



MORE—CONNECT

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MORE-CONNECT

Final selection of favourable concept based on LCA

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For more information about the MORE-CONNECT project see the project website:

<http://www.more-connect.eu>

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1 The reference building

1.1 Description of reference building



Figure 1. MORE-CONNECT pilot building in Tallinn, Estonia

1.2 Building typology

As reference building, the building from the pilot project is used. It is a typical 5-storey house, built in 1986 and made of prefabricated concrete large panel elements and analogous to mass production apartment buildings (series 111-121) from 1960-1990. The building has a full-scale cellar. It has an insulated flat roof structure with bituminous felt cover and a number of ventilation chimneys. The building has a simple, rectangular floor plan. It has 2 similar wings, 2 stairways, with similarly designed flats. The net area of the building is 3824 m² and the heated area 3306 m².

Existing 250mm concrete panel exterior wall consists of 2 concrete sections and insulation layers: 60mm external reinforced concrete slab + 70mm wood-chip insulation layer + 50mm phenolic foam insulation layer + 70mm internal reinforced concrete slab. The existing flat roof with parapet is covered with bitumen felt and insulated with wood-chip boards.

1.3 Typical problems

Unsatisfied overall present energy performance of the existing envelope: $U_{wall}=1.0W/(m^2K)$, $U_{roof}=1.1W/(m^2K)$, $U_{floor}=0.6W/(m^2K)$, thermal bridges, lack or sufficient ventilation, water-proofing failures on balconies and on window drip molds. Wooden windows with high thermal transmittance ($U_{window}=1.8W/(m^2K)$) have broken closing mechanisms and fixings. There are failures and water leak-

age in the area of the chimney-roof. There is possible overheating during winter season, insufficient thermal comfort at southern part of living spaces in the summer period. According to measurements a temperature factor $f_{Rsi} < 0.80$ was calculated, which is below the accepted limit [1]. Because of serious thermal bridges in these type of buildings [2], mold growths on interior surface, especially in the corners of exterior walls and roof.

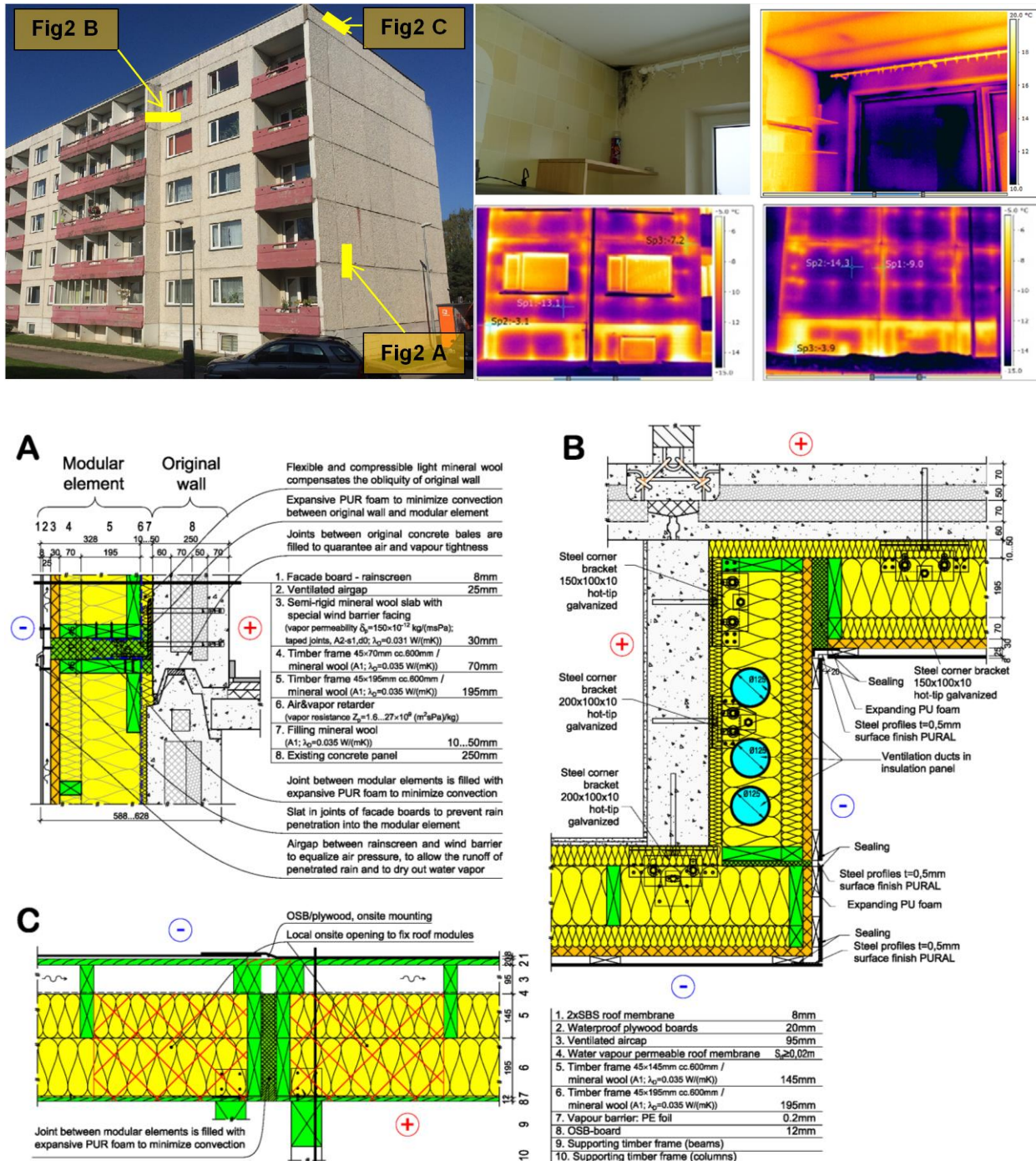


Figure. 2. Overview of the reference building before renovation from outside (above left) and inside (above right) with thermal camera images and designed solutions at the different structural points of the pilot building (below).

In the sense of energy consumption - the pilot building has similar problems typical to many other older buildings: high energy consumption, insufficient ventilation, overheating during winter, unsatisfactory thermal comfort. Fresh air inlet was initially designed through the slits around untightened window wooden-frames and natural exhaust via kitchen and sanitary rooms to central shaft. The building has a one-pipe radiator heating system without thermostats and the room temperature for the whole building is regulated by a heat substation depending on the outdoor temperature [3]. Pre-renovation total delivered annual energy with III indoor climate category (ICC III, acceptable, moderate level of expectation) was 214kWh/(m²·a): for heating and ventilation 149kWh/(m²·a), for domestic hot water (DHW) 30kWh/(m²·a), for appliances and electricity 30kWh/(m²·a), for fans and pumps 5kWh/(m²·a). The heating system will be replaced with a two-pipe system with hydronic radiators and thermostats. The building's initial passive stack ventilation system will be replaced with a mechanical supply and exhaust ventilation with heat recovery. The deficit of places for ventilation ducts in this project design will be solved with the integration of preheated air supply ducts into the renovation module panels, where the ducts will be located in the middle of the insulation layers (see Fig.2 B).

1.4 Dimensions and characteristics of the reference building

The following table summarizes the dimensions and characteristics of the reference building after the renovation:

Parameter	Unit	Data	Parameter	Unit	Data
Building period		1986	Typical indoor temperature	°C	21
Gross heated floor area	m ²	4318	Average electricity consumption per year and m ² (excluding heating, cooling, ventilation)	kWh/(a*m ²)	26
Wall area (excl. windows)	m ²	1891	U-value wall	W/(m ² *K)	0.11
Roof area pitched	m ²	-	U-value roof pitched	W/(m ² *K)	-
Roof area flat	m ²	766	U-value roof flat	W/(m ² *K)	0.10
Attic floor (if attic is unheated)	m ²	-	U-value attic floor	W/(m ² *K)	-
Area of ceiling of cellar	m ²	768	U-value ceiling of cellar	W/(m ² *K)	0.38
Area of windows to North	m ²	251	U-value windows	W/(m ² *K)	0.80
Area of windows to East	m ²	-	g-value windows	Factor	0.50
Area of windows to South	m ²	243	Energy need hot water	kWh/(a*m ²)	30
Area of windows to West	m ²	-	Energy need for cooling	kWh/m ²	-
Average heated gross floor area per person	m ²	20	Airflow rate	m ³ /(h*m ²)	1.0

2 The MORE-CONNECT solution

No major changes assumed in typical floor plan. Staircases will be re-formed in corridors and in front of the building. Open balconies on south and north longer walls will be closed with glazing. Roof will be made with sharper slope, wider edges and wind boxes. HVAC equipment will be placed into the container on roof. PV panels and solar collectors for DHW will be placed on rooftop area.



Figure 3. Renovation solution for MORE-CONNECT pilot building in Tallinn, Estonia.

The building envelope above ground (walls and roof) was insulated with prefabricated modular panels. Basement walls were insulated with an external thermal insulation composite system. Prefabricated modular panels consist of a timber frame structure filled with mineral wool. In principle, also other lightweight structures and insulation materials are conceivable. To get accurate information about the unevenness and roughness of the existing surfaces, 3D laser scanning of the envelope was conducted before the design.

The total thickness of designed modular wall elements is 340-380mm (see Fig.2 A), depending on the surface flatness of the existing wall. The total thickness of the thermal insulation in wall panels is 305-345mm: 30mm wind barrier, 70+195mm insulation between timber frames and 10-50mm light elastic mineral wool to fill the unevenness and roughness of the existing surfaces, $U_{wall}=0.11W/(m^2\cdot K)$. In the wall panel with dimensions $\approx 2.7\times 9m$, installed in horizontal direction, are up to three preinstalled windows. To minimize joints between the modules and connections of pipes on site, the panels with ventilation ducts will be installed in vertical direction. According to the structural design of the pilot building, there is no need for additional foundation for the wall module panels. Self-supporting modules will be hanged with the help of designed fixings, allowing adjustment of modules in all directions.

Designed roof elements were installed on the specially built timber frame because the original roof has an inward slope and parapet. Therefore, under the formed slope roof, in 0.6-1.2m high attic between old and new roof technical appliances are planned to be placed (e.g. heat exchangers, duct dispensers, automatics etc.). The total thickness of the thermal insulation in the roof modules is 340mm, $U_{roof}=0.10W/(m^2\cdot K)$.

To avoid thermal bridges and to minimize the impact of air leakage and convection, smart connectors and innovative fixings, adhesive sealants and elastic polyurethane (PUR) foam were used in the joints between the modules. All vertical joints between wall modules were protected with sealing and steel strips under the facade boards. Horizontal joints were equipped with slits (drip molds) to prevent rain penetration to the insulation. All internal intersections between modules were sealed and filled with expansive PUR foam. To avoid having to tighten the existing envelope, the airtightness of the building with prefabricated highly-insulated modules was ensured.

3 Investigated renovation packages

These renovation packages include the MORE-CONNECT solutions. The renovation packages are assessed with respect to greenhouse gas emissions, primary energy use, and costs.¹

For the selection of favorable concepts, the investigated renovation packages are shown in the following table:

Renovation Package	Description
Ref	In the reference case, the required indoor climate conditions (indoor temperature and ventilation airflows) are ensured.
M1	The wall is insulated with a MORE-CONNECT prefab element including 15 cm of mineral wool.
M2	The wall is insulated with a MORE-CONNECT prefab element including 30 cm of mineral wool.
M3	M2 + roof insulation with MORE-CONNECT prefab element including 20 cm of mineral wool.
M4	M2 + roof insulation with MORE-CONNECT prefab element including 35 cm of mineral wool.
M5	M4 + replacement of windows with U-value 1.1 W/(m ² K)
M6	M4 + replacement of windows with U-value 0.8 W/(m ² K).
M7	M6 + insulation of basement floor with 150 mm of EPS
M8	M7+ supply-exhaust ventilation system with heat recovery
M9	M8 + 100 m ² of solar collectors for domestic hot water
M10	M9 + 87 m ² of PV-panels
M11	M10 + waste water heat recovery

The heating systems taken into account were:

- district heating (reference case)
- ground source heat pump
- wood pellets

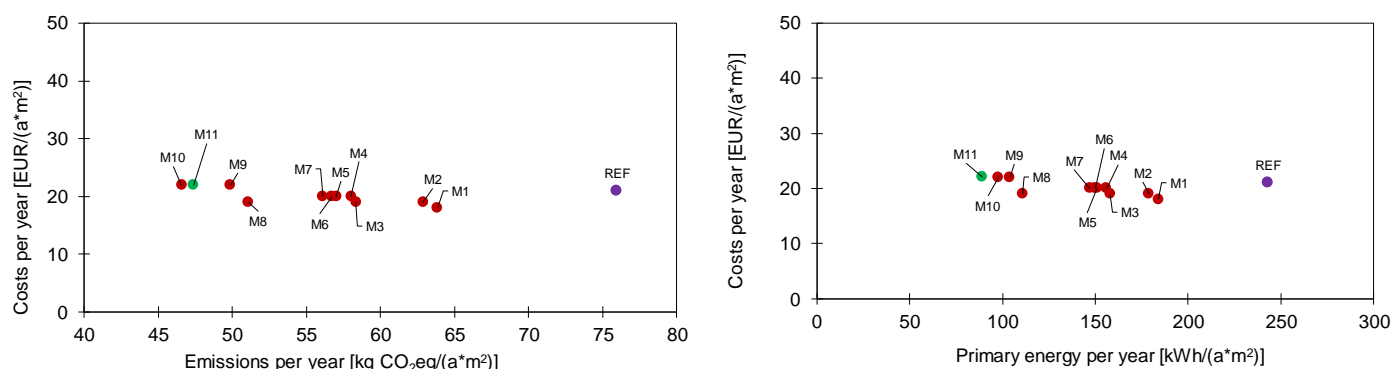
¹ For a description of the assessment methodology, a separate document is available entitled: «Methodological framework and instructions for the selection of favourable concepts for the pilot projects (Task 6.1 part 1)»

4 Assessment of investigated renovation packages and pre-selection of favorable concept

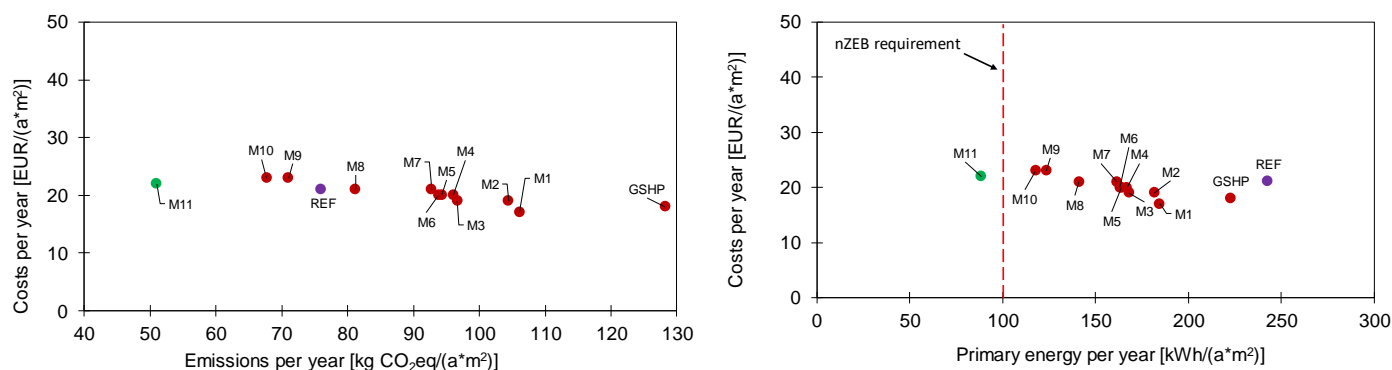
4.1 Overview graphs

For the pilot building, the expected impacts of the investigated renovation packages are shown in the following graphs (favorable concept M11 is shown in green):

Heating system: district heating (REF)



Heating system: ground source heat pump (GSHP)



Heating system: wood pellets (WP)

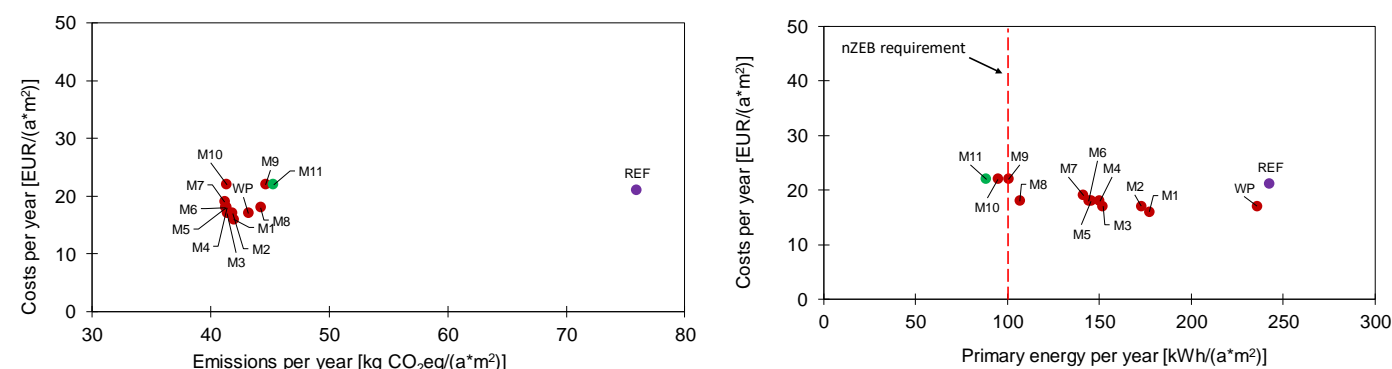


Figure 4. Graphs showing impacts on greenhouse gas emissions (left hand side) and primary energy use (right hand side) vs. costs of various renovation packages for the MORE-CONNECT pilot building in Tallinn, Estonia, in combination with district heating (top), ground source heat pump (center), and wood pellets (bottom). Note the different scales on the x-axis for the greenhouse gas emissions in the graphs on the left hand side.

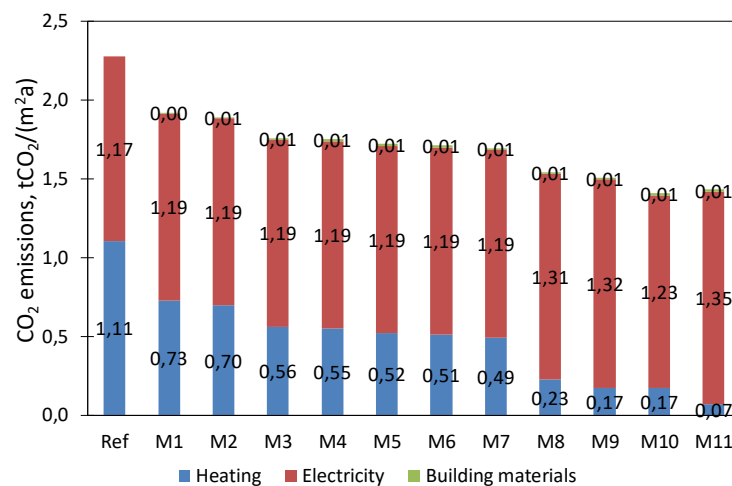
4.2 Discussion of results from assessment

Future nearly Zero Energy Buildings (nZEB) should be much more highly insulated than buildings developed some years ago [4]. The design of the pilot started with preliminary energy and economical calculations [5,6]. The calculated primary energy use of nZEB renovation shows a 2/3 reduction. However, energy cost reduction alone is not enough to make nZEB renovation profitable for a building owner.

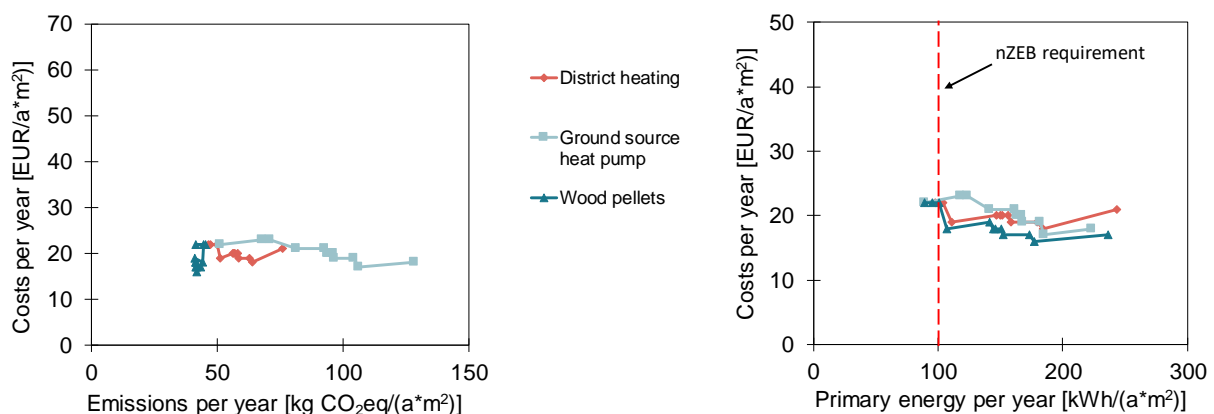
The biggest difference with similar projects done in Europe, where existing external panels were removed, is that in our solution the fully finished modules are meant to be installed onto the existing structures. Therefore, the construction is finished quicker and there is no need for house owners to leave their premises during the construction works.

4.3 Aspects related to reuse of materials, embodied energy and indoor environment

Embodied energy of construction materials used for insulating in renovation have negligible effect on building overall CO₂ emissions over 30 years period. Embodied energy of building materials used for insulating the building is in same range as emissions from one year heating energy use. Therefore embodied energy from building materials was excluded from further analysis.



Emissions were calculated based on heating energy and electricity use. Graphs below show comparison of different heating systems:



Results shows that nZEB requirements are possible to fulfill with all three analyzed heating systems. In terms of emissions, ground source heat pump increases the emissions because electricity production in Estonia is mainly based on oil shale. Emission factor for electricity is 1.1 kgCO₂/kWh. Seasonal COP for ground source heat pump is approximately 3.5. This means that 1 kWh of net heat energy need produces $1.1/3.5=0.31$ kgCO₂/kWh which is almost three times higher than district heating emission factor 0.12 kgCO₂/kWh. 60% of district heating is based on natural gas and 40% is based on wood chips.

Wood pellets show good results in emissions calculations but have some practical restrictions. In Estonia, when building is located in district heating area, then it is obligatory to use district heating. In addition, wood pellets in large buildings are complicated to use. This will require special room for boiler and another room for pellets storage. In city area, it is more reasonable to use district heating, instead of small wood heated boiler in every building. It is easier to minimize air pollution risks in one large district heating boiler, than in many small boilers owned by different owners.

PV-panels show better results regarding the reduction of CO₂ emissions, compared to solar collectors. Nevertheless, solar collectors are used because the pilot building is a university dormitory for students with small children. This means that water consumption is higher than in average apartment buildings and use of solar collectors for heating the hot water is reasonable.

4.4 Lessons learnt based on pilot project

A pilot nZEB renovation of a typical concrete large panel apartment building was conducted in Estonia. This is one of the first deep energy renovations that have been designed to correspond to the nZEB target of new buildings. In addition to the use of prefabricated modular panels for building envelope insulation, the design solution includes many other tasks to be researched: parallel comparison of two different ventilation solutions: apartment based balanced ventilation heat recovery (VHR) and centralized balanced VHR; parallel comparison of heating of DHW by solar collectors and sewage heat recovery.

The hygrothermal performance of the building envelope, constructed of concrete large panels and covered with prefabricated modular elements was analyzed in this research. Thermal transmittance of the developed prefabricated modular panels is $U \approx 0.10 \text{ W}/(\text{m}^2 \cdot \text{K})$. One of the most critical design tasks was the selection of a vapor barrier for the module panel to avoid problems related with dry-out of possible constructional moisture.

The analysis and the whole process of design itself showed that it is essential to consider the initial state of the building when highly-insulated module panels are intended to be used for an nZEB renovation. One of the challenges in this process is the decisive importance of the interaction between the design process and the construction work at the building site. The analysis, design and other preparation activities of the integrated nZEB design process gave us a unique experience, showing weak links in the chain and helping to prevent major faults in the construction of the pilot and in the further processes of design.

5 Final selection of favorable concept

Description of the selected favorable concept is shown in the following table:

Renovation Package	Description
Reference case	In the reference case, the required indoor climate conditions (indoor temperature and ventilation airflows) are ensured.
Pre-selection	<ul style="list-style-type: none"> • wall insulation with a MORE-CONNECT prefab element including 30 cm of mineral wool • roof insulation with MORE-CONNECT prefab element including 35 cm of mineral wool • replacement of windows with U-value 0.8 W/(m²K) • insulation of basement floor with 150 mm of EPS • new two-pipe heating system • supply-exhaust ventilation system with heat recovery • 100 m² of solar collectors for domestic hot water • PV-panels (10 kW) • waste water heat recovery
Final selection	<ul style="list-style-type: none"> • wall insulation with a MORE-CONNECT prefab element including 20 cm of mineral wool • roof insulation with 30 cm of mineral wool • replacement of windows with U-value 1.1 W/(m²K) • new two-pipe heating system • supply-exhaust ventilation system with heat recovery • PV-panels (30 kW)

The heat supply system for the favorable concept is district heating (same as in reference case). In Estonia, when a building is located in district heating area, then it is obligatory to use district heating. Wood pellets show also good results in emissions calculations but have some practical restrictions. In city area, it is more reasonable to use district heating, instead of small wood heated boiler in every building. It is easier to minimize air pollution risks in one large district heating boiler, than in many small boilers owned by different owners. In addition, wood pellets in large buildings are complicated to use. This will require special room for boiler and another room for pellets storage.

The pre-selected concept was designed to achieve nZEB (EPC A) requirements. Results from pilot building showed that nZEB level renovation is not cost-efficient in comparison with competing renovation approaches. In the final selection, the aim was to reduce investment cost and achieve at least the same energy efficiency as new apartment buildings (EPC class C). Main changes compared to the pre-selection are:

- MORE-CONNECT wall element is lighter and easier to produce (U-0.15 W/m²K)
- Roof is not insulated with prefabricated element
- Thermal transmittance of windows is U-1.1 W/m²K
- Basement floor is not insulated
- Solar collectors are not used
- More PV-panels are added to the roof

Results show that with selected renovation package it is possible to achieve low-energy building level (EPC B) and total costs for 30 years period do not increase for the building owner.

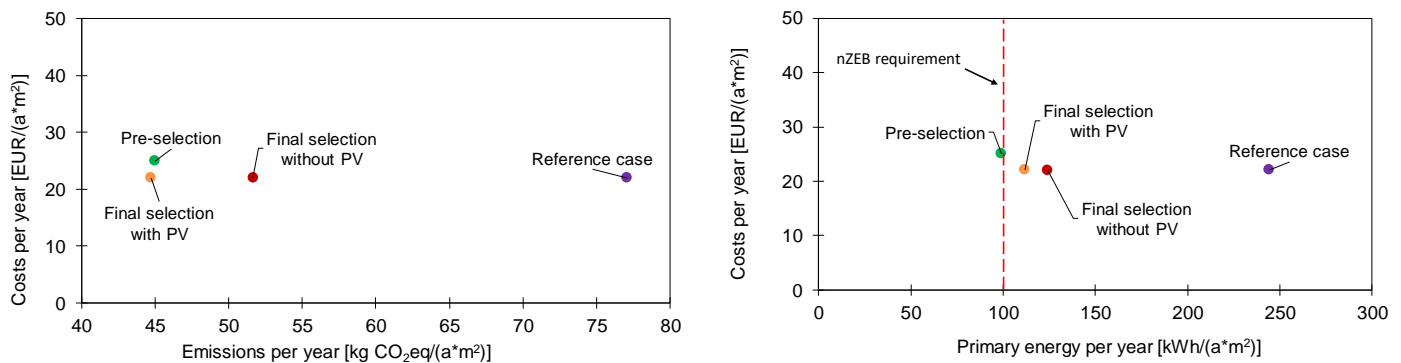


Figure 1. Graphs showing impacts on greenhouse gas emissions (left hand side) and primary energy use (right hand side) vs. costs of various renovation packages for the MORE-CONNECT pilot building in Tallinn, Estonia, in combination with district heating.

Without PV panels, it is possible to achieve energy efficiency requirement level of new apartment building (EPC C). In existing building it not always possible to use on-site renewable energy production because of the building orientation or the higher neighborhood buildings.

6 Further development of MORE-CONNECT solution

The final selection is based on thinner and lighter external wall elements in order to simplify automated production and reduce cost. Main problems with the production and installation of the pilot building wall elements were:

- Installing the ventilation ducts to the wall element
- External addition framing and insulation in order to achieve lower thermal transmittance
- Installing of the mineral wool based wind barrier
- Installing the facade boards
- Anchoring the wall elements to the facade

Possible solutions to minimize those problems are thinner wall element based on 145 mm of timber framing (no additional framing, U-0.15 W/m²K), using other types of façade materials (façade boards are expensive, heavy and complicate to install on production lines) and install wall elements on top of each other on a separate foundation (anchoring wall elements only to the existing façade is complicated and time consuming).

7 References

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