European Commission, Horizon 2020 Programme

MORE-CONNECT

Final selection of favourable concept based on LCA

Country: Latvia

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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. As reference building, the MORE-CONNECT pilot building in City of Cesis, Latvia, is used

As reference building, the Latvian pilot building from the MORE-CONNECT project is used. The Latvian pilot building is a typical brick multi apartment building built in 1967. The pilot building is a silicate brick residential house with a lateral bearing system. The house has a wooden roof structure with slate covering. The building has a simple, rectangular floor plan. It has two floors with similarly designed flats. The house has a pitched roof with a number of chimneys. Attic is unheated. All old wooden windows were replaced by PVC windows 7 – 10 year ago. The building represents typical buildings constructed in 50ies – 60ies last century. This type of building is very common in rural areas and small cities.

1.2 Dimensions and characteristics of the reference building

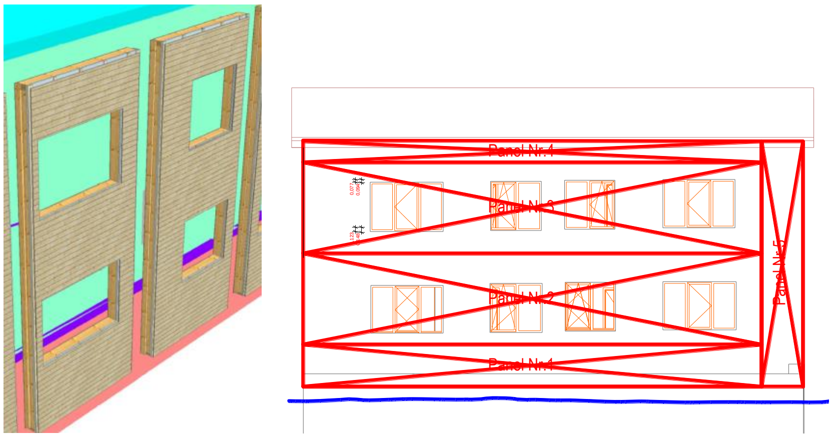
The following table summarizes the dimensions and characteristics of the reference building:

Parameter	**Unit**	**Data**
Building period		1967
Gross heated floor area	m^2	208
Wall area (excl. windows)	m^2	268
Roof area pitched	m^2	n/a
Roof area flat	m^2	n/a
Attic floor (if attic is unheated)	m^2	145
Area of ceiling of cellar	m^2	145
Area of windows to North	m^2	19
Area of windows to East	m^2	8
Area of windows to South	m^2	14
Area of windows to West	m^2	4
Average heated gross floor area per person	m^2	17

Parameter	**Unit**	**Data**
Typical indoor temperature	°C	23
Average electricity consumption per year and m^2 (excluding heating, cooling, ventilation)	kWh/ $(a*m^2)$	Not available
U-value wall	$W/(m^2*K)$	1.0
U-value roof pitched	$W/(m^2*K)$	n/a
U-value roof flat	$W/(m^2*K)$	n/a
U-value attic floor	$W/(m^2*K)$	0.3
U-value ceiling of cellar	kWh/m^2	0.9
Energy need for cooling	$W/(m^2*K)$	n/a
U-value windows	Factor	1.8
g-value windows	$W/(m^2*K)$	Not available
Energy need hot water	kWh/m^2	n/a
Airflow rate *Infiltration rate under 50Pa*	$m^3/(h*m^2)$	4.8

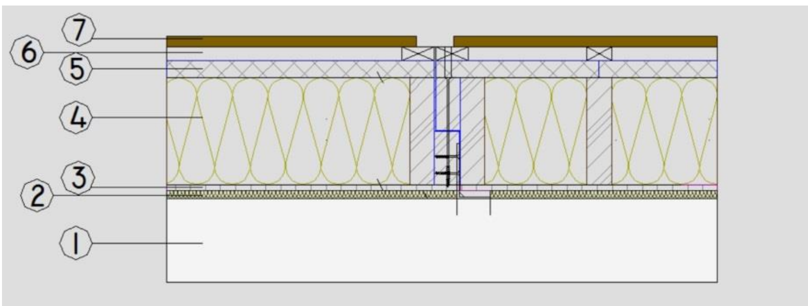
2 The MORE-CONNECT solution

The Latvian pilot building is the first full scale renovation with prefabricated panels in Latvia. The main aim of this research work is to develop, to test and to document the full process of a modular retrofitting process. Within the scope of this study several options were taken into consideration. The thermal insulation of the external building envelope was set as a primary target. Installation of mechanical ventilation and renewable energy sources were indicated as second and third priorities. Transmission heat losses in the Latvian pilot building make up 80% of total heat losses. So specific attention was paid to the selection of an optimal panel layout. The proposed panel solution should fulfil requirements for Latvian building code 002-15 “Thermal performance of building envelope” as well allow dimensions for save transportation.



a) First option b) alternative solution

Figure 2. Evaluation of possible panel layout options



1 Existing wall
2 Connection layer between existing wall and modular panel
3 Frame base
4 Main load bearing and thermal insulation layer
5 Wind protection
6 Ventilated air gap
7External finishing

The proposed solution allows later integration of mechanical or natural ventilation. A mechanical ventilation solution can easily be adopted depending on inhabitants' needs and may include room based heat recovery and hybrid ventilation solutions.

The final renovation option was chosen on the basis of the total construction costs taking into account estimated energy savings for various renovation options.

3 Investigated renovation packages

For the identification of favourable concepts, an assessment of various possible renovation packages is carried out. 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 pre-selection of favourable concepts, the investigated renovation packages are shown in the following table:

Renovation Package	Description
Ref	In the reference case, the wall and the windows are repainted and the pitched roof is re-furbished. These measures do not improve the energy performance of the building. The building is already connected to the existing district heating network. The maintenance cost for existing district heat substation and repairing costs for building envelope were in-cluded in this scenario.
M1	The windows are replaced by energy efficient U-value 1.0 W/(m^{2}K)
M2	The wall is insulated with a MORE-CONNECT prefab element including 15 cm of mineral wool.
M3	The wall is insulated with a MORE-CONNECT prefab element including 20 cm of mineral wool.
M4	Wall 20cm +Roof 20
M5	Wall 20cm +Roof 30
M6	Wall 40cm + Roof 30cm
M7	Wall 20cm + Roof 30cm + cellar 10cm
M8	Wall 20cm + Roof 30cm + cellar 10cm+window
M9	Wall 40cm + Roof 30cm + cellar 10cmWindow uW1

The heating systems taken into account were:

— District heating;

— Heat pump

— Wood pellet boiler

— Natural gas boiler

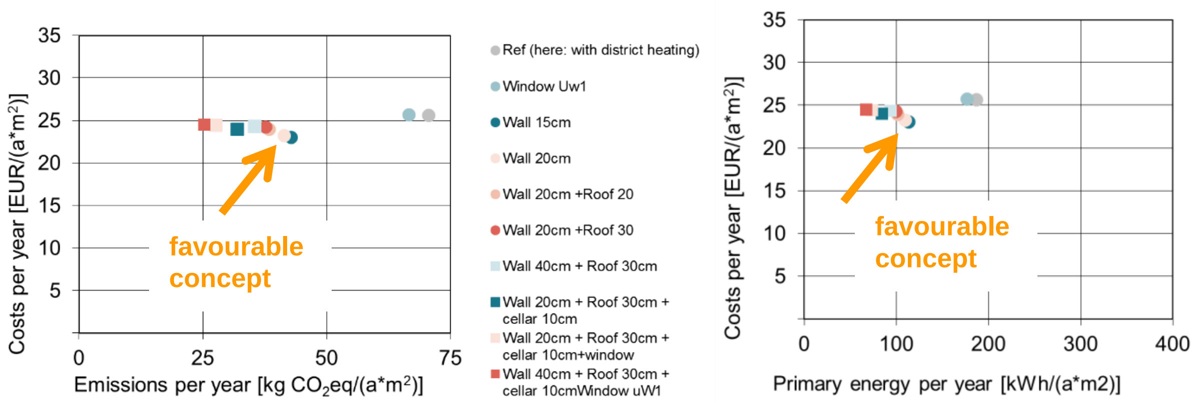
[1] For a description of the assessment methodology, a separate document is available entitled: «Methodological framework and instructions for the selection of favourable concepts for the pilot projects (Task 6.1 part 1)»

4 Assessment of investigated renovation packages and selection of favourable concept

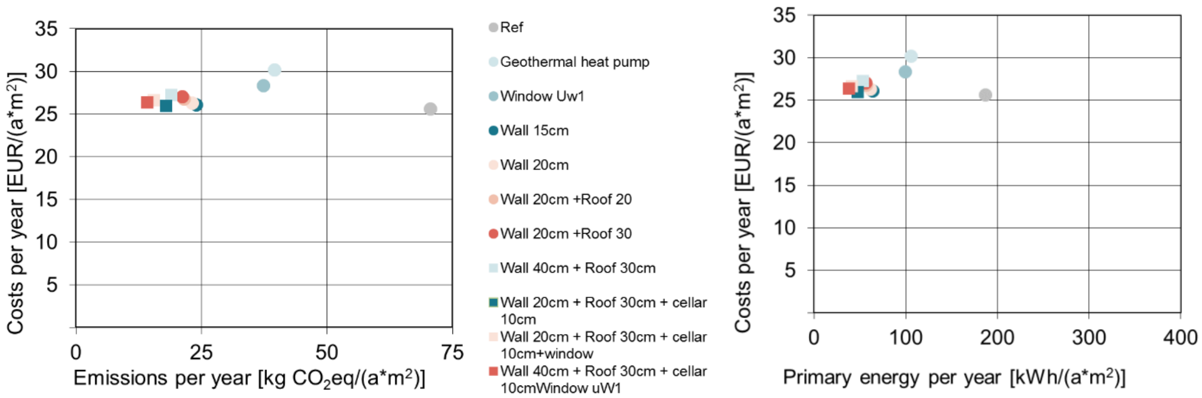
4.1 Overview graphs

For the reference building, the expected impacts of the investigated renovation packages are shown in the following graphs:

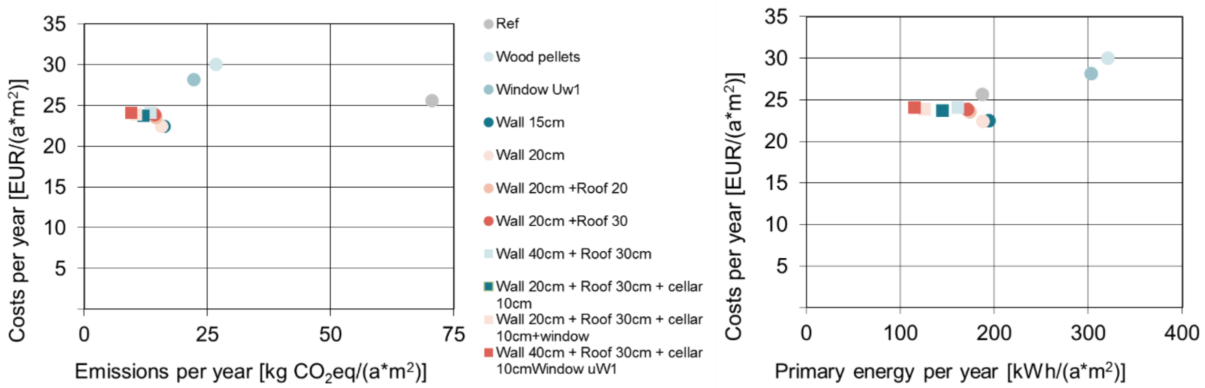
Heating system: district heating



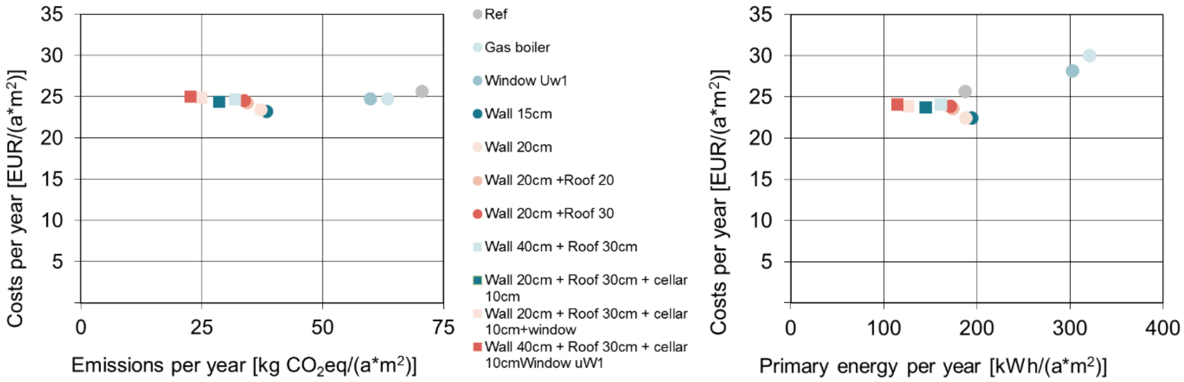
Heating system: soil-water heat pump



Heating system: wood pellet boiler



Heating system: Natural gas boiler



4.2 Discussion of results from assessment

The existing district heating system ensures a relatively low consumption of primary energy. Replacement of district heating by soil-water heat pump ensures the most significant reduction of primary energy. Both solutions allow primary energy consumption below 100kWh/m^2.

Replacement of the connection to the district heating system by a wood pellet boiler or a natural gas boiler slightly increases primary energy consumption. In both cases, primary energy consumption varies between 100 kWh/m^2 and 200 kWh/m^2, depending on retrofitting solution.

The installation of a wood pellet boiler ensures significant reduction of CO_2 emissions. CO_2 emissions are close to or below 25 kg CO_2eq/(a*m^2) with such a solution. The soil-water heat pump has slightly higher CO_2 emission values, but does not exceed 25 kg CO_2eq/(a*m^2) for a majority of retrofitting solutions. Existing district heating system has a CO_2 emissions range between 25 and 41 kgCO_2eq/(a*m^2). The CO_2 emissions are highest with the installation of a natural gas boiler.

The most efficient building retrofitting strategy is **M9** scenario "Wall 40cm + Roof 30cm + cellar 10cmWindow uW1". Application of this scenarios reduces CO2 consumption up to 22.6 CO_2eq/(a*m2). However, this results in highest investments - 25.04EUR/(a*m^2). For this scenario, investments are 1.11 Euro/CO_2. While investments for favorable concept M3 are 0.63 Euro/CO_2

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

Polyurethane and polystyrene thermal insulation materials are the materials with the highest embodied energy among thermal insulation materials. The materials with lowest embodied energy are loose materials.

Polyurethane and polystyrene are not used in Latvian MORE-CONNECT solutions. According to existing studies the stone wool has an embodied energy value two times higher than wood wool. The most environmental friendly material is cellulose. However, use of cellulose material is not common in automated production lines.

Thermal conductivity of cellulose is slightly higher in comparison to stone wool and varies in the range of 0.039 to 0.043 W/mK. Thermal conductivity of stone wool is 0.032 up to 0.038 W/mK. The main fact why cellulose wasn't use in MORE-CONNECT is the absence of necessary equipment at the existing production lines. It is recommended that already existing production lines used by MORE-CONNECT project partners are modified to use loose materials.

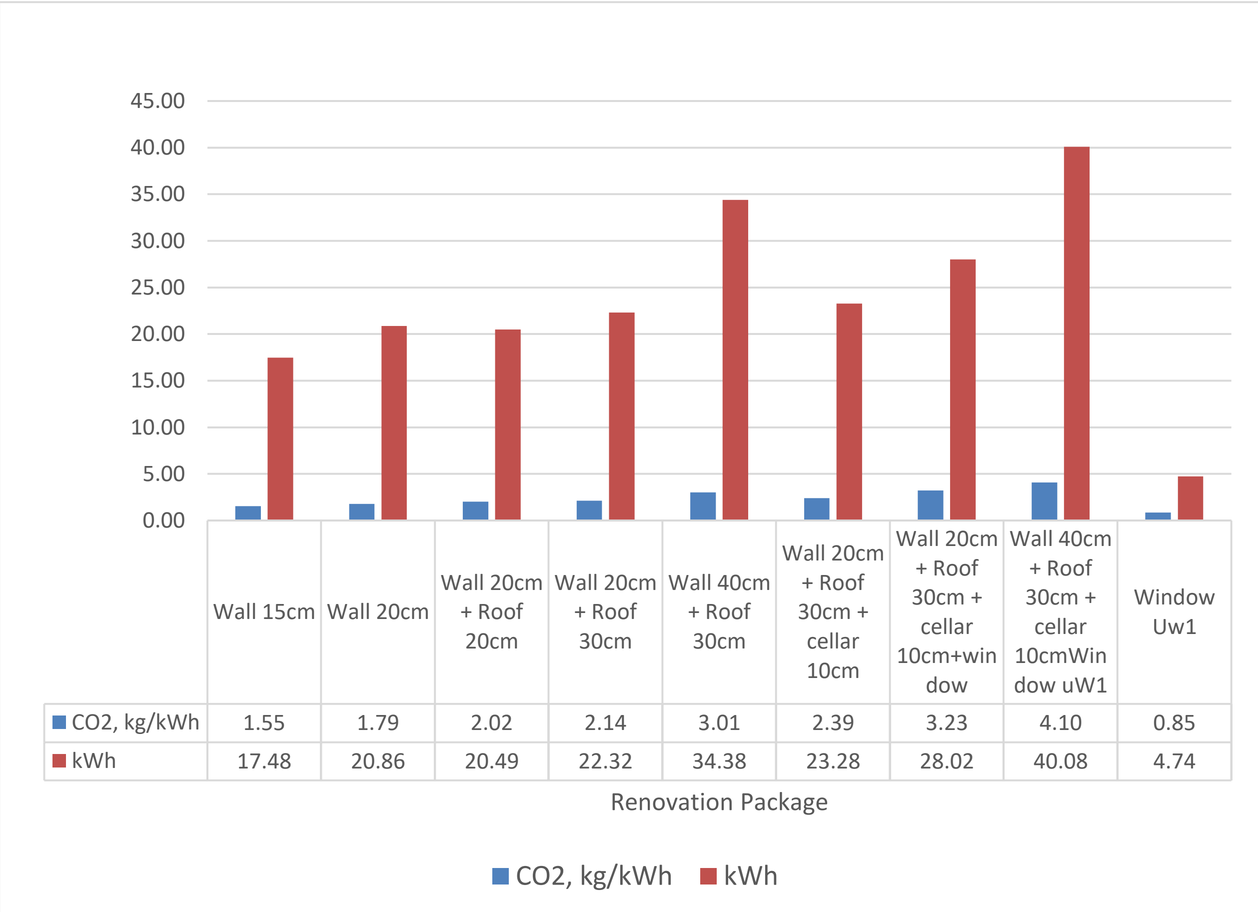
The MORE-CONENCT solution includes wooden carcass and mineral wool.

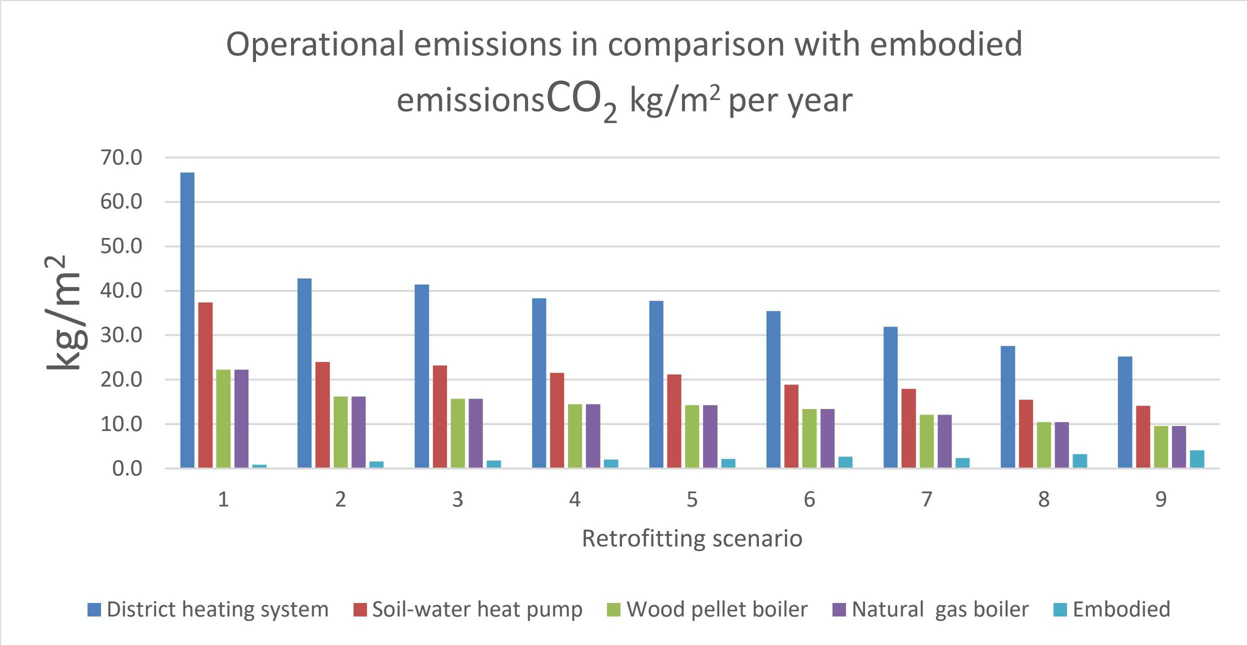
The MORE-CONNECT solution ensures significant reduction of building airtightness rate and increases indoor operative temperature. MORE-CONNECT panels have only few connectors, which allows easy replacement of panels after the end of their service life. Compact shapes of panels are suitable for fast and safe transportation from construction site to factory where such panels can be demolished and separated into pieces in a warehouse using special power tools. Since the panels are produced at a manufacturer, more reliable information on used materials properties will be available. The easy demolition and transportation process prevents materials from negative impact of ambient environment and reduces risks of mechanical damage to the materials, thus preventing moistening and mechanical damages of materials. It can be concluded that the MORE-CONNECT solution is suitable for reuse/recycling at the end of its service life.

4.4 Assessment of renovation packages' embodied energy and CO_2 emissions

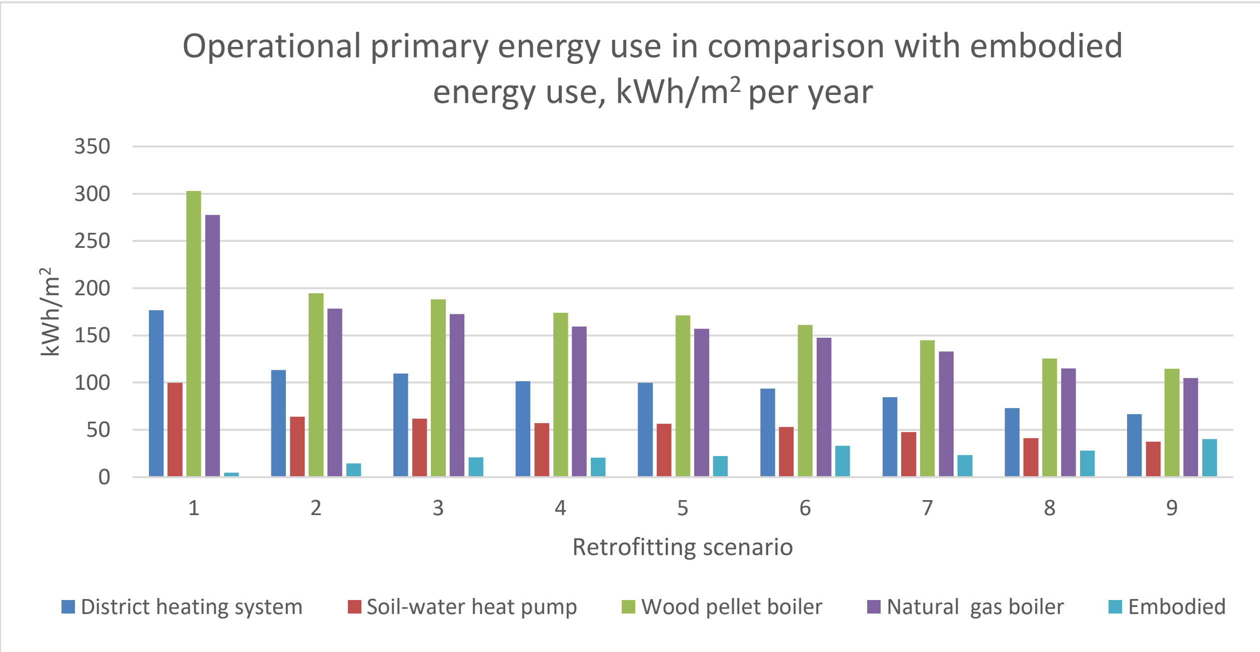
For the assessment of the embodied energy and the embodied CO_2 emissions of the materials used for the renovation packages it is assumed that the service life of used materials is 30 years. Calculations of the embodied energy/emissions impact include only retrofitting of building envelope and window replacement.

The following graphs show the results of the assessment:





1 - Window; 2 - Wall 15cm; **3 -** Wall 20cm; **4 -** Wall 20cm +Roof 20; **5 -** Wall 20cm +Roof 30; **6 -** Wall 40cm + Roof 30cm; **7 -** Wall 20cm + Roof 30cm + cellar 10cm; **8 -** Wall 20cm + Roof 30cm + cellar 10cm+window; **9 -** Wall 40cm + Roof 30cm + cellar 10cm+Window



1 - Window; 2 - Wall 15cm; **3 -** Wall 20cm; **4 -** Wall 20cm +Roof 20; **5 -** Wall 20cm +Roof 30; **6 -** Wall 40cm + Roof 30cm; **7 -** Wall 20cm + Roof 30cm + cellar 10cm; **8 -** Wall 20cm + Roof 30cm + cellar 10cm+window; **9 -** Wall 40cm + Roof 30cm + cellar 10cm+Window

4.5 Assessment of life cycle impact of optional PV system

The pilot building has a pitched roof oriented towards North and South. Both sides' slopes have an inclination of 15° and an area of 77 m². The area of brick chimneys of 0.9 m² should be deducted from the total roof area. The PV panel mounting is assumed to take place on the South side with a maximum available area of 75 m². The primary energy factor for electricity in Latvia is 1.5.

PV system capacity and required PV panel area

Installed power	2kWp	3kWp	4kWp	5kWp	6kWp	7kWp	8kWp
kWh embodied primary energy use / /kWh electricity produced from PV	≈0.25						
*Necessary area of PV array, m²	18.2	27.3	36.4	45.5	55.5	63.6	75**
Panel costs, Euro	5278	7917	10556	13195	16095	18444	21750

**calculations are based on the PV module 250Wp power;*
***available roof area;*

Produced PV electricity can be used to operate not only household devices but also a heat pump. For the demonstration building, a 7kWp PV system will be the most optimal in terms of available space and amount of produced electricity.

Amount of produced PV electricity by 7kWp PV system (polysunonline)

Month	I	II	III	IV	V	VI	VII	VII	IX	X	XI	XII
Energy, kWh	279	363	625	699	827	753	760	766	553	454	335	122

The PV system does not just produce electricity in summer time. During the heating season the 7kWp PV system produces 2877 kWh. It can therefore also contribute to the operation of a heat pump.

The total lifetime embodied primary energy use for the PV system producing 1 kWh electricity per year is ≈7.2 kWh, as calculated from the yearly value multiplied by 30 years for the system lifetime of the PV system. Primary energy use of the Latvian mix of electricity is 1.5 kWh per kWh of electricity consumed, this means that by replacing electricity from the grid, the PV system has paid back the energy that had been necessary for its production after 4.8 years.

4.6 Lessons learnt based on pilot project

Building retrofitting as done within the MORE-CONNECT project was the first full-scale modular retrofitting in Latvia. The retrofitting process was organized and coordinated by Riga Technical University. Highly skilled staff in the field of 3D scanning, BIM technology and energy efficiency were involved for evaluation and technology assessment. However, staff couldn’t work on technical project and architectural design. According to Latvian legislation all necessary construction permits can be obtained by certified engineers. For architectural design the external architectural company was selected based on procurement law. According to this law the main section criterion is lowest prices and experience plays minor role. Due to this fact, an architectural company with minimal 3D design experience was selected. This led to significant increases in person months spent for design. Results of 3D scanning weren't used in an efficient manner. RTU and MORE-CONNECT industrial partner staff had to spend extra time to finalize all necessary activities to develop a solution for the wire integration and to draw the preliminary panel layout.

For successful building renovation based on prefabricated panels, the selected architectural company should have advanced experience in 3D design and be able to work with point cloud data. This will allow more precise project development taking into account real building geometry and existing building systems placed on the facades.

The prefabricated panels mounting was done using only mechanical level to ensure horizontal and vertical alignment of the panel plane. Due to this inaccurate method a slight vertical shift up to 5 mm accrued for each panel. This led to an overlap between the last panel with the first panel. Based on this experience it is recommended to use theodolite or laser level to insure panel strict vertical placement without any vertical or horizontal shifts.

The panel producer should have Computer Numerical Control (CNC) production line. This will allow to produce panels with correct dimensions taking into consideration specifics of each retrofitted building such as position of existing windows, external elements placed on the facade, vertical deviations. In addition, CNC production lines allows production of panels with sufficient space for building systems in the facades takin into account its real location.

In scope of this project extra costs for the addition of panels and transportation costs acquired due to panels occurred. This issue can be easily avoided during the construction process. The selected construction company should use modern equipment for panel mounting. Specially equipped cranes and laser levels should be used. It is recommended to use crane lifting beams to avoid panel spin during lifting. Laser level will ensure precise vertical control.

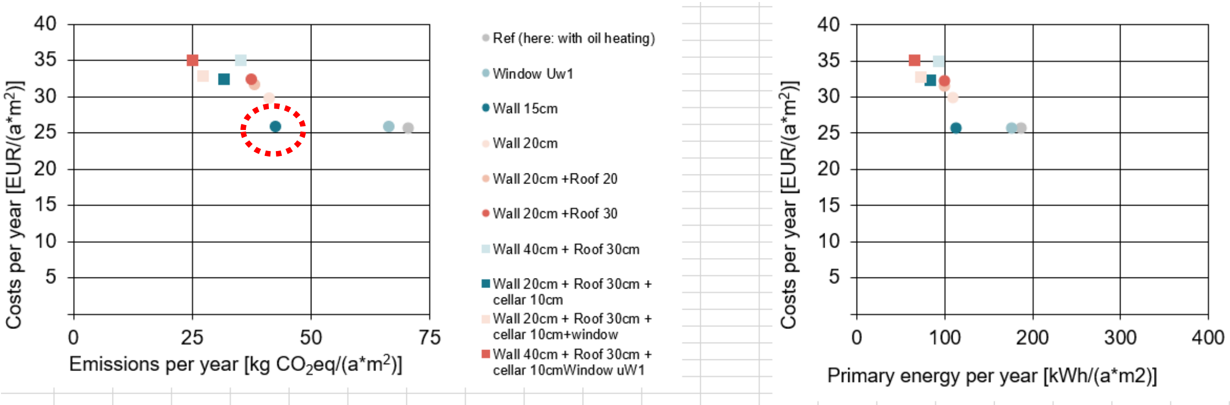
Figure 3 Example of lifting beams (source: WORD on-line picture)

4.7 Selection of favourable concept

This chapter provides assessment of favourable concept based on real construction costs and possible future construction costs reduction due to better planning and business plan.

The main market for the future mass implementation of prefabricated retrofitting is multi apartment buildings. Majority of Latvian multi apartment buildings are connected to the existing district heating systems. Thus presented selection of favourable concept is focused on buildings connected to the existing district heating system.

The following graphs show various packages of renovation measures, taking into consideration real construction costs.



As it can be seen overall costs are significantly higher than originally estimated. Costs are higher in comparison to traditional renovation. However, some possible optimization of production and construction costs can be achieved due to possible market upscale and mass production.

According to the real price estimation the favourable concept includes insulation of existing wall using 15 cm thick insulation panel.

5 Conclusions

Based on the experience with the pre-selected favourable concept implemented in the pilot, several recommendations were developed how the implementation of the MORE-CONNECT can be facilitated; however, overall, the pre-selected favourable concept remains valid also for the final selection of the favourable concept.

Based on the assessment carried out and the experience of the pilot project, the final favourable concept is chosen as follows:

1. As heating system, the existing district heating system is chosen. It has the second lowest primary energy use and reasonably low CO_2 emission values. There are two main reasons why heap pump and wood systems weren't chosen;

    a. Existing legislation requires that buildings covered by existing district heating keep their connection to DH grid;

    b. Installation of heat pump underground loop requires extra permission from local authorities and plot of land owners.

2. Replacement of existing windows has the lowest reduction of CO_2 emissions and primary energy;

3. Full renovation including windows replacement (renovation Nr.9) has the highest embodied energy increase. In this case embodied energy is equal to building energy consumption with installed soil-water heat pump. Replacement of existing windows isn't efficient to minimize overall environmental impact of retrofitting solution. However, it is integral part of a complex renovation approach and ensures better use of daylight and thermal comfort.

4. Wall insulation with 15 cm mineral wool was chosen as the solution which allows significant energy savings with optimal life cycle costs. Attic slab already is assumed to be already insulated by 10 mm mineral wool as this was the case in the pilot project. Only minor repair works and extra blowing insulation are assumed to be necessary to restore exiting attic thermal insulation.

5. Existing windows usually have a U-value of 1.8 W/(m^2K). Typical modern windows have U-value equal to 0.9 – 1.0 W/(m^2K) with average costs 120 – 150 Euro/m^2. So the relatively high investments ensure less than two times reduction of the U-value. On the other hand, 110 - 130 Euro/m^2 investments in wall thermal insulation gives a U-value reduction from 0.9 W/(m^2K) to 0.18 W/(m^2K).

6. Cellar ceiling insulation wasn't taken into consideration since cellar heights are often low and an extra layer of insulation would significantly reduce space height.

7. At the current stage ventilation heat losses correspond to 20% from total heat losses. It was decided not to take into consideration installation of fully mechanical ventilation. The renovation solution allows later installation of controlled ventilation.

8. Application of PV panels allows significant reduction of operational primary energy and minimizes operational CO_2 emissions. A 7kWp PV array produces 6536 kWh annually or 2877 kWh during the heating season. Total primary energy savings are 4905 kWh annually.
9. The implementation of retrofitting package for Latvian pilot buildings allowed to estimate construction costs and construction works specifics more precisely.
10. As favourable concept the 15 cm thick insulation panels can be proposed for future implementations. However, future energy price increases and cost optimization could increase the attractiveness of higher levels of insulation.