European Commission, Horizon 2020 Programme

MORE-CONNECT

Pre-selection of favourable concept to be tested in the pilot

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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 pilot building

1.1 Description of pilot building

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

1.2 Building typology

The pilot building 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 m^2 and the heated area 3306 m^2.

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^{2}K), U_{roof}=1.1W/(m^{2}K), U_{floor}=0.6W/(m^{2}K)), 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^{2}K)) have broken closing mechanisms and fixings. There are failures and water leakage 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.

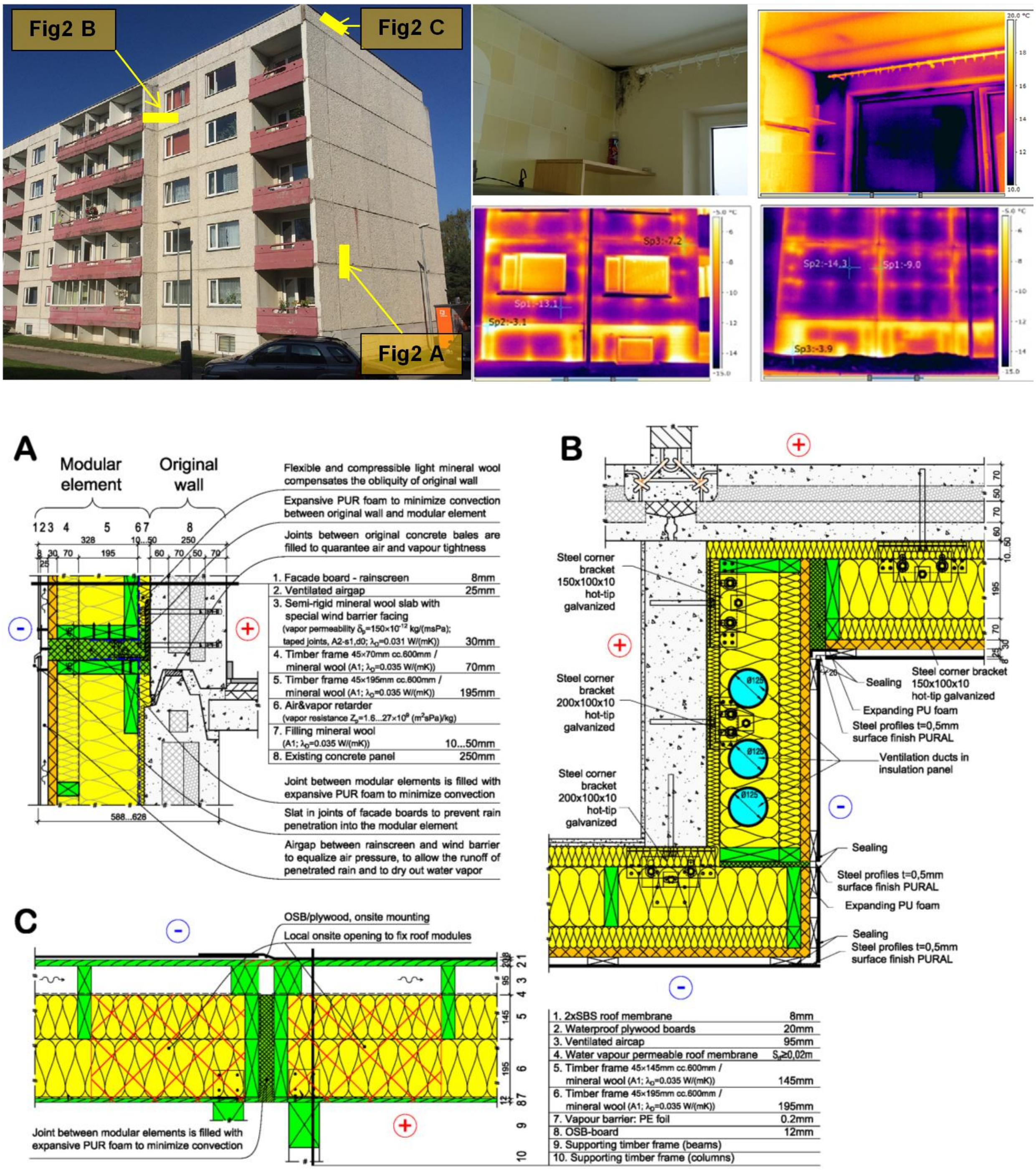


Figure. 2. Overview of the pilot building before renovation from outside (above left) and inside (above right) with thermal camera images and designed solutions at the different structural points of the pilot building (below).

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/(m^2·a): for heating and ventilation 149kWh/(m^2·a), for domestic hot water (DHW) 30kWh/(m^2·a), for appliances and electricity 30kWh/(m^2·a), for fans and pumps 5kWh/(m^2·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 pilot building

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

Parameter	Unit	Data
Building period		1986
Gross heated floor area	m^2	4318
Wall area (excl. windows)	m^2	1891
Roof area pitched	m^2	-
Roof area flat	m^2	766
Attic floor (if attic is unheated)	m^2	-
Area of ceiling of cellar	m^2	768
Area of windows to North	m^2	251
Area of windows to East	m^2	-
Area of windows to South	m^2	243
Area of windows to West	m^2	-
Average heated gross floor area per person	m^2	20

Parameter	Unit	Data
Typical indoor temperature	°C	21
Average electricity consumption per year and m^2 (excluding heating, cooling, ventilation)	kWh/($a*m^2$)	26
U-value wall	W/(m^2*K)	0.11
U-value roof pitched	W/(m^2*K)	-
U-value roof flat	W/(m^2*K)	0.10
U-value attic floor	W/(m^2*K)	-
U-value ceiling of cellar	W/(m^2*K)	0.38
U-value windows	W/(m^2*K)	0.80
g-value windows	Factor	0.50
Energy need hot water	kWh/($a*m^2$)	30
Energy need for cooling	kWh/m^2	-
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) is planned to be insulated with prefabricated modular panels. Basement walls are planned to be 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·K). In the wall panel with dimensions ≈2.7×9m, 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 will be 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·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 will be used in the joints between the modules. All vertical joints between wall modules will be protected with sealing and steel strips under the facade boards. Horizontal joints will be equipped with slits (drip molds) to prevent rain penetration to the insulation. All internal intersections between modules will be sealed and filled with expansive PUR foam. To avoid having to tighten the existing envelope, it is planned to ensure the airtightness of the building with prefabricated highly-insulated modules.

3 Investigated renovation packages

For the identification of favorable 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 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 widows with U-value 1.1 W/(m^{2}K)
M6	M4 + replacement of widows 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

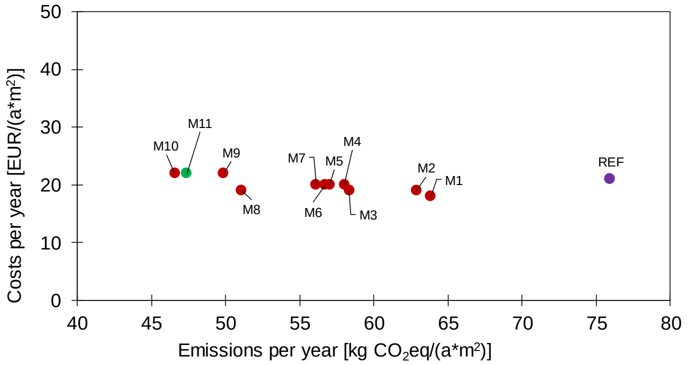
[1] For a description of the assessment methodology, a separate document is available entitled: «Methodological framework and instructions for the selection of favourable concepts for the pilot projects (Task 6.1 part 1)»

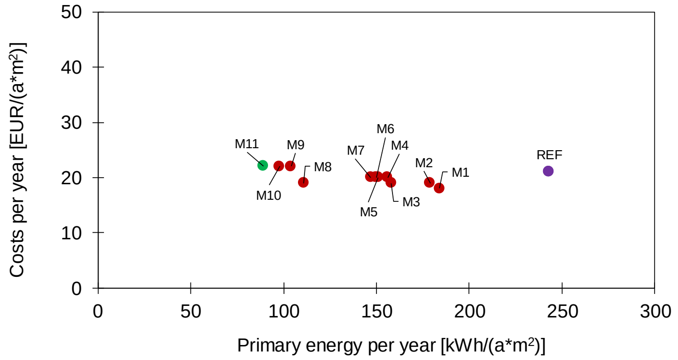
4 Assessment of investigated renovation packages and pre-selection of favorable concept

4.1 Overview graphs

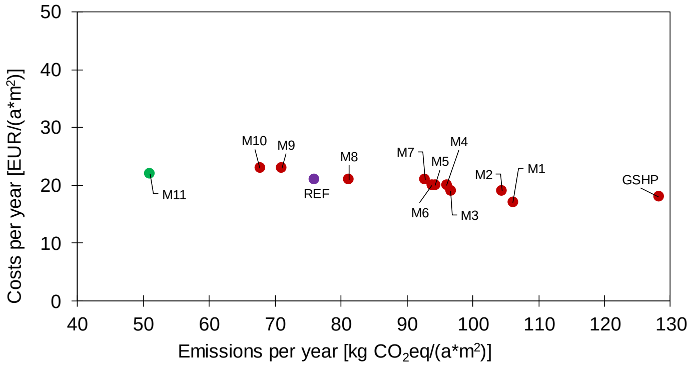
For the pilot building, the expected impacts of the investigated renovation packages are shown in the following graphs (favorable concept M11 is shown in green):

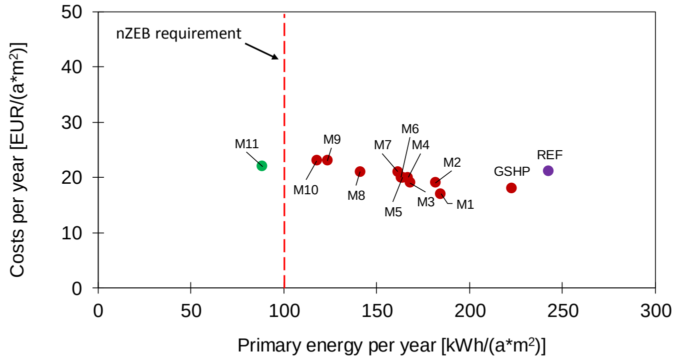
Heating system: district heating (REF)



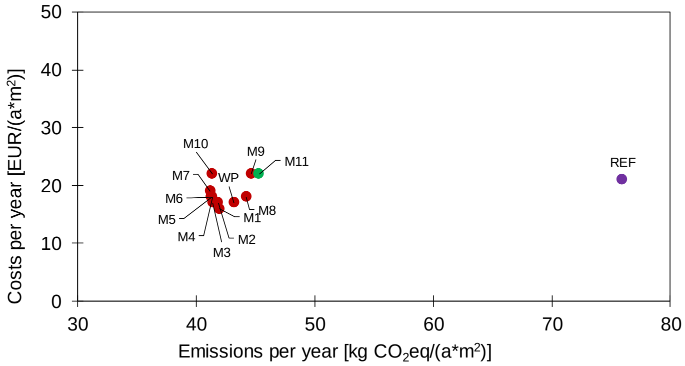


Heating system: ground source heat pump (GSHP)





Heating system: wood pellets (WP)



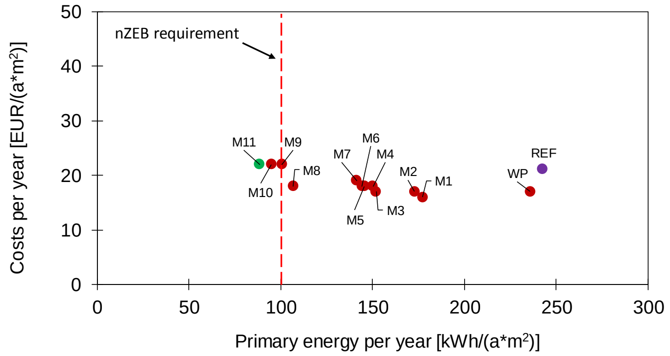


Figure 4. Graphs showing impacts on greenhouse gas emissions (left hand side) and primary energy use (right hand side) vs. costs of various renovation packages for the MORE-CONNECT pilot building in Tallinn, Estonia, in combination with district heating (top), ground source heat pump (center), and wood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

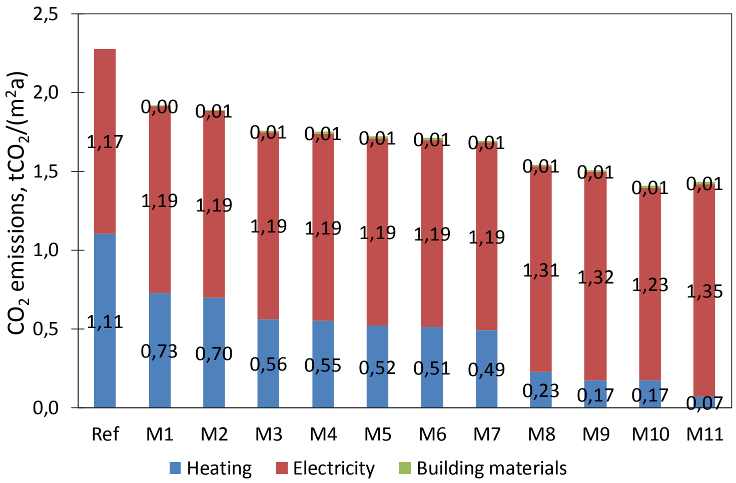
Future nearly Zero Energy Buildings (nZEB) should be much more highly insulated than buildings developed some years ago [4]. The design of the pilot started with preliminary energy and economical calculations [5,6]. The calculated primary energy use of nZEB renovation shows a 2/3 reduction. However, 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.

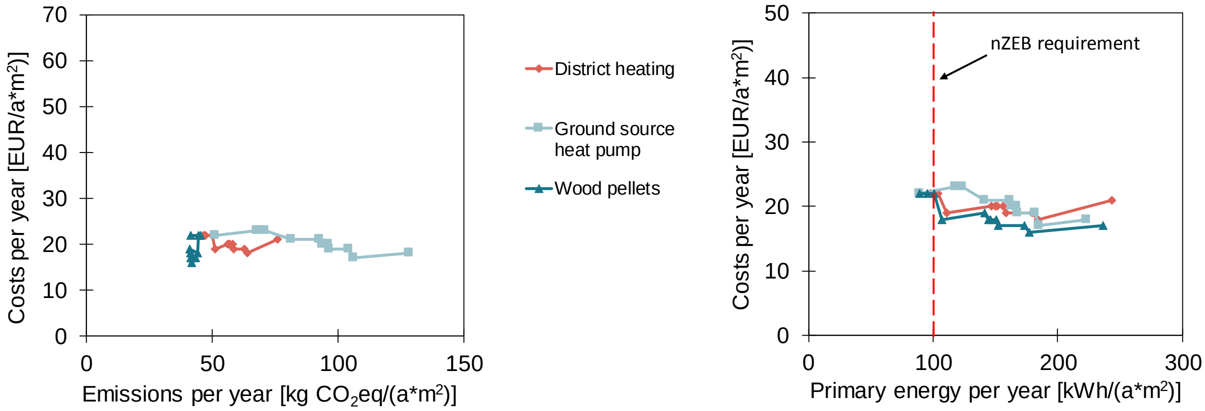
Longer constructional moisture dry-out periods and obstacles to its capability weaken the hygrothermal condition of the whole building envelope. Therefore, it is necessary to pay special attention to the hygrothermal performance and moisture safety of the design and building processes of highly-insulated buildings. It was previously shown [7] that in highly-insulated buildings, high thermal resistance and vapor permeability of the wind barrier layer are the key components of a well-functioning building envelope and a longer constructional moisture dry-out period is detrimental to the hygrothermal condition. In the common timber-frame wall the PE-foil, as the air and vapor barrier, does not cause any serious problems to the hygrothermal performance [8,9]. In highly-insulated modular panels, installed onto the existing concrete wall, it prevents the moisture dry-out and could pose a higher risk of mold growth. One of the most critical hygrothermal design tasks was the selection of a vapor barrier for the wall module [10]. The most influential parameters here are a built-in moisture dry-out after the installation of the insulation modules (requires a relatively permeable vapor barrier) and the long-term performance where a vapor tightening barrier is required because the joints of the original wall would not be air- and vapor tight. We did not find any previous studies about this matter from our literature review.

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 CO_2 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 $kgCO_2$/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 $kgCO_2$/kWh which is almost three times higher than district heating emission factor 0.12 $kgCO_2$/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 CO_2 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 Conclusions

A pilot nZEB renovation of a typical concrete large panel apartment building is planned to be 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 $U \approx 0.10 \mathrm{W/(m^2 \cdot K)}$. 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. A smart vapor retarder with changing vapor permeability was needed.

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. Engineers and designers should include hygrothermal modelling into design practices to assure the moisture safety of structures and sustainability in the long term. 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 References

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