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Solutions sets for cost optimisation of nearly zero energy buildings (NZEBs) in four European countries

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Abstract. Nearly zero energy buildings (NZEBs) are required as the minimum standard for all new buildings in Europe by January 2021. NZEBS should, according to the Energy Performance of Buildings Directive (EPBD) [1], be cost optimal, i.e. the cost of constructing and operating the building over its lifetime should be at its minimum. The EU Horizon2020 research project CoNZEBs, identify and assess technology solution sets that lead to cost reductions of new NZEBs in four EU member states. Focussing on buildings that comply with national NZEB requirements, designers can easily ignore alternative solutions that make the building cheaper while remaining within national requirements. This is not done intentionally, but primarily due to use of a traditional design thinking where optimisation is done on component level instead of a more holistic approach. Changing one building component may influence the cost and performance of other components. These alternative solutions take offset in a typical national multi-family building design and analyses the different lifetime costs in terms of costs for construction, and energy. Analyses of costs in different countries reveals different solutions sets being optimal. In CoNZEBs we compare different solution sets and investigate the possibility for "exporting" solution sets from one country to another.

1. Introduction

In the CoNZEBs (Solution sets for the cost reduction of new Nearly Zero-Energy Buildings - 01/06/17 to 30/11/19.) project analyses of possible solution sets for cost optimisation of multi-family NZEBs [2] are done in the participating countries by identification of a NZEB building that are considered typical for the national building tradition. The typical buildings meets the national requirements for NZEBs. Analyses of possible alternative solutions – constituting solution sets – that show the same calculated energy performance, but have lower investment and potentially lower energy cost. Some of the typical buildings are selected real buildings, while others are artificial ones (Figure 1).

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Figure 1. Illustration of typical multi-family houses used for the CoNZEBs solution set analyses in Denmark, Germany, Italy and Slovenia.

In the following, we discuss solution sets, which are a combination of technologies, i.e. building fabric and technical building systems that together with ordinary building components constitute a building that meets the NZEB requirements. We do not mention parts of the solution sets that are common building elements, but only the special solutions relevant for obtaining the NZEB level. This could e.g. be systems for utilization of renewable energy sources; not commonly used insulation or window technologies; novel technologies, etc. A minimum of four solution sets are identified and analysed in each of the participating countries.

2. Solution sets

Based on identification of a typical NZEB residential building in each of the participating countries, solutions sets that can potentially reduce the investment cost while at least maintaining the overall energy performance have been identified. Analyses of the solution sets was carried out using national tools for proving compliance with energy performance requirements.

The focus of the work done in this section of the report was to identify solution sets that reduce the construction and/or energy cost for NZEBs while at the same time maintaining the level of primary energy demand in the building. In this context, a solution set is a combination of different measures to the building envelope and/or technical building systems - e.g. reduced façade insulation in combination with rooftop PV - that in total delivers the same energy performance, but at lower investment costs. Each of the participating countries have analysed several candidate solution sets, in e.g. Germany eight different sets, before selecting the ones presented in the project report.

The solution sets are:

- Denmark:
    1. High efficiency insulation in exterior walls resulting in lower construction costs for foundations, window fittings and roofs.
    2. Reduced insulation in walls, roof and floor; roof PV panels; domestic hot water (DHW) solar heating; decentral mechanical ventilation, efficient water fixtures.
    3. Reduced insulation in walls, roof and floor; roof PV panels; DHW solar heating.
    4. Four-layer windows; water saving fixtures; natural ventilation (illegal as balanced mechanical ventilation is required in new multi-family houses).
    5. Reduced insulation in walls, roof and floor; decentral mechanical ventilation; heat recovery on grey wastewater.
- Germany:
    1. Decentral direct electric heating (e.g. heated glass or marble plates) and decentral direct electric DHW system, decentral ventilation system with heat recovery, roof PV panels, heat recovery from shower wastewater and reduced insulation level.

2. Central supply and exhaust ventilation and heating system with air-air heat pump, decentral electrical DHW heater and heat recovery from shower wastewater and reduced insulation level.
3. Central combined heating and DHW system with district heating, central exhaust ventilation system and reduced insulation level.
4. Central heating system with exhaust air-water heat pump in central exhaust ventilation system supported by condensing gas boiler, decentral DHW heat exchange modules, roof PV panels and reduced insulation level.

- Italy, Rome:
  1. Thermal driven solution with variations in the composition of the external walls and the technology of the windows. Use of condensing boiler for both heating and DHW production.
  2. Electricity driven solution with variations in the composition of the external walls and the technology of the windows. Heat pump for both heating and DHW supply. No use of solar thermal collectors.
  3. Electricity driven solution with variations in the composition of the external walls and the technology of the windows. Electric radiators for space heating mainly supplied by the PV panels (not compliant with energy performance (EP) requirements for using PV panels to feed electric directly into systems of heating). According to the legislative decree 28/2011 energy from PV panels cannot be counted for in the contribution of renewable sources if they directly feed electric systems for heating, DHW or ventilation services.
  4. Low-tech thermal driven solution with variations in the composition of the external walls and the technology of the windows. Use of condensing boiler for both heating and DHW production. Reduction of PV panels based on real needs: this is illegal in Italy since standard requires a minimum amount of PV panels as a function of building surface area.
- Italy, Turin:
  1. Low-tech thermal driven solution with variations in the composition of the external walls and the technology of the windows. Use of condensing boiler for both heating and DHW production. Combined use of solar collectors both for heating and DHW.
  2. Low-tech thermal driven solution with variations in the composition of the external walls and the technology of the windows and extra insulation (super NZEB envelope). Use of condensing boiler for both heating and DHW production. Combined use of solar collectors both for heating and DHW. Mechanical extract ventilation.
  3. Electricity driven solution with variations in the composition of the external walls and the technology of the windows. Air water heat pump for both heating and DHW supply. No solar collectors.
  4. Electricity driven solution with variations in the composition of the external walls and the technology of the windows and extra insulation (super NZEB envelope). Air water heat pump for both heating and DHW supply. No solar collectors. Mechanical extract ventilation.
  5. Electricity driven solution with variations in the composition of the external walls and the technology of the windows and extra insulation (super NZEB envelope). Electric radiators for space heating mainly supplied by the PV panels (not compliant with EP requirements for using PV panels to feed electric directly into systems of heating).
- Slovenia:
  1. District heating as generation for heating and DHW; use of mechanical ventilation with 85 % heat recovery; better airtightness.
  2. Air heat pump as generation for heating and DHW; use of mechanical ventilation with 85 % heat recovery; triple glazing windows; better airtightness
  3. Air heat pump as generation for DHW; condensing gas boiler for heating; use of mechanical ventilation with 85 % heat recovery; triple glazing windows; better airtightness.

4. Air heat pump as generation for heating and DHW; roof PV panels; use of hygro-sensible ventilation system; triple glazing windows; better airtightness.

In the solutions sets shown above, decrease of the insulation level at the thermal envelope is one of the common features. This is natural when considering the resulting cost reductions that include: lower costs for insulation material, lower costs for windows, smaller facade area, smaller foundations and roof if maintaining the same habitable area.
Replacement of traditional heating systems with less costly ones are also among the solutions. In some cases, this is not legal due to national legislation that e.g. prohibits direct use of electricity for space heating.
In NZEBs, domestic hot water is one of the prime contributors to the buildings energy demand. Hence, in some solution sets, water saving fixtures or heat recovery on the grey wastewater have been used to reduce the energy demand for domestic hot water. This opens for use of less efficient solutions elsewhere in the building and thus lowering the investment costs. A summary of cost optimisation results from the four countries are shown in Table 1. Construction cost reductions (building construction and technical building systems) ranges from 0.2 to 8.5 % of the total building cost for NZEBs in the four countries.

Table 1. Summary of cost results from analyses of solution sets. Building envelope is the average U-value of the building fabric [W/m²K]. Energy cost is given in €/(m²yr) and investment cost is the difference compared to the typical NZEB in €/m². Area refers to the reference floor area used in respective national calculations.

	Danish solution sets					
	Typ. NZEB	DK-1	DK-2	DK-3	DK-4	DK-5
Building envelope	0.26	0.26	0.31	0.21	0.31	0.31
Energy costs$_{(GFA)}$	11.8	11.8	11.8	11.7	11.7	11.7
Investment costs$_{(GFA)}$	1247	-2.1	-5.5	-18.1	-15.0	-12.6
	German solution sets					
	Typ. NZEB	GER-2	GER-3	GER-7	GER-8	
Building envelope	0.22	0.31	0.31	0.31	0.31	
Energy costs$_{(NFA)}$	3.33	6.43	6.91	7.00	4.22	
Investment costs$_{(NFA)}$	1974	-84	-57	-83	-44	
	Italian solution sets, Rome					
	Typ. NZEB	ITR-1	ITR-2	ITR-3	ITR-4	
Building envelope	0,34	0.34	0.34	0.34	0.34	
Energy costs$_{(NIA)}$	0.81	0.85	0.61	1.25	0.85	
Investment costs$_{(NIA)}$	1375	-78	-68	-92	-94	
	Italian solution sets, Turin					
	Typ. NZEB	ITT-1	ITT-2	ITT-3	ITT-4	ITT-5
Building envelope	0.30	0.30	0.24	0.30	0.24	0.24
Energy costs$_{(NIA)}$	1.70	1.22	1.20	1.81	1.68	1.92
Investment costs$_{(NIA)}$	1375	-63	-62	-65	-64	-56
	Slovenian solution sets					
	Typ. NZEB	SI-1	SI-2	SI-3	SI-4	
Building envelope	0.413	0.413	0.333	0.333	0.333	
Energy costs	3.19	3.42	2.39	2.43	1.1	
Investment costs	762	-65	-32	-18	-5	

3. Summary

In this section, possible solutions from other countries are evaluated for possible use in the four countries.

3.1. Denmark

Use of decentral electrical resistance heating (German and Italian solution sets) has a potential for lowering the cost of NZEBs in Denmark. However, due to the differences in primary energy factors for district heating vs. electricity it will be difficult to meet the energy performance requirements in electrically heated buildings. Saved cost for the heating system could be used for improved energy performance elsewhere in the building and in this way potentially lower the investment cost while maintaining the primary energy performance.

3.2. Germany

The transfer of solution sets has to take into account the different starting points (base cases) in the country. That means for Germany that for example solution sets focussing on the addition of solar thermal are not attractive because this technology is already included in the base case, also because of the general requirement to apply renewable energy systems. It is also difficult to transfer a complete solution set because of the different base cases. More efficient insulation material or windows with 4-layer glazing have to be evaluated in comparison with the base case using national costs. Therefore, the transfer is not too easy.

Interesting technologies (parts of the solution sets) for the German market are according to the view of the German CoNZEBs team:

- Water saving fixtures: However two points have to be considered:
  - They will result in a slightly reduced comfort
  - They have no impact in the current German calculation method, which defines the DHW to 15 kWh/(m²_net_floor_area per year) independent on the type of fixtures. Thus they cannot be compensated with lower insulation or similar.
- Roof PV: This will have a positive impact on electricity-driven systems (e.g. ventilation or direct electrical heating). It is already part of two German solution sets. However, with the upcoming revision of the German energy ordinance it cannot be accounted for direct electrical heating anymore.
- Direct electrical heating, hygro-sensitive (demand-controlled) ventilation are also part of some of the German solution sets
- Optimisation of the thermal quality of the building envelope (balance between U-values of windows, walls, roof, cellar, and ceiling): The German solution sets have focus on alternative technologies. It can be assumed though, that an optimisation of different building envelope U-values can result in slightly lower investment costs. However, this is depending on the actual case, location and time of the building construction and is difficult to predict in general.
- Improved airtightness: The impact of a better airtightness can be calculated with the German energy performance methodology and will lead to lower requirements at other building parts (e.g. U-values of the building envelope). If investment costs are considered only this will lead to savings in the German case as well. On the other hand it will lead to probably higher planning costs and costs for the airtightness test (blower door or similar). The blower door test is however required anyway if a ventilation system is accounted for in the energy performance calculation.

3.3. Italy

The use of solution sets developed in the other participant countries is strictly related to the Italian NZEB definition and requirements, as well to the climatic conditions, that are substantially different, especially for Rome. Without taking into account the specific values referring to the technologies contained in a specific solution set, but considering the general approach, the following considerations apply:

- Danish solution sets. DK-1 is a potential applicable solution that should be double-checked with costs of high performing insulation materials. Solutions DK-2, DK-3 and DK-5 should be carefully addressed since the combination of ventilation with heat recovery to be re-paid by less insulation might be not cost efficient in most north Italian applications and, for sure, not in Mediterranean climates like Rome. DK-4 is not suitable, due to high costs of such performing windows, which do not provide significant savings at Mediterranean latitudes.

- Concerning the German solutions, solutions GER-2, GER-3 and GER-SS8 have focus on recovery and fresh stations from DHW, but this has limited advantages in Italy because of the mandatory use of renewable energies, with solar thermal for DHW among the most effective. The solution GER-7 has potential applications in buildings, located in area where district heating with sufficiently low primary energy factor (to be certified by the company providing the service).
- The Slovenian solutions appear not cost effective for Italy, due to high performance ventilation with heat recovery and works on increased air-tightness, which are not so common in Italy. SI-4 has higher potential applications, especially in Turing, where ventilation and triple glazing unit are better justified by climatic conditions.

3.4. Slovenia
DK-2 could be adopted and used also in Slovenia, especially due to the usage of PV panels and DHW solar heating, which present a good solution for achieving necessary renewable energy source (RES) ratio. This solution set foresees the usage of de-central mechanical ventilation, which is also used in the Slovenian typical NZEB. Also, the use of energy efficient taps could be adopted in Slovenia. Currently the use of energy efficient taps is required in green public procurement regulation for public buildings only. However, in Slovenian social housing the energy used for domestic hot water (DHW) is quite big. The implementation of energy efficient taps in social housing presents a good potential for reducing the energy used for DHW and water savings.
IT-2 is also a solution set that could be used in Slovenian market. The key technology that is interesting the use of autoclaved aerated concrete blocks, which nowadays are less commonly used as the brick walls are. The use of heat pumps in this solution set presents the technology with raising importance, due to growing share of RES in grid electricity and due to regulation of supported self-supply with PV.

3.5. General
Investment cost reductions range from 1 €/m² (with a slightly better energy performance) to 94 €/m², with the highest cost savings in an Italian solution set. Solution sets can obviously not be compared directly across climate zones and national legislation. However, it is envisaged that some solutions in another country's solution set may inspire to new combinations and hence new solution sets. The CoNZEBs project clearly follows the 'common thread' to identify cost efficient solutions for low energy buildings established in many previous cooperation projects and adds valuable new components to these.

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