity, production target is 2739.0 kWh/a.
* PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 1164.0 kWh/m2. Area needed to reach the target is around 15.0 m².
* PV wall panels (efficiency: 14.0 % , system loss:14.0%, directed: south, slope: 90 degrees). Estimated annual solar radiation is 832.0 kWh/m2. Area needed to reach the target is around 28.0 m².

Figure 25. Polish scenario 2 energy consumption estimation results and installed renovation options.

7.3.3 Polish scenario 3

Estimated energy consumption savings for Polish scenario 3. 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 4,0 to 0,9 [W/ m^2,K]. Total estimated window area is 26,0 m^2.
- Replacement of windows with a new type (G-value). Window glazing has changed from DOUBLE to SELECTIVEDOUBLE. Total estimated window area is 26,0 m^2.
- Insulation of outside walls. U-value changed from 1,73 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, share target 60%. Estimated annual solar radiation is 1164,0 kWh/ m^2. Solar collector (efficiency: 38,0 %, system loss:14,0%, direct: south, slope: local latitude) needed to reach the target is around 18,0 m^2.
- Installation of PV panels, production target 25%. Estimated areas for PV panels to cover the target. Appliance electricity, local production is 2739,0 kWh/a.
  - PV roof panels (efficiency: 19,0%, system loss: 14,0%, direct: south, slope: local latitude). Estimated annual solar radiation is 1164,0 kWh/m^2. Area needed to reach the target is around 15,0 m^2.
  - PV wall panels (efficiency:14,0%, system loss: 14,0%, direct: south, slope: 90 degree). Estimated annual solar radiation is 832,0 kWh/ m^2. Are needed to reach the target is around 28,0 m^2.
- Heating demand is 9546 kWh
- Domestic hot water demand is 10322 kWh
- Electricity demand for appliances/lighting is 11036 kWh

RINNO-TOOL RESULTS

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			Appliances and lighting 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	127947	457	0	20644	74	0	11036	39	0	0	0	0
After	23334	83	0	6072	22	4250	8298	30	2738	0	0	0
Savings	104613	374		14572	52		2738	9		0	0	

Primary energy analysis			
	Baseline kWh/a	After renovation kWh/a	Savings kWh/a
Delivered primary energy for heating:	140741	25668	115073
Delivered primary energy for cooling:	0	0	0
Delivered primary energy for hot water:	22708	6679	16029
Delivered primary energy for appliances/lighting:	33109	24894	8215
Total delivered primary energy:	196558	57241	139317

Installed refurbishmen measures:

A2. Installing new ventilation system -- Estimated annual mechanical air flow is 90.0 % from original.

Installed refurbishmen measures:

A2. Installing new ventilation system -- Estimated annual mechanical air flow is 90.0 % from original.

A5. Sealing the envelope -- Estimated annual Infilatration air flow is 70.0 % from original.

B2. Replacement of windows with improved thermal performance (U-value) -- The U-value has changed from 4.0 to 0.9 [W/m2,K]. Total estimated window area is 26.0 m².

B5. Replacement of windows with a new type (G-value) -- Window glazing has changed from SINGLE to SELECTIVEDOUBLE. Total estimated window area is 26.0 m².

C5. Insulation of outside walls -- U-value changed from 1.73 to 0.15 [W/m2,K].
* K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 153.0 mm.
* EKOLAB (λ=0.037 W/mK) insulation thickness needed is around 226.0 mm.

H5. Solar collector as an auxiliary hot water system, share target high -- The share of auxiliary heating is 60.0 %. Estimated annual solar radiation is 1164.0 kWh/m2. Solar collector (efficiency: 38.0% , system loss:14.0%, directed: south, slope: local latitude) needed to reach the target is around 18.0 m²

J14. Main space heating, change of boiler to enable the use of gas -- Annual delivered main space heating energy is 19.0 % from the original. Local production is -20.0 % from the demand of 19368.0 kWh. Auxiliary space heating demand is 0.0 kWh.

M14. DHW, change of boiler to enable the use of gas -- Annual delivered domestic hot water heating energy is 30.0 % from the original. Local production is -47.0 % from the demand of 4129.0 kWh. Auxiliary hot water heating demand is 6194.0 kWh.

N11. Installation of pv panels, production target 25% -- Estimated areas for PV panels to cover the target.
Appliance electricity, local production is 2739.0 kWh/a.
* PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 1164.0 kWh/m2. Area needed to reach the target is around 15.0 m².
* PV wall panels (efficiency: 14.0 % , system loss:14.0%, directed: south, slope: 90 degrees). Estimated annual solar radiation is 832.0 kWh/m2. Area needed to reach the target is around 28.0 m².
All delivered electricity, production target is 2739.0 kWh/a.
* PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 1164.0 kWh/m2. Area needed to reach the target is around 15.0 m².
* PV wall panels (efficiency: 14.0 % , system loss:14.0%, directed: south, slope: 90 degrees). Estimated annual solar radiation is 832.0 kWh/m2. Area needed to reach the target is around 28.0 m².

Figure 26: Polish scenario 3 energy consumption estimation results and installed renovation options.

7.3.4 Polish scenario 4

Estimated energy consumption savings for Polish scenario 4. are compared to other scenarios in paragraph 7.3.4 Comparison between Polish scenarios.

Estimated results for Polish scenario 4 energy consumption with a list of installed renovation options are presented in the Figure 27.

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 4,0 to 0,9 [W/ m^2,K]. Total estimated window area is 26,0 m^2.
- Replacement of windows with a new type (G-value). Window glazing has changed from DOUBLE to SELECTIVEDOUBLE. Total estimated window area is 26,0 m^2.
- Insulation of outside walls. U-value changed from 1,73 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 0,4 to 0,15 [W/m^2,K]
- Main space heating, change of boiler to enable the use of gas. Annual delivered domestic hot water heating energy is 9,0 % from the original. Local production is -20.0% from the demand of 9546,0 kWh. Auxiliary hot water heating demand is 10322,0 kWh.
- DHW ,change of boiler to enable the use of gas
- Installation of PV panels, production target 75%. Estimated areas for PV panels to cover the target. Appliance electricity, local production is 2739,0 kWh/a.
  - PV roof panels (efficiency: 19,0%, system loss: 14,0%, direct: south, slope: local latitude). Estimated annual solar radiation is 1164,0 kWh/m^2. Area needed to reach the target is around 39,0 m^2.
  - PV wall panels (efficiency:14,0%, system loss: 14,0%, direct: south, slope: 90 degree). Estimated annual solar radiation is 832,0 kWh/ m^2. Are needed to reach the target is around 74,0 m^2.
- Heating demand is 9546 kWh

- Domestic hot water demand is 10322 kWh
- Electricity demand for appliances/lighting is 11036 kWh

RINNO-TOOL RESULTS

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			Appliances and lighting 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	127947	457	0	20644	74	0	11036	39	0	0	0	0
After	11501	41	0	15179	54	0	3679	13	7358	0	0	0
Savings	116446	416		5465	20		7357	26		0	0	

Primary energy analysis			
	Baseline kWh/a	After renovation kWh/a	Savings kWh/a
Delivered primary energy for heating:	140741	12651	128090
Delivered primary energy for cooling:	0	0	0
Delivered primary energy for hot water:	22708	16697	6011
Delivered primary energy for appliances/lighting:	33109	11036	22073
Total delivered primary energy:	196558	40384	156174

Installed refurbishmen measures:
A2. Installing new ventilation system -- Estimated annual mechanical air flow is 90.0 % from original.

Installed refurbishmen measures:
A2. Installing new ventilation system -- Estimated annual mechanical air flow is 90.0 % from original.
A5. Sealing the envelope -- Estimated annual Infilatration air flow is 70.0 % from original.
B2. Replacement of windows with improved thermal performance (U-value) -- The U-value has changed from 4.0 to 0.9 [W/m2,K]. Total estimated window area is 26.0 m².
B5. Replacement of windows with a new type (G-value) -- Window glazing has changed from SINGLE to SELECTIVEDOUBLE. Total estimated window area is 26.0 m².
C5. Insulation of outside walls -- U-value changed from 1.73 to 0.15 [W/m2,K]. * K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 153.0 mm. * EKOLAB (λ=0.037 W/mK) insulation thickness needed is around 226.0 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 0.4 to 0.15 [W/m2,K]. * K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 105.0 mm. * EKOLAB (λ=0.037 W/mK) insulation thickness needed is around 155.0 mm.
J14. Main space heating, change of boiler to enable the use of gas -- Annual delivered main space heating energy is 9.0 % from the original. Local production is -20.0 % from the demand of 9546.0 kWh. Auxiliary space heating demand is 0.0 kWh.
M14. DHW, change of boiler to enable the use of gas -- Annual delivered domestic hot water heating energy is 74.0 % from the original. Local production is -47.0 % from the demand of 10322.0 kWh. Auxiliary hot water heating demand is 0.0 kWh.
N5. Installation of pv panels, production target 75% -- Estimated areas for PV panels to cover the target. **Appliance electricity**, local production is 7358.0 kWh/a. * PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 1164.0 kWh/m2. Area needed to reach the target is around 39.0 m². * PV wall panels (efficiency: 14.0 % , system loss:14.0%, directed: south, slope: 90 degrees). Estimated annual solar radiation is 832.0 kWh/m2. Area needed to reach the target is around 74.0 m². **All delivered electricity**, production target is 7358.0 kWh/a. * PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 1164.0 kWh/m2. Area needed to reach the target is around 39.0 m². * PV wall panels (efficiency: 14.0 % , system loss:14.0%, directed: south, slope: 90 degrees). Estimated annual solar radiation is 832.0 kWh/m2. Area needed to reach the target is around 74.0 m².

Figure 277: Polish scenario 4 energy consumption estimation results and installed renovation options.

7.3.5 Comparison between Polish scenarios

All four Polish scenarios main results are collected to on table 6. Comparison shows that scenario 4 is saving energy most of the three scenarios.

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

Space heating								
	Scenario 1		**Scenario 2**		**Scenario 3**		**Scenario 4**	
	Delivered kWh/a	Local production	Delivered kWh/a	Local production	Delivered kWh/a	Local production	Delivered kWh/a	Local production
Before	127947	0	127947	0	127947	0	127947	0
After	21546	0	24890	0	23334	0	11501	0
Savings	**106401**		**103057**		**104613**		**116446**	
Hot water								
	Scenario 1		**Scenario 2**		**Scenario 3**		**Scenario 4**	
	Delivered kWh/a	Local production	Delivered kWh/a	Local production	Delivered kWh/a	Local production	Delivered kWh/a	Local production
Before	20644	0	20644	0	20644	0	20644	0
After	6072	4250	6072	4250	6072	4250	15179	0
Savings	**14572**		**14572**		**14572**		**5465**	
Appliance electricity								
	Scenario 1		**Scenario 2**		**Scenario 3**		**Scenario 4**	
	Delivered kWh/a	Local production	Delivered kWh/a	Local production	Delivered kWh/a	Local production	Delivered kWh/a	Local production
Before	11036	0	11036	0	11036	0	11036	0
After	8298	2738	8298	2738	8298	2738	3679	7358
Savings	**2738**		**2738**		**2738**		**7357**	
Space cooling								
	Scenario 1		**Scenario 2**		**Scenario 3**		**Scenario 4**	
	Delivered	Local	Delivered	Local	Delivered	Local	Delivered	Local

	kWh/a	production	kWh/a	production	kWh/a	production	kWh/a	production
Before	0	0	0	0	0	0	0	0
After	0	0	0	0	0	0	0	0
Savings	**0**		**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 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 5,6 to 1,4 [W/m^2,K]. Total estimated window area is 117,0 m^2.
- Replacement of windows with a new type (G-value). Window glazing has changed from DOUBLE to SELECTIVEDOUBLE. Total estimated window area is 117,0 m^2.
- Insulation of outside walls. U-value changed from 2,15 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
- Main space heating, Air to water heat pump. Annual delivered main space heating energy is 12,0 % from the original. Local production is 67,0% from the demand of 76541,0 kWh. Auiliary space heating demand is 0,0 kWh.
- DHW, change of boiler to enable the use of oil. Annual delivered domestic hot water heating energy is 29,0% from the original.
- Installation of PV panels, production target 25%. Estimated areas for PV panels to cover the target. Appliance electricity, local production is 7890,0 kWh/a.
    - PV roof panels (efficiency: 19,0%, system loss: 14,0%, direct: south, slope: local

latitude). Estimated annual solar radiation is 1121,0 kWh/m^2. Area needed to reach the target is around 44,0 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 83,0 m^2.

- Insulating hot water heating system pipes. Hot water circulation pipe losses from 10,0 to 5,0 kWh/m^2,a
- Heating demand is 76540 kWh
- Domestic hot water demand is 34942 kWh
- Electricity demand for appliances/lighting is 31795 kWh

RINNO-TOOL RESULTS

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			Appliances and lighting 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	204328	136	0	45306	30	0	31795	21	0	0	0	0
After	25344	17	51196	13093	9	20949	23906	16	7889	0	0	0
Savings	178984	119		32213	21		7889	5		0	0	

Primary energy analysis			
	Baseline kWh/a	After renovation kWh/a	Savings kWh/a
Delivered primary energy for heating:	204328	65389	138939
Delivered primary energy for cooling:	0	0	0
Delivered primary energy for hot water:	116890	33780	83110
Delivered primary energy for appliances/lighting:	82032	61678	20354
Total delivered primary energy:	403250	160847	242403

Installed refurbishmen measures:
A2. Installing new ventilation system -- Estimated annual mechanical air flow is 100.0 % from original.
A5. Sealing the envelope -- Estimated annual Infiltration air flow is 59.0 % from original

Installed refurbishmen measures:
A2. Installing new ventilation system -- Estimated annual mechanical air flow is 100.0 % from original.
A5. Sealing the envelope -- Estimated annual Infilatration air flow is 59.0 % from original.
B2. Replacement of windows with improved thermal performance (U-value) -- The U-value has changed from 5.6 to 1.4 [W/m2,K]. Total estimated window area is 117.0 m².
B5. Replacement of windows with a new type (G-value) -- Window glazing has changed from SINGLE to SELECTIVEDOUBLE. Total estimated window area is 117.0 m².
C2. Insulation of outside walls -- U-value changed from 2.15 to 0.2 [W/m2,K]. * K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 114.0 mm. * EKOLAB (λ=0.037 W/mK) insulation thickness needed is around 168.0 mm.
J8. Main space heating, air to water heat pump -- Annual delivered main space heating energy is 13.0 % from the original. Local production is 67.0 % from the demand of 76541.0 kWh. Auxiliary space heating demand is 0.0 kWh.
M8. DHW Air to water heat pump -- Annual delivered domestic hot water heating energy is 29.0 % from the original. Local production is 62.0 % from the demand of 34042.0 kWh. Auxiliary hot water heating demand is 0.0 kWh.
N11. Installation of pv panels, production target 25% -- Estimated areas for PV panels to cover the target. **Appliance electricity**, local production is 7890.0 kWh/a. * PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 1121.0 kWh/m2. Area needed to reach the target is around 44.0 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 83.0 m². **All delivered electricity**, production target is 17499.0 kWh/a. * PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 1121.0 kWh/m2. Area needed to reach the target is around 96.0 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 184.0 m².
O2. Insulating hot water heating system pipes -- Hot water circulation pipe losses from 8.0 to 2.0 kWh/m².a

Figure 28: French scenario 1 energy consumption estimation results and installed renovation options.

7.4.2 French scenario 2

Estimated energy consumption savings for French scenario 2. 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 29.

Installed refurbishment measures and additional information for French scenario 1:

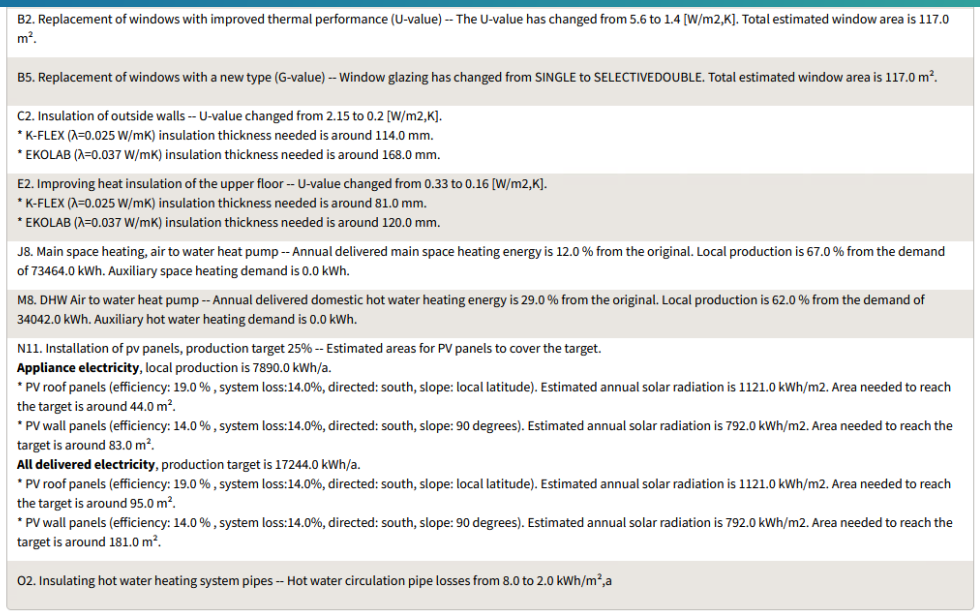
- Replacement of windows with improved thermal performance (U-value) – The U-value has changed from 5,6 to 1,4 [W/m^2,K]. Total estimated window area is 117,0 m^2.
- Replacement of windows with a new type (G-value). Window glazing has changed from DOUBLE to SELECTIVEDOUBLE. Total estimated window area is 117,0 m^2.
- Insulation of outside walls. U-value changed from 2,15 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
- Main space heating, ground source heat pump. Annual delivered main space heating energy is 8,0% from the original.

- DHW, Air to water heat pump. Annual delivered main space heating energy is 29,0% from the original. Local production is 62,0 % from the demand of 34042,0 kWh. auxiliary space heating demand is 0,0 kWh.
- Installation of PV panels, production target 25%. Estimated areas for PV panels to cover the target. Appliance electricity, local production is 7890,0 kWh/a.
    - PV roof panels (efficiency: 19,0%, system loss: 14,0%, direct: south, slope: local latitude). Estimated annual solar radiation is 1121,0 kWh/m^2. Area needed to reach the target is around 44,0 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 83,0 m^2.
- Insulating hot water heating system pipes. Hot water circulation pipe losses from 10,0 to 5,0 kWh/m^2,a

	Space heating			Hot water			Appliances and lighting 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	204328	136	0	45306	30	0	31795	21	0	0	0	0
After	24326	16	49138	13093	9	20949	23906	16	7889	0	0	0
Savings	180002	120		32213	21		7889	5		0	0	

Primary energy analysis			
	Baseline kWh/a	After renovation kWh/a	Savings kWh/a
Delivered primary energy for heating:	204328	62760	141568
Delivered primary energy for cooling:	0	0	0
Delivered primary energy for hot water:	116890	33780	83110
Delivered primary energy for appliances/lighting:	82032	61678	20354
Total delivered primary energy:	403250	158218	245032

Installed refurbishmen measures:
A2. Installing new ventilation system -- Estimated annual mechanical air flow is 100.0 % from original.
A5. Sealing the envelope -- Estimated annual Infilatration air flow is 59.0 % from original.



B2. Replacement of windows with improved thermal performance (U-value) -- The U-value has changed from 5.6 to 1.4 [W/m2,K]. Total estimated window area is 117.0 m^2.

B5. Replacement of windows with a new type (G-value) -- Window glazing has changed from SINGLE to SELECTIVEDOUBLE. Total estimated window area is 117.0 m^2.

C2. Insulation of outside walls -- U-value changed from 2.15 to 0.2 [W/m2,K].
* K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 114.0 mm.
* EKOLAB (λ=0.037 W/mK) insulation thickness needed is around 168.0 mm.

E2. Improving heat insulation of the upper floor -- U-value changed from 0.33 to 0.16 [W/m2,K].
* K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 81.0 mm.
* EKOLAB (λ=0.037 W/mK) insulation thickness needed is around 120.0 mm.

J8. Main space heating, air to water heat pump -- Annual delivered main space heating energy is 12.0 % from the original. Local production is 67.0 % from the demand of 73464.0 kWh. Auxiliary space heating demand is 0.0 kWh.

M8. DHW Air to water heat pump -- Annual delivered domestic hot water heating energy is 29.0 % from the original. Local production is 62.0 % from the demand of 34042.0 kWh. Auxiliary hot water heating demand is 0.0 kWh.

N11. Installation of pv panels, production target 25% -- Estimated areas for PV panels to cover the target.
Appliance electricity, local production is 7890.0 kWh/a.
* PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 1121.0 kWh/m2. Area needed to reach the target is around 44.0 m^2.
* 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 83.0 m^2.
All delivered electricity, production target is 17244.0 kWh/a.
* PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 1121.0 kWh/m2. Area needed to reach the target is around 95.0 m^2.
* 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 181.0 m^2.

O2. Insulating hot water heating system pipes -- Hot water circulation pipe losses from 8.0 to 2.0 kWh/m^2,a

Figure 29: French scenario 2 energy consumption estimation results and installed renovation options.

7.4.3 French scenario 3

Estimated energy consumption savings for French scenario 3. 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 30.

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 5,6 to 1,4 [W/m^2,K]. Total estimated window area is 117,0 m^2.
- Replacement of windows with a new type (G-value). Window glazing has changed from DOUBLE to SELECTIVEDOUBLE. Total estimated window area is 117,0 m^2.
- Insulation of outside walls. U-value changed from 2,15 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
- Heat recovery for ventilation system. Efficiency has changed from 0,0 to 0,55.
- Main space heating, air to water heat pump.

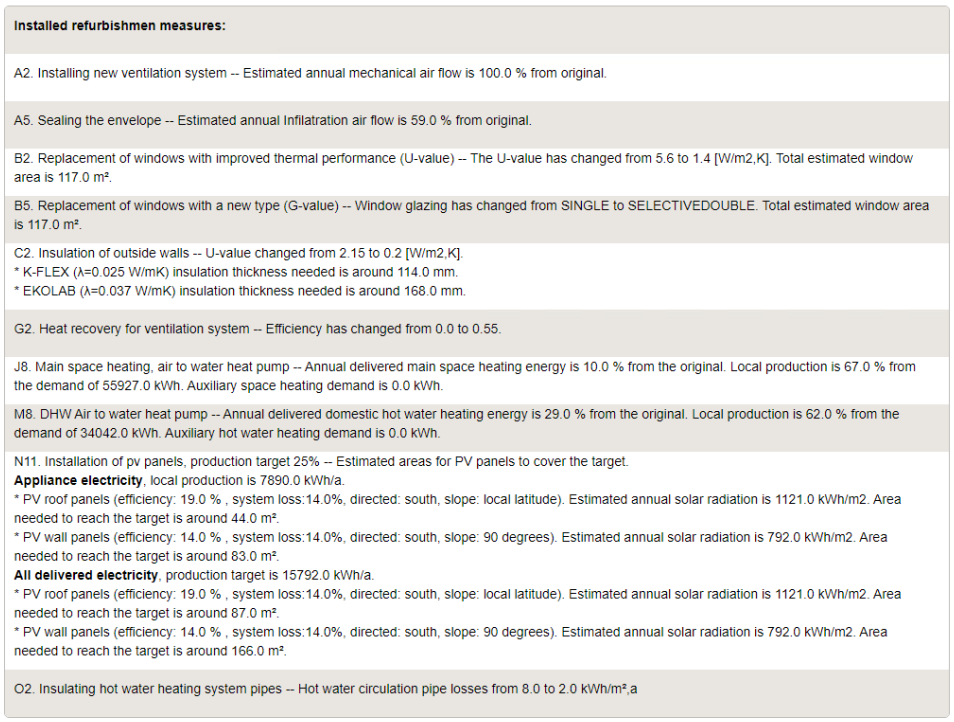
- DHW, Air to water heat pump. Annual delivered main space heating energy is 29,0% from the original. Local production is 62,0 % from the demand of 34042,0 kWh. auxiliary space heating demand is 0,0 kWh.
- Installation of PV panels, production target 25%. Estimated areas for PV panels to cover the target. Appliance electricity, local production is 7890,0 kWh/a.
    - PV roof panels (efficiency: 19,0%, system loss: 14,0%, direct: south, slope: local latitude). Estimated annual solar radiation is 1121,0 kWh/m^2. Area needed to reach the target is around 44,0 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 83,0 m^2.
- Insulating hot water heating system pipes. Hot water circulation pipe losses from 10,0 to 5,0 kWh/m^2,a
- Heating demand is 55926 kWh
- Domestic hot water demand is 34042 kWh
- Electricity demand for appliances/lighting is 31795 kWh

RINNO-TOOL RESULTS

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			Appliances and lighting 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	204328	136	0	45306	30	0	31795	21	0	0	0	0
After	18519	12	37408	13093	9	20949	23906	16	7889	0	0	0
Savings	185809	124		32213	21		7889	5		0	0	

Primary energy analysis			
	Baseline kWh/a	After renovation kWh/a	Savings kWh/a
Delivered primary energy for heating:	204328	47778	156550
Delivered primary energy for cooling:	0	0	0
Delivered primary energy for hot water:	116890	33780	83110
Delivered primary energy for appliances/lighting:	82032	61678	20354
Total delivered primary energy:	403250	143236	260014



Installed refurbishmen measures:

A2. Installing new ventilation system -- Estimated annual mechanical air flow is 100.0 % from original.

A5. Sealing the envelope -- Estimated annual Infilatration air flow is 59.0 % from original.

B2. Replacement of windows with improved thermal performance (U-value) -- The U-value has changed from 5.6 to 1.4 [W/m2,K]. Total estimated window area is 117.0 m².

B5. Replacement of windows with a new type (G-value) -- Window glazing has changed from SINGLE to SELECTIVEDOUBLE. Total estimated window area is 117.0 m².

C2. Insulation of outside walls -- U-value changed from 2.15 to 0.2 [W/m2,K].
* K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 114.0 mm.
* EKOLAB (λ=0.037 W/mK) insulation thickness needed is around 168.0 mm.

G2. Heat recovery for ventilation system -- Efficiency has changed from 0.0 to 0.55.

J8. Main space heating, air to water heat pump -- Annual delivered main space heating energy is 10.0 % from the original. Local production is 67.0 % from the demand of 55927.0 kWh. Auxiliary space heating demand is 0.0 kWh.

M8. DHW Air to water heat pump -- Annual delivered domestic hot water heating energy is 29.0 % from the original. Local production is 62.0 % from the demand of 34042.0 kWh. Auxiliary hot water heating demand is 0.0 kWh.

N11. Installation of pv panels, production target 25% -- Estimated areas for PV panels to cover the target.
Appliance electricity, local production is 7890.0 kWh/a.
* PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 1121.0 kWh/m2. Area needed to reach the target is around 44.0 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 83.0 m².
All delivered electricity, production target is 15792.0 kWh/a.
* PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 1121.0 kWh/m2. Area needed to reach the target is around 87.0 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 166.0 m².

O2. Insulating hot water heating system pipes -- Hot water circulation pipe losses from 8.0 to 2.0 kWh/m²,a

Figure 30: French scenario 2 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 3 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	204328	0	204328	0	204328	0
After	25344	51196	24326	33214	18519	33214
Savings	**178984**		**180002**		**208782**	
Hot water						
	Scenario 1		**Scenario 2**		**Scenario 3**	

	Delivered kWh/a	Local production	Delivered kWh/a	Local production	Delivered kWh/a	Local production
Before	45306	0	45306	0	45306	0
After	13093	20949	13093	20949	13093	20949
Savings	**32213**		**32213**		**32213**	
Appliance electricity						
	Scenario 1		**Scenario 2**		**Scenario 3**	
	Delivered kWh/a	Local production	Delivered kWh/a	Local production	Delivered kWh/a	Local production
Before	31795	0	31795	0	31795	0
After	23906	7889	23906	7889	23906	7889
Savings	**7889**		**7889**		**7889**	
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**	

7.5 Results for the Danish scenarios

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

7.5.1 Danish 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 31.

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 2,22 to 0,9 [W/m^2,K]. Total estimated window area is 138,0 m^2.
- Replacement of windows with a new type (G-value). Window glazing has changed from DOUBLE to SELECTIVEDOUBLE. Total estimated window area is 138,0 m^2.
- Heat recovery for ventilation system. Efficiency has changed from 0,55 to 0,9.
- Installation of pv panels, production tarket 100%. Estimated areas for PV panels to cover the target. Local production is 24105,0 kWh/a.
    - PV roof panels efficiency: 19,0%, system loss: 14,0%, directed: south, slope: local latitude). Estimated annual solar radiation is 1095,0 kWh/m2. Area needed to reach the target is around 68,0 m2.
    - PV wall panels efficiency: 14,0%, system loss: 14,0%, directed: south, slope: 90% degrees). Estimated annual solar radiation is 801,0 kWh/m2. Area needed to reach the target is around 125,0 m2.
- Insulating hot water heating system pipes. Hot water circulation pipe losses from 13,0 to 8,0 kWh/m^2,a
- Heating demand is 41150 kWh
- Domestic hot water demand is 16961 kWh
- Electricity demand for appliances/lighting is 24105 kWh

RINNO-TOOL RESULTS

Donel
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			Appliances and lighting 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	69937	102	0	20817	30	0	24105	35	0	0	0	0
After	41990	61	0	17307	25	0	12052	18	12052	0	0	0
Savings	27947	41		3510	5		12053	17		0	0	

Primary energy analysis			
	Baseline kWh/a	After renovation kWh/a	Savings kWh/a
Delivered primary energy for heating:	59446	35692	23754
Delivered primary energy for cooling:	0	0	0
Delivered primary energy for hot water:	17694	14711	2983
Delivered primary energy for appliances/lighting:	45799	22900	22899
Total delivered primary energy:	122939	73303	49636

Installed refurbishmen measures:

A2. Installing new ventilation system -- Estimated annual mechanical air flow is 146.0 % from original.

A5. Sealing the envelope -- Estimated annual Infilatration air flow is 75.0 % from original.

B2. Replacement of windows with improved thermal performance (U-value) -- The U-value has changed from 2.22 to 0.9 [W/m2,K]. Total estimated window area is 138.0 m².

B5. Replacement of windows with a new type (G-value) -- Window glazing has changed from DOUBLE to TRIPLE. Total estimated window area is 138.0 m².

G2. Heat recovery for ventilation system -- Efficiency has changed from 0.55 to 0.9.

N2. Installation of pv panels, production target 50% -- Estimated areas for PV panels to cover the target.
Appliance electricity, local production is 12053.0 kWh/a.
* PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 1095.0 kWh/m2. Area needed to reach the target is around 68.0 m².
* PV wall panels (efficiency: 14.0 % , system loss:14.0%, directed: south, slope: 90 degrees). Estimated annual solar radiation is 801.0 kWh/m2. Area needed to reach the target is around 125.0 m².
All delivered electricity, production target is 12053.0 kWh/a.
* PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 1095.0 kWh/m2. Area needed to reach the target is around 68.0 m².
* PV wall panels (efficiency: 14.0 % , system loss:14.0%, directed: south, slope: 90 degrees). Estimated annual solar radiation is 801.0 kWh/m2. Area needed to reach the target is around 125.0 m².

O2. Insulating hot water heating system pipes -- Hot water circulation pipe losses from 13.0 to 8.0 kWh/m²,a

Figure 31: Danish scenario 1 energy consumption estimation results and installed renovation options.

7.5.2 Danish scenario 2

Estimated energy consumption savings for Danish scenario 2. are compared to other scenarios in paragraph 7.4.4 Comparison between Danish scenarios.

Estimated results for Danish scenario 2 energy consumption with a list of installed renovation options are presented in the Figure 32.

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 2,22 to 0,9 [W/m^2,K]. Total estimated window area is 138,0 m^2.
- Replacement of windows with a new type (G-value). Window glazing has changed from DOUBLE to TRIPLE. Total estimated window area is 138,0 m^2.
- Insulation of outside walls
- Heat recovery for ventilation system. Efficiency has changed from 0,55 to 0,9.
- Installation of pv panels, production tarket 100%. Estimated areas for PV panels to cover the target. Local production is 12053,0 kWh/a.
    - PV roof panels efficiency: 19,0%, system loss: 14,0%, directed: south, slope: local latitude). Estimated annual solar radiation is 1095,0 kWh/m2. Area needed to reach the target is around 68,0 m2.
    - PV wall panels efficiency: 14,0%, system loss: 14,0%, directed: south, slope: 90% degrees). Estimated annual solar radiation is 801,0 kWh/m2. Area needed to reach the target is around 125,0 m2.
- Insulating hot water heating system pipes. Hot water circulation pipe losses from 13,0 to 8,0 kWh/m^2,a
- Heating demand is 30742 kWh
- Domestic hot water demand is 16961 kWh
- Electricity demand for appliances/lighting is 24105 kWh

RINNO-TOOL RESULTS

Donel
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			Appliances and lighting 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	69937	102	0	20817	30	0	24105	35	0	0	0	0
After	22315	32	0	17307	25	0	12052	18	12052	0	0	0
Savings	47622	70		3510	5		12053	17		0	0	

Primary energy analysis			
	Baseline kWh/a	After renovation kWh/a	Savings kWh/a
Delivered primary energy for heating:	59446	18967	40479
Delivered primary energy for cooling:	0	0	0
Delivered primary energy for hot water:	17694	14711	2983
Delivered primary energy for appliances/lighting:	45799	22900	22899
Total delivered primary energy:	122939	56578	66361

Installed refurbishmen measures:
A2. Installing new ventilation system -- Estimated annual mechanical air flow is 146.0 % from original.

Installed refurbishmen measures:
A2. Installing new ventilation system -- Estimated annual mechanical air flow is 146.0 % from original.
A5. Sealing the envelope -- Estimated annual Infilatration air flow is 75.0 % from original.
B2. Replacement of windows with improved thermal performance (U-value) -- The U-value has changed from 2.22 to 0.9 [W/m2,K]. Total estimated window area is 138.0 m².
B5. Replacement of windows with a new type (G-value) -- Window glazing has changed from DOUBLE to TRIPLE. Total estimated window area is 138.0 m².
C5. Insulation of outside walls -- U-value changed from 0.7 to 0.25 [W/m2,K]. * K-FLEX (λ=0.025 W/mK) insulation thickness needed is around 65.0 mm. * EKOLAB (λ=0.037 W/mK) insulation thickness needed is around 96.0 mm.
G2. Heat recovery for ventilation system -- Efficiency has changed from 0.55 to 0.9.
N2. Installation of pv panels, production target 50% -- Estimated areas for PV panels to cover the target. **Appliance electricity**, local production is 12053.0 kWh/a. * PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 1095.0 kWh/m2. Area needed to reach the target is around 68.0 m². * PV wall panels (efficiency: 14.0 % , system loss:14.0%, directed: south, slope: 90 degrees). Estimated annual solar radiation is 801.0 kWh/m2. Area needed to reach the target is around 125.0 m². **All delivered electricity**, production target is 12053.0 kWh/a. * PV roof panels (efficiency: 19.0 % , system loss:14.0%, directed: south, slope: local latitude). Estimated annual solar radiation is 1095.0 kWh/m2. Area needed to reach the target is around 68.0 m². * PV wall panels (efficiency: 14.0 % , system loss:14.0%, directed: south, slope: 90 degrees). Estimated annual solar radiation is 801.0 kWh/m2. Area needed to reach the target is around 125.0 m².
O2. Insulating hot water heating system pipes -- Hot water circulation pipe losses from 13.0 to 8.0 kWh/m²,a

Figure 32: Dannis scenario 2 energy consumption estimation results and installed renovation options.

7.5.3 Comparison between Danish scenarios

Two Danish 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 8: Two Danish scenarios main results

Space heating				
	Scenario 1		**Scenario 2**	
	Delivered kWh/a	Local production	Delivered kWh/a	Local production
Before	69937	0	69937	0
After	41990	0	22315	0
Savings	**27947**		**47622**	
Hot water				
	Scenario 1		**Scenario 2**	
	Delivered kWh/a	Local production	Delivered kWh/a	Local production
Before	20817	0	20817	0
After	17307	0	17307	0
Savings	**3510**		**3510**	
Appliance electricity				
	Scenario 1		**Scenario 2**	
	Delivered kWh/a	Local production	Delivered kWh/a	Local production
Before	24105	0	24105	0
After	12052	24105	12052	12052
Savings	**12053**		**12053**	
Space cooling				
	Scenario 1		**Scenario 2**	
	Delivered kWh/a	Local production	Delivered kWh/a	Local production
Before	0	0	0	0
After	0	0	0	0
Savings	**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. The 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 & Shemeikka, 2007; Ketomäki, 2015; Tuomisto, n.d.)

The calculations are based on existing standards.

9 Conclusions

This report described the development work done for the VTT Digital Twin toolkit 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
- Modifications needed by the updated renovation scenarios

- Updated calculations for the updated scenarios
- Collecting relevant information from BIM models to support renovation decision making
- 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

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

10 References

Biström, H., & Shemeikka, J. (2007). *Simplified Building Simulator v 1.0 SmokeTest of the Simplified Building Simulator Smoke Tests of the Simplified Building Simulator*. http://cic.vtt.fi/epass/vtt/docs/Validation_of_the_calculation_core_for_E-PASS.pdf

Ketomäki, J. (2015). *Validating E-PASS energy calculator with IDA Indoor Climate and Energy simulation software*. http://cic.vtt.fi/epass/vtt/step_1.php

Kurnitski, J. (2013). Technical definition for nearly zero energy buildings - Active House Alliance. *Journal of the Federation of European Heating, Ventilation and Air Conditioning Associations*, *50*(May-03), 22–28. https://www.rehva.eu/rehva-journal/chapter/technical-definition-for-nearly-zero-energy-buildings

Paiho, S., Abdurafikov, R., & Hoang, H. (2015). Cost analyses of energy-efficient renovations of a Moscow residential district. *Sustainable Cities and Society*, *14*, 5–15. https://doi.org/10.1016/j.scs.2014.07.001

Paiho, S., Abdurafikov, R., Hoang, H., & Kuusisto, J. (2015). An analysis of different business models for energy efficient renovation of residential districts in Russian cold regions. *Sustainable Cities and Society*. https://doi.org/10.1016/j.scs.2014.07.008

Paiho, S., Hedman, Å., Abdurafikov, R., Hoang, H., Sepponen, M., Kouhia, I., & Meinander, M. (2013). Energy saving potentials of Moscow apartment buildings in residential districts. *Energy and Buildings*. https://doi.org/10.1016/j.enbuild.2013.07.084

Paiho, S., Hoang, H., Hedman, Å., Abdurafikov, R., Sepponen, M., & Meinander, M. (2014). Energy and emission analyses of renovation scenarios of a Moscow residential district. *Energy and Buildings*, *76*, 402–413. https://doi.org/10.1016/j.enbuild.2014.03.014

Paiho, S., Pinto Seppä, I., & Jimenez, C. (2015). An energetic analysis of a multifunctional façade system for energy efficient retrofitting of residential buildings in cold climates of Finland and Russia. *Sustainable Cities and Society*, *15*, 75–85. https://doi.org/10.1016/j.scs.2014.12.005

Piira, K., Kantorovitch, J., Kannari, L., Piippo, J., & Vu Hoang, N. (2022). Decision

Support Tool to Enable Real-Time Data-Driven Building Energy Retrofitting Design. *Energies 2022, Vol. 15, Page 5408*, *15*(15), 5408. https://doi.org/10.3390/EN15155408

RINNO project. (2021). *Deliverable 1.4: RINNO Pilot Analysis and Deployment Plan*.

Tuomisto, M. (n.d.). *NewBEE Prototype Testing & Assessment Functionality testing of Energy performance assessment E-PASS*. Retrieved September 9, 2022, from http://cic.vtt.fi/epass/vtt/docs/Functionality_testing_of_E-PASS.pdf

ABOUT RINNO

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

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

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