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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 Milevsko, Czech Republic

The pilot building – a residential house – has been built in 1958 as a part of a social housing settlement in Milevsko, South-Bohemian Region. This particular building has 24 studios (room, kitchen, bathroom, hall), 31 m^2 each, in three upper stories. Technical or housing facilities and cellars were put in the basement. The building has a central hall, flats are oriented either to the east or to the west, every flat has two windows. The building has gable roof (33°), attic space is currently unused. The building has a longitudinal wall structural system made of brick (450 mm), ceilings are made of reinforced cast concrete. Façades are plastered, original windows and exterior doors have already been replaced with insulating double-glazed windows with plastic frame. The building uses a district heating system, which is utilized also for hot water preparation. The typical problems of the reference building are unsatisfying winter thermal comfort, overall energy performance, ruptures in plaster, devastated common shared areas, and insufficient ventilation supporting a mould growth mostly in the basement floor or even in the bathrooms or kitchens. Such type of building covers about 5 % of complete multi-family housing stock and belongs to the most frequent multi-family residential building in the Czech Republic.

1.2 Dimensions and characteristics of the pilot building

The following table summarizes the dimensions and characteristics of the pilot building.

Tab. 1: Dimensions and characteristics of the pilot building

Parameter	Unit	Data
Building period		1946–1960
Gross heated floor area	m^2	993.3
Wall area (excl. windows)	m^2	776.9
Roof area pitched	m^2	-
Roof area flat	m^2	-
Attic floor (if attic is unheated)	m^2	410.4
Area of ceiling of cellar	m^2	369.1
Area of windows to North	m^2	11.1
Area of windows to East	m^2	51.8
Area of windows to South	m^2	17.7
Area of windows to West	m^2	51.8
Average heated gross floor area per person	m^2	40.1/20.7[1]

Parameter	Unit	Data
Typical indoor temperature	°C	20
Average electricity consumption per year and m^2 (excluding heating, cooling, ventilation and user (plug-in) electricity)	kWh/(a*m^2)	8.8
U-value wall	W/(m^2*K)	1.4
U-value roof pitched	W/(m^2*K)	-
U-value roof flat	W/(m^2*K)	-
U-value attic floor	W/(m^2*K)	0.9
U-value ceiling of cellar	W/(m^2*K)	2.2
U-value windows	W/(m^2*K)	1.2
g-value windows	Factor	0.67
Energy need hot water	kWh/m^{2}a	35.2
Energy need for heating	kWh/m^{2}a	186.6
Airflow rate	m^3/(h*m^2)	0.78

[1] higher value: national declarative calculation; lower value: expected real occupancy density

2 The MORE-CONNECT solution

MORE-CONNECT tries to solve the renovation issue by developing prefabricated, multifunctional renovation elements for the total building envelope (façades and roof) and installation building services that will enable modular retrofitting of residential buildings. These elements can be combined, selected and configured by the end-user, based on his specific needs. This information can be used as input into advanced Building Information Modelling systems to control and steer the further production process of these elements. In this way, unique series of one can be made in a mass production process for the same reduced price of mass production.

In detail, the MORE-CONNECT solution is described in a separate report prepared in the MORE-CONNECT project [5].

3 Investigated renovation packages

For the identification of favourable concepts, an assessment of possible renovation variants (packages) was carried out with respect to greenhouse gas emissions, primary energy use, and costs.[1]

The investigated renovation packages covered partly solutions commonly used in the Czech Republic, partly environmentally friendly solutions focused on natural materials and sources used. The renovation packages also included the MORE-CONNECT solutions. It was expected that the commonly used solutions would be generally favourable as they have been pre-selected by the market, while the environmentally friendly solutions created a target boundary from the environmental point of view. Comparison of packages covering these approaches allowed an evaluation of how far or close the environmentally friendly concepts are from the market pre-selection.

The renovation packages were assessed within the framework of different heating systems that were possible in case of the pilot building. The heating systems taken into account were:

- District heating (current heating system),
- Heat pump,
- Natural gas,
- Wooden pellets.

The process of the assessment was multi-step (see also Fig. 1). Each renovation step improved certain part of a building and consisted of several variants of given improvement. The variants were delimited by material or technology used and/or by level of improvement. From each renovation step, a partial optimum was selected. That subsequently advanced to the next step as a basis. Assessment steps were:

- Firstly, the "anyway" renovation was considered as the basic case. It comprised the restoration of the functionality of the renovated building elements, yet without improvement of their energy performance.
- Second, additionally, a change of heating system was considered. No other improvement was supposed. This case served as a reference for further renovation steps.
- Step 1: External walls were provided with additional thermal insulation.
- Step 2: Ceiling of the last storey (attic floor) and basement ceiling were provided with additional thermal insulation.
- Step 3: Triple-pane glazing windows were used.
- Step 4: Mechanical ventilation system with heat recovery was used (considering either mechanical ventilation only or warm-air heating system within).
- Step 5: PV panels of various sizes were added (applied to both variants from the previous step).

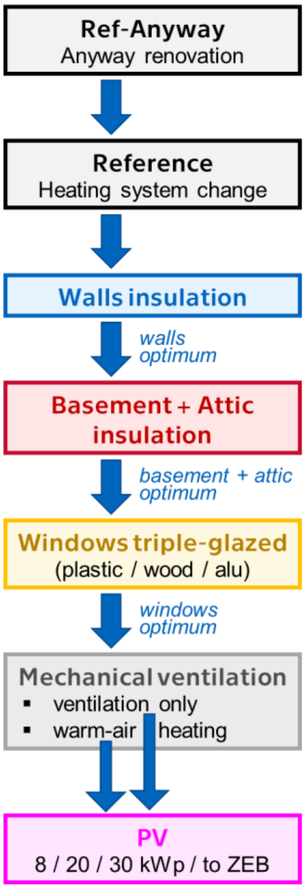

Fig. 1: Assessment steps

The detailed description of the investigated renovation packages is stated in the Tab. 2.

[1] For a description of the assessment methodology, a separate document is available which has been prepared within the MORE-CONNECT project [6]

Tab. 2: Renovation packages taken into account within pre-selection of favourable concept

Step	Renov. Pack.	Description
Step 1	Ref-anyway	In the reference case ("anyway" renovation), the façades plasters are refurbished and repainted, the water-proofing failures in the basement and the attics are refurbished. These measures do not improve the energy performance of the building.
	Ref	Additionally to Ref-anyway, considering change of heating system
	P1	Additionally to Ref , Walls are provided with ETICS with 10 cm of EPS (windows retained the existing ones since they were already replaced by plastic ones with double glazing recently)
	P2	Additionally to Ref , Walls are provided with ETICS with 30 cm of EPS (windows retained the existing ones since they were already replaced by plastic ones with double glazing recently)
	P3	Additionally to Ref , Walls are provided with a MORE-CONNECT panel including 10 cm of mineral wool, new double-glazed windows with plastic frames as a part of the panel
	P4	Additionally to Ref , Walls are provided with a MORE-CONNECT panel including 20 cm of mineral wool, new double-glazed windows as a part of the panel (furthermore, windows frame material impact was investigated for plastic, wooden and aluminium frames)
	P5	Additionally to Ref , Walls are provided with a MORE-CONNECT panel including 20 cm of mineral wool and vacuum insulation, new double-glazed windows with plastic frames as a part of the panel
Step 2	P6	Additionally to step1 optimum, ceiling of the last storey (attic floor) are provided with 20 cm of mineral wool, basement with 6 cm of mineral wool
	P7	Additionally to step1 optimum, ceiling of the last storey (attic floor) are provided with 40 cm of mineral wool, basement with 14 cm of mineral wool
	P7x9	Additionally to step1 optimum, ceiling of the last storey (attic floor) are provided with 40 cm of wood blown insulation, basement with 14 cm of mineral wool
	P8	Additionally to step1 optimum, ceiling of the last storey (attic floor) are provided with 20 cm of wood blown insulation, basement with 6 cm of wood-fibres insulation
	P9	Additionally to step1 optimum, ceiling of the last storey (attic floor) are provided with 40 cm of wood blown insulation, basement with 14 cm of wood-fibres insulation
Step 3	P10	Additionally to step2 optimum, the windows are replaced with new 3-glazed windows with plastic frames and U-value for the entire window of 0.7 W/(m2K)
Step 4	P11	Additionally to step3 optimum, mechanical ventilation system with heat recovery is installed for ventilation
	P12	Additionally to step3 optimum, mechanical ventilation system with heat recovery is installed for both ventilation and warm air heating
Step 5	P13	Additionally to P11, PV panels of 8 kWp are installed
	P14	Additionally to P11, PV panels of 20 kWp are installed
	P15	Additionally to P11, PV panels of 30 kWp are installed
	P16	Additionally to P12, PV panels of 8 kWp are installed
	P17	Additionally to P12, PV panels of 20 kWp are installed
	P18	Additionally to P12, PV panels of 30 kWp are installed
	P19	Additionally to P11, PV panels of such power to reach net zero primary energy
	P20	Additionally to P12, PV panels of such power to reach net zero primary energy

Embodied environmental parameters' data of the materials and technologies used were taken from the Ecoinvent 3.3 database [1], [2]. Conversion factors of non-renewable primary energy and greenhouse gas emission factors ($CO_{2,ekv.}$) related to operational energy consumption were taken from the Czech Gemis database (2009) [3], [4] as factors from this database are expected to represent better the energy mix in the Czech Republic than the official factors set for the purpose of declarative calculations. The factors used in the calculations are listed in Tab. 3.

Tab. 3: Conversion and emission factors of operational energy consumption [3], [4]

Energy carrier	**Primary energy** [kWh/kWh]	**$CO_{2,ekv}$** [kg $CO_{2,ekv}$/kWh]
District heating	2.23	0.79
Electricity from the grid for heat pump	3.16	0.75
Natural gas	1.46	0.32
Pellets	0.11	0.03
Electricity from the grid	3.16	0.75
Electricity produced (PV)	-3.16	-0.75

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

4.1 Consecutive pre-selection of favourable variant per each step

The step-by-step evaluation was carried out for the case with district heating (it is the current heating system in case of the Czech pitot building and is expected to be probably maintained). The evaluation and favourable package selection substantiation is provided below.

4.1.1 Step1: External walls insulation

Comparison of wall insulation variants to each other and to the reference case (“anyway” renovation) is shown in Fig. 2. Compared to the reference case, any variant of wall insulation decreased the environmental burden by about 40 %. An external thermal insulation composite system (ETICS) is the most frequent way of wall insulation in the Czech Republic and both ETICS cases (P1, P2) had the lowest cost from all investigated variants. The variant with thinner insulation (P1) had higher impact on both primary energy and greenhouse gas emissions since environmental parameters related to operational energy consumption had bigger influence than the embodied quantities. The MORE-CONNECT solution with 10 cm of main insulation layer (P3) had similar environmental impact as 30 cm ETICS (P2) but showed higher price by about 12 %. The MORE-CONNECT solution with 20 cm of main insulation (P4) showed slightly lower environmental impact than the 10cm MORE-CONNECT solution with almost the same cost in case of plastic-

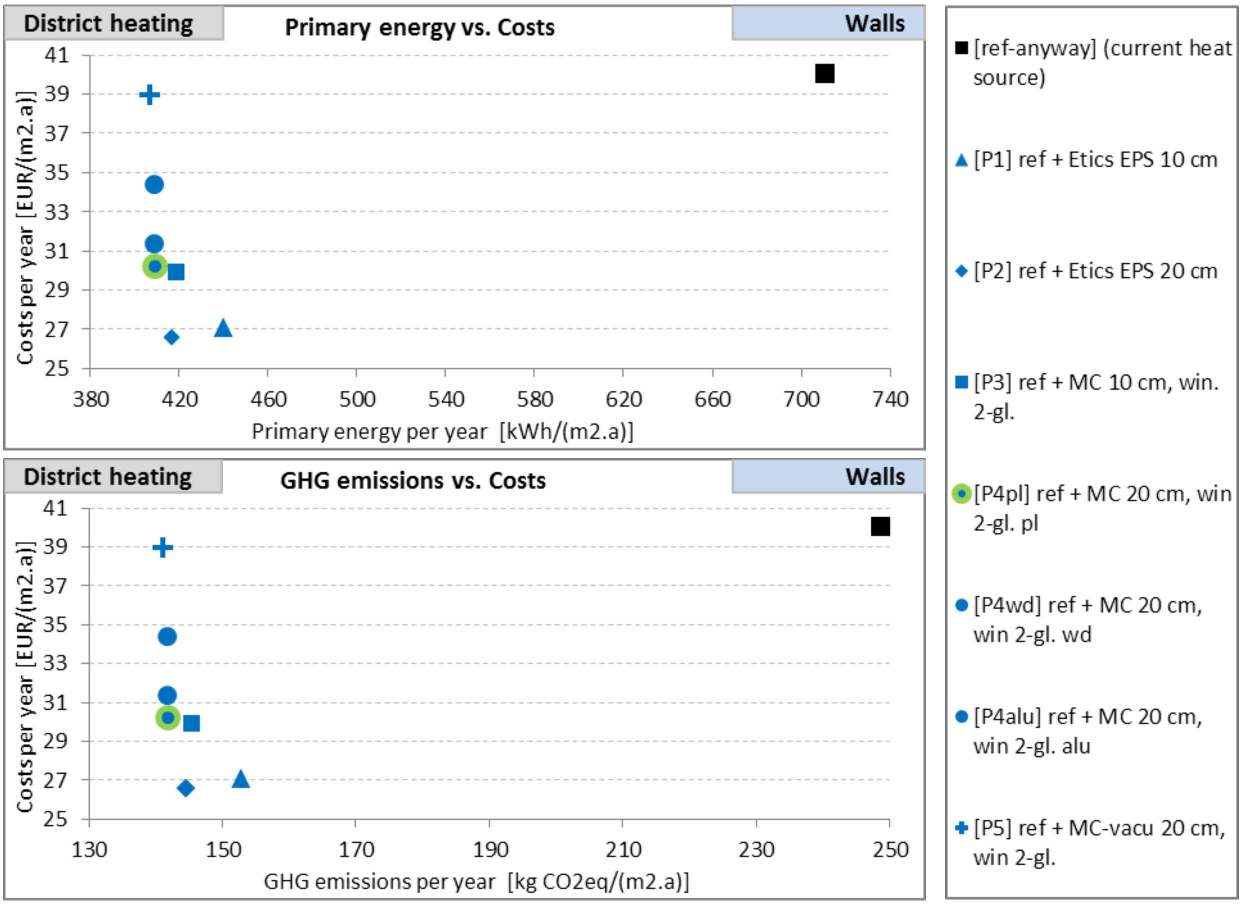

Fig. 2: Pre-selection of favourable concept – step 1: walls insulation (district heating); selected variant marked with green circle (top – primary energy vs. costs impact, bottom – greenhouse gas emissions vs. costs impact)

frame windows (P4pl). Aluminium frames (P4alu) were connected with higher costs by 4 %, wooden frames (P4wd) were the most expensive ones (costs higher by 14 % compared to plastic frames). The MORE-CONNECT solution containing vacuum insulation layer throughout the panel (to reach better insulation parameters without significant increase in thickness) (P5) showed noticeably higher cost with only negligible decrease in primary energy use or greenhouse gas emissions.

The results indicate that MORE-CONNECT solution for walls may be comparable to ETICS with EPS. The prices were found only slightly higher in the case of MORE-CONNECT panels, while ETICS resulted with higher greenhouse gas emissions. Therefore, **MORE-CONNECT panel with 20 cm of main thermal insulation and plastic-frame windows (P4pl) was considered to the optimal solution for walls in this step**. This solution means 42% reduction of primary energy, 43% reduction of GHG emissions and 25% save of yearly costs compared to the reference case ("anyway" renovation).

4.1.2 Step 2: Attic and basement insulation

In step 2, attic floor and basement ceiling insulation were added. The results of the variants taken into account are in Fig. 4. Compared to an initial point (pre-selected variant from the previous step – P4pl), addition of basement ceiling and attic floor insulation reduces environmental burden by about 38 % and costs by approx. 25 % in average. Higher insulation levels led to better results in all criteria. The variants with similar insulation level had almost the same environmental impact and only slightly differed in costs – wood wool insulation is connected with slightly higher costs. Variants P7 and P7x9 hardly differ. Mineral wool for basement is the safest option among the considered materials in relation to possible higher relative air humidity risks in the basement. Regarding the attic floor, blown wood fibre insulation was considered as more favourable due to easier application at complicated geometric conditions around attic beams. Therefore, **variant with 14 cm of mineral wool at basement ceiling and 40 cm of blown wood fibre insulation on attic floor (P7x9) was considered as optimal within this step**.

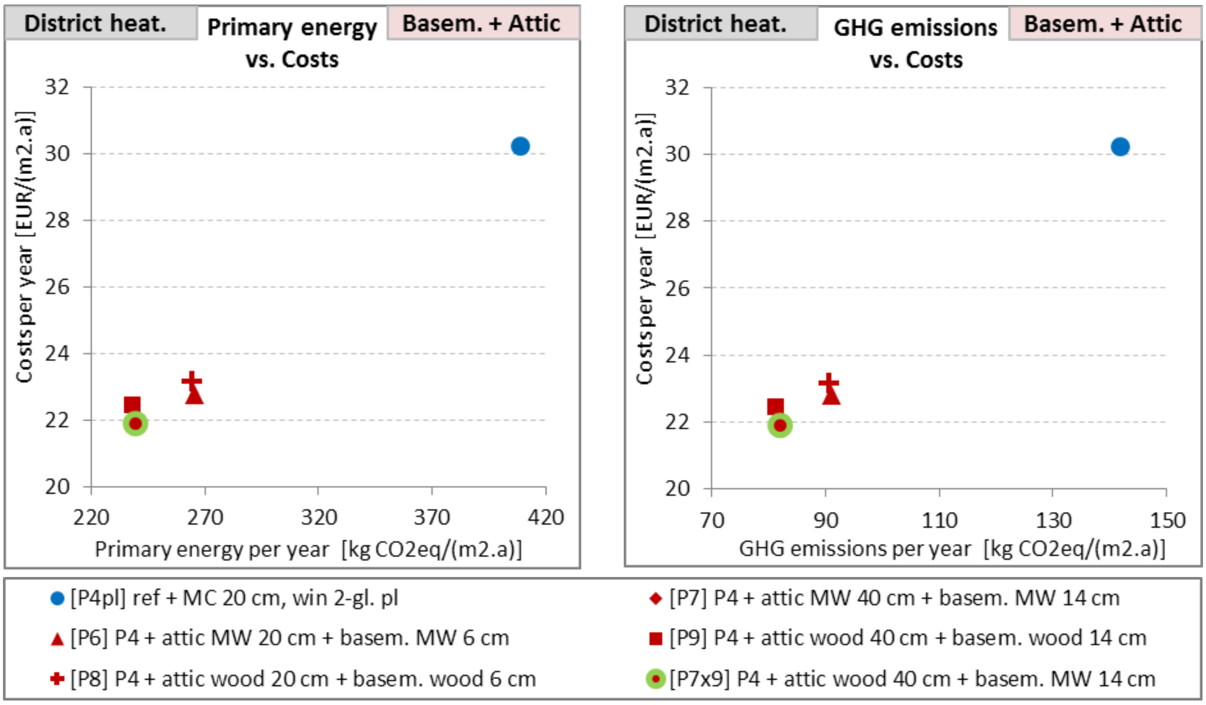

Fig. 3: Pre-selection of favourable concept – step 2: basement and attic insulation (district heating); selected variant marked with green circle
(left – primary energy vs. costs impact, right – greenhouse gas emissions vs. costs impact)

4.1.3 Step 3: Triple-pane glazing windows

As a subsequent step, windows with triple-pane glazing were used instead of double-pane glazing. Variants differ in window frame material. The results are shown in Fig. 4. Use of triple-glazed windows decreased primary energy use and greenhouse gas emissions compared to double-glazed ones (initial case), regardless of the material of frames. The differences between environmental impacts of frame material are negligible. On costs, the window frame material has, however, significant impact. Only windows with plastic frames (P10pl) led to a cost reduction. Wooden frames (P10wd) showed the highest cost, aluminium frame cost (P10alu) lie between wooden and plastic frames. **Plastic-frame triple-glazed windows variant (P10pl) was considered as optimal in this step**.

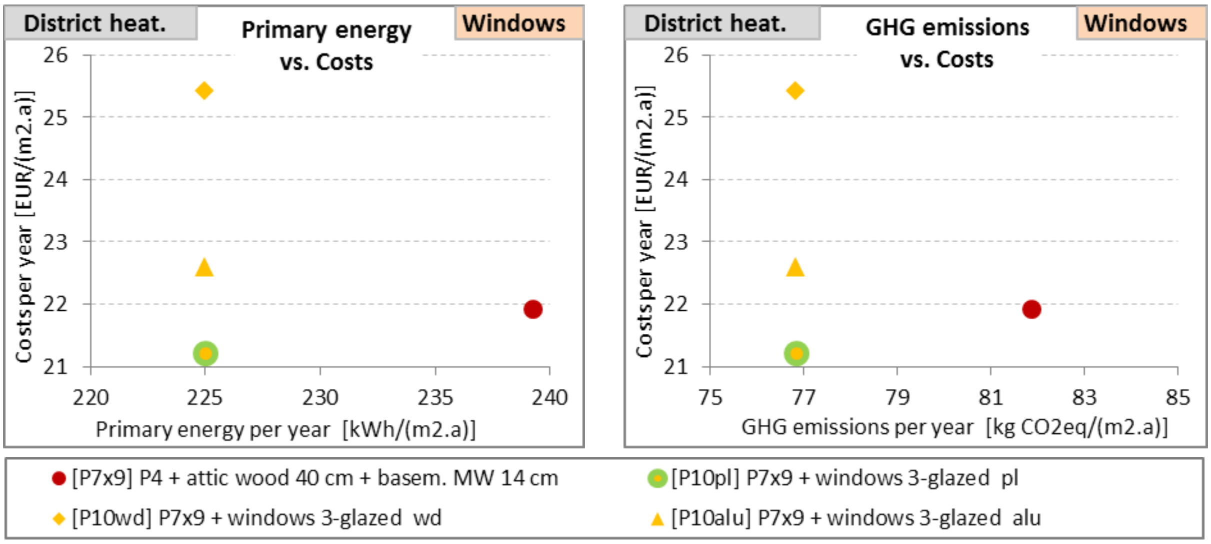

Fig. 4: Pre-selection of favourable concept – step 3: triple-pane glazing windows (district heating); selected variant marked with green circle (left – primary energy vs. costs impact, right – greenhouse gas emissions vs. costs impact)

4.1.4 Step 4: Mechanical ventilation

This step comprised of an addition of a mechanical ventilation system with heat recovery. One variant counts with mechanical ventilation only (P11), another one counts with mechanical ventilation combined with worm air heating system (P12). Comparison is provided in Fig. 5. Both variants resulted in decrease of environmental impact compared to naturally ventilated initial case. Internal air quality improvement, alt-

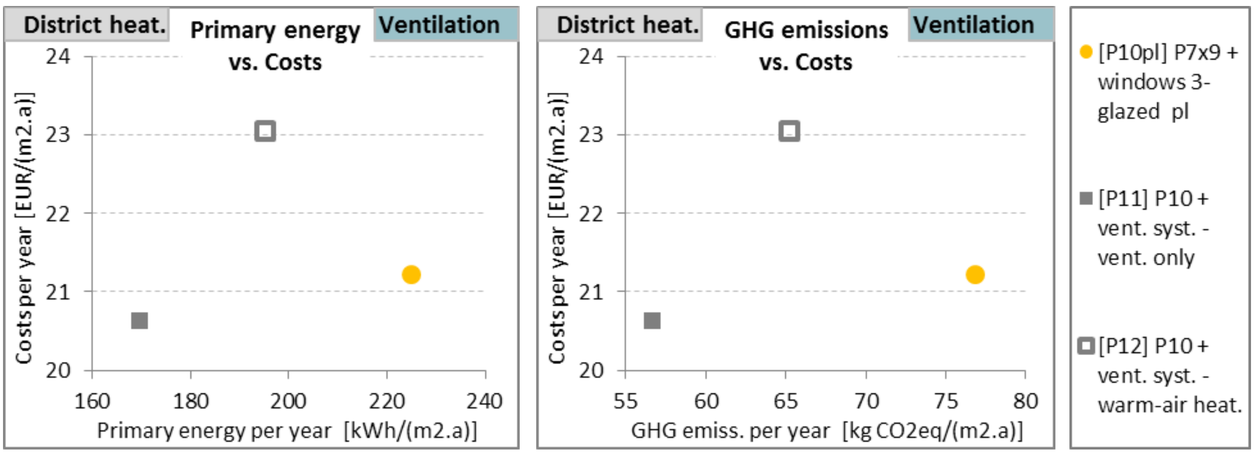

Fig. 5: Pre-selection of favourable concept – step 4: mechanical ventilation (district heating); (left – primary energy vs. costs impact, right – greenhouse gas emissions vs. costs impact)

hough not covered by this analysis, is another argument in favour of the mechanical ventilation system installation. The system designed for ventilation only is more favourable solution in all the assessed criteria than the system combining ventilation with warm-air heating. However, decision whether to preserve original hot-water heating system or to replace it by warm-air heating system depends on factors beyond the scope covered by the performed optimization analysis. **Since warm-air heating system implies a more complex solution, it was decided to implement this solution within the pilot to verify the design, feasibility and functionality. Optimal variant is, however, not chosen in this step and both variants using mechanical ventilation proceed as a basis for further step**.

4.1.5 Step 5: PV panels installation

The last step involved installation of PV panels onto the pilot building (no battery storage was considered). Areas available for installation were: pitched roof (south and west orientation, slope 32°, 180 m^2 + 180 m^2), south gable wall (90 m^2), and west and east façades (80 m^2 + 80 m^2). Environmental impact of exported electricity is accounted in yearly balance by using minus conversion and emission factors (see Tab. 3). The variants taken into account differed in installed power. Results are depicted in Fig. 6. Installation of PV panels led to primary energy and greenhouse gas emission decrease and slight increase in costs (the higher the installed power, the higher the decrease or increase respectively). **The final decision about favourable installed power lies beyond the scope of this study** as it depends on actual energy set-up, real electricity consumption profile, possibility to build a smart grid with some other buildings etc.

To reach net zero primary energy level with district heating, for the variant with mechanical ventilation only (P19) installed PV power of 81 kWp would be needed which corresponds to the following size of the PV installation: fully covered roof and gable wall (i.e. 180+180 m^2 on roof, 90 m^2 on gable wall) and 15+15 m^2 on façades. Variant assuming warm-air heating (P20) would not reach net zero primary energy even with fully utilized available area for PV which produced 103 kWp. Current legislation in the Czech Republic, however, restricts installed power to maximum 30 kWp.

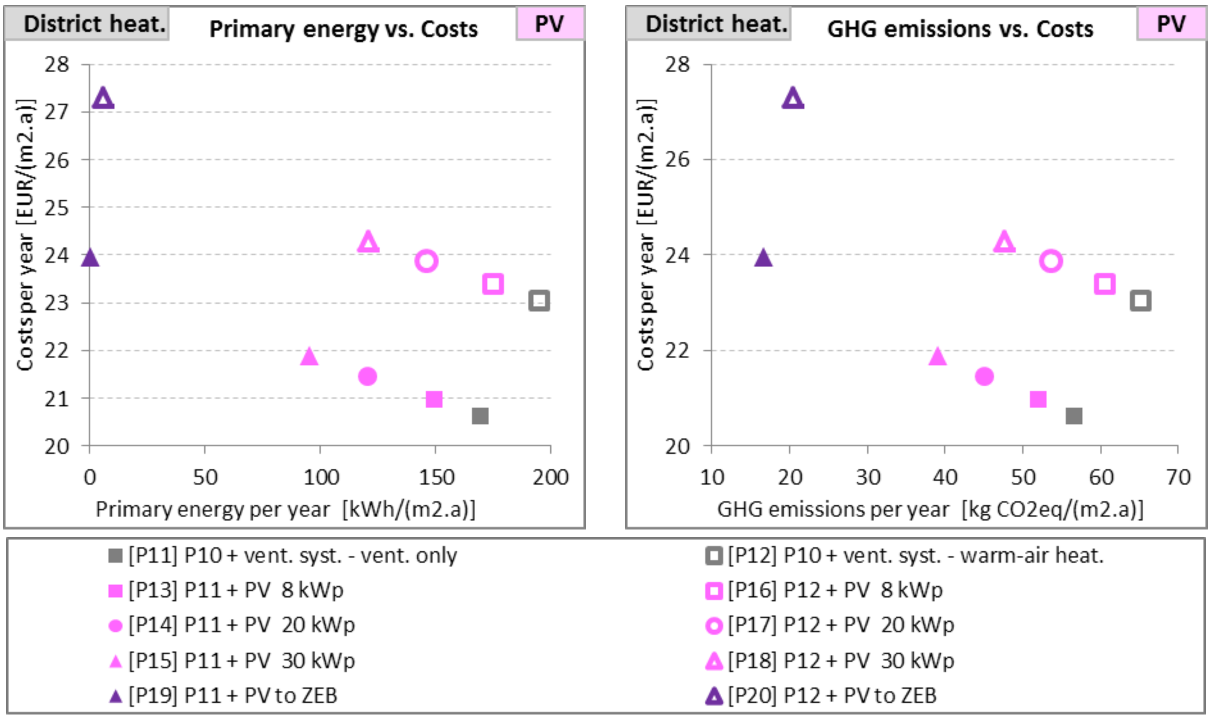

Fig. 6: Pre-selection of favourable concept – step 5: PV installation (district heating); (left – primary energy vs. costs impact, right – greenhouse gas emissions vs. costs impact)

4.2 Overview graphs

The expected impacts of the investigated renovation packages of the Czech pilot building, taking into account different heating systems are shown in Fig. 7 and Fig. 8. It should be noted that the environmental assessment strongly depends on conversion and emission factors. These factors usually reflect current energy mix and/or the political convention. Therefore, the results are valid for the Czech Republic current conditions and are not generalizable.

Absolute criteria values differ among the heat sources. District heating is the current heat source in case of the pilot building. District heating in the Czech Republic is mainly based on brown coal which is reflected in conversion factors and, therefore, environmental burden with this source is the highest from all considered sources. The lowest environmental burden is connected with pellets; environmental impact is at about 1/5 to 1/10 compared to other sources. Heat pump and natural gas cases lie between them; the heat pump shows slightly lower environmental impact than natural gas.

As far as costs are concerned, pellets would be the most favourable source, followed by preservation of district heating system, third would be the change to natural gas, while heat pump would be the least favourable solution.

To reach net zero primary energy such power and areas of PV are needed:
(P19 is package with mechanical ventilation only; P20 assumes warm-air heating):

- District heating
  - Package P19: 81 kWp; fully covered roof and gable wall (i.e.180+180 m^2 on roof, 90 m^2 on gable wall) and 15+15 m^2 on façades
  - Package P20: did not reach net zero primary energy even with fully utilized available area for PV which means 180+180 m^2 on roof, 90 m^2 on south gable wall and 80+80 m^2 on west and east façades producing in total 103 kWp
- Heat pump (COP = 2.6 is considered)
  - Package P19: 42 kWp; 124+124 m^2 on roof
  - Package P20: 48 kWp; 143+143 m^2 on roof
- Natural gas
  - Package P19: 50 kWp; 148+148 m^2 on roof
  - Package P20: 58 kWp; 171+171 m^2 on roof
- Pellets
  - Package P19: 15 kWp; 44+44 m^2 on roof
  - Package P20: 17 kWp; 50+50 m^2 on roof

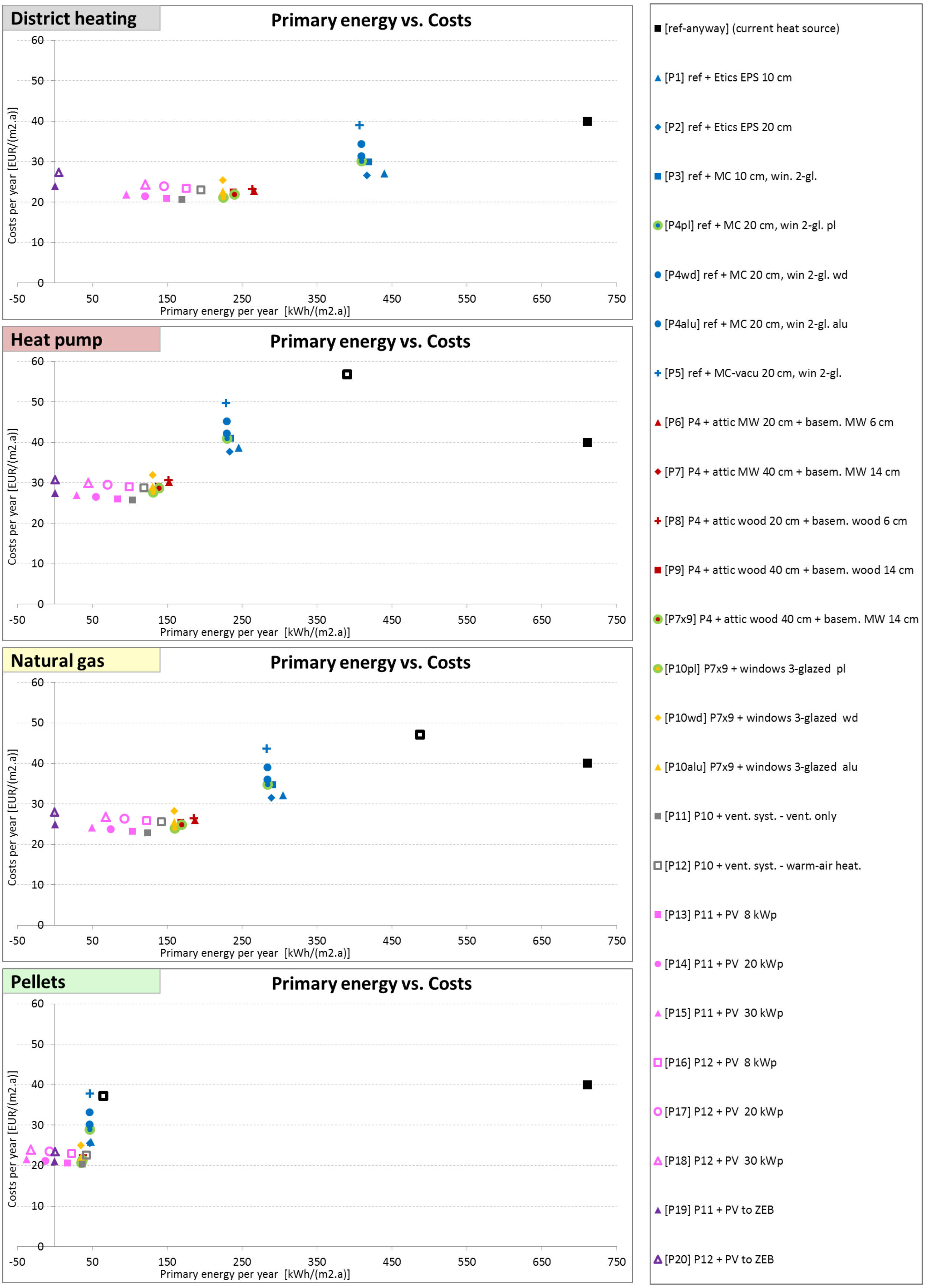

Fig. 7: Impacts on primary energy use and costs of various renovation packages for the MORE-CONNECT pilot in the Czech Republic, in combination with various types of heating systems

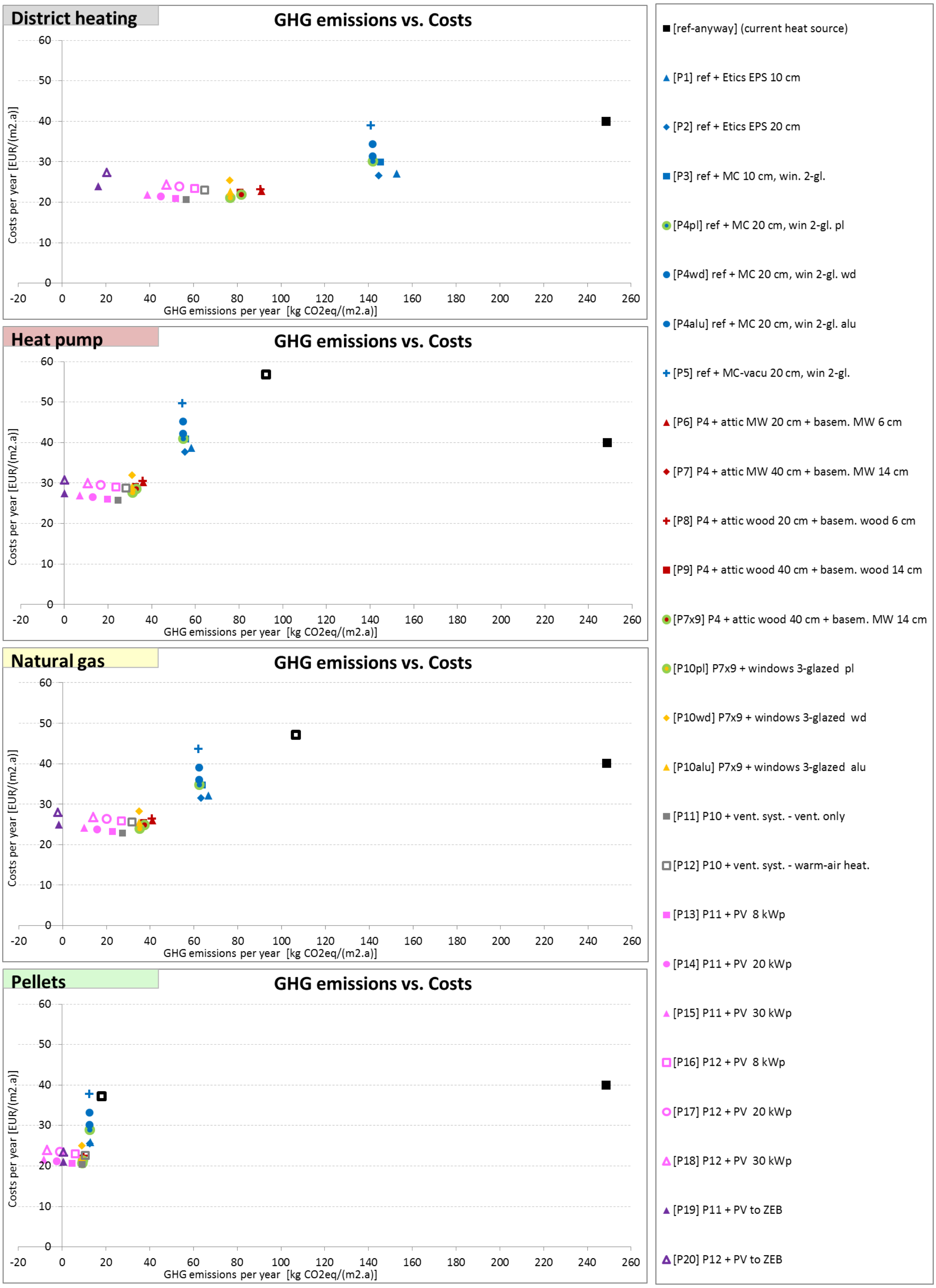

Fig. 8: Impacts on greenhouse gas emissions and costs of various renovation packages for the MORE-CONNECT pilot in the Czech Republic, in combination with various types of heating systems

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

The embodied environmental parameters (the embodied primary energy and the embodied greenhouse gas emissions) were calculated and taken into account for all variants. The simplified life cycle analysis was performed using the Ecoinvent 3.3 database which can fit for the local Czech conditions. The more localized general data are not available for the Czech Republic. However, the environmental data carries unspecified uncertainties that relativize the overall results. The presented values should be only used to compare the variants in the set.

The possible reuse of the materials was not specifically assessed, but some relation can be found in both environmental parameters – embodied emissions and embodied energy. Lower values relate to the reusable, recycled or renewable materials used in the design. The recycled materials carry lower environmental burden thank to the life cycle system borders that cut off the burden from the material's primary production.

The environmental assessment shows the ways which can be taken in the near future to move forward to the zero emission buildings and quantifies the cost of the measures needed to reach the environment saving targets.

4.4 Conclusions

The presented graphs showed numerous renovation packages, involving different building elements, different materials, and different energy efficiency levels, in combination with various heating systems. For each renovation package and for each combination with a heating system, the impacts on primary energy use, greenhouse gas emissions, and costs differ. In order to pre-select a favourable concept, a choice has to be made taking into account these three dimensions.

The analysis proved that complete renovation does make sense. Each step grouping a set of renovation packages led to decrease in environmental impact compared to the previous step. The differences between environmental burden of the last step and of the reference case are significant. As far as costs are concerned, not all investigated packages brought costs reduction compared to the previous case, but a variant connected with lower costs was always available.

Based on the assessment carried out, the pre-selected favourable concept that is to be implemented in the pilot is chosen as follows:

- Walls are provided with a MORE-CONNECT panel including 20 cm of mineral wool as a main insulation layer. Vacuum insulation is not used apart from local weakened details where there is no other way how to sufficiently insulate the structure. *U*-value of walls provided with the panel is 0.12 W/(m^{2}K).
- Attic floor is provided with 40 cm of blown wood fibre insulation, *U*-value is 0.11 W/(m^{2}K). There are used 14 cm of additional mineral wool insulation in the basement, *U*-value reaches 0.27 W/(m^{2}K).
- Windows are new, triple-glazed with plastic frames and *U*-value for the entire window of 0.7 W/(m^{2}K).
- Ventilation system connected with warm-air heating will be implemented in the pilot since it implies more sophisticated solution which is desirable to be tested.

Installation of PV panels led to primary energy and greenhouse gas emission decrease and slight increase in costs. The final decision about suitable installed power lies beyond the scope of this study as it depends on actual energy set-up, real electricity consumption profile, possibility to build a smart grid with some other buildings etc. Current legislation in the Czech Republic restricts installed power to maximum 30 kWp. If the goal was to reach a zero-energy building level (in annual balance) at current legislation limits, the goal is only achievable with the biomass as a heat source.

As far as heating system and heat source are concerned, the situation strongly depends on the local conditions. In case of the Czech pilot building in Milevsko, the current source is district heating and the possibility of the heat source change is not expected (both the building and the district heating system is owned by the same owner – the municipality pushes rather on improvements in environmental parameters of district heating than disconnecting the consumers). In general case, conversion to natural gas can be expected as the most probable – when not giving a special consideration to the reduction of the environmental impact – due to accessibility of such source, low space demands, almost maintenance-free solution and reasonable costs. Taking into account the optimisation results, wooden pellets appear as most favourable heat source. However, certain complication can be found regarding the need of pellets supply and storage. Heat pump solution has at the moment with the current electricity mix in the Czech republic similar advantages as natural gas, however, results in higher initial costs and, with respect to the socio-economic situation of inhabitants, it can therefore be seen as unfavourable under current framework conditions. However, it can be expected that heat pump solutions become more favourable for cost-effectively reducing non-renewable primary energy use and greenhouse gas emissions when the share of renewable energy sources in the electricity mix increases.

It should be kept in mind that the environmental assessment strongly depends on conversion and emission factors and also on the embodied environmental data available. The factors at the disposal reflect current energy mix in the Czech Republic and partially also the political convention. The embodied environmental data carries unspecified uncertainties. Both relativize the overall results. The presented results are therefore not generalizable; they are only valid for the Czech Republic and should only be used to compare the variants in the set.

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