Cost optimisation and life cycle assessments of nearly zero energy buildings

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The CoNZEBs project aims at reducing barriers for deployment of low-energy housing by identifying solutions sets for reduction of construction costs as well as the long-time life cycle cost and life cycle environmental impact.

Keywords: solution sets, cost reduction, life cycle costs, life cycle environmental assessments, global warming potential, non-renewable primary energy

Introduction

The EU Horizon 2020 research project CoNZEBs (Solution sets for the cost reduction of new Nearly Zero-Energy Buildings (NZEB) - 01/06/17 to 30/11/19), identify and assess technology solution sets that lead to significant cost-reductions of new NZEBs in four EU member states (Denmark, Germany, Italy and Slovenia). All solution sets have been assessed by life cycle costs (LCC) analysis and life cycle environmental assessment (LCA) providing a longer-term perspective than the construction costs. Some results obtained are quite remarkable as they indicate that a balance point between energy saving measures and renewable energy (solar) supply has been crossed. In other words, the LCC and LCA analyses show that both for economic and environmental reasons it pays off to reduce insulation levels and introduce PV-systems and/or solar heating systems on NZEBs. Results from this work – primarily for one of the countries – Denmark – is presented in the following.

Solution sets

In the project, solution sets have been developed, 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.

Analyses of the solution sets was carried out using national tools for proving compliance with energy performance requirements.

The solution sets are for Denmark:

1. High efficiency insulation in exterior walls resulting in lower construction costs for foundations, window fittings and roofs.
2. Domestic hot water (DHW) solar heating; reduced insulation in walls, roof and floor.
3. Four-layer windows; water saving fixtures; natural ventilation (illegal as balanced mechanical ventilation is required in new multi-family houses); heat recovery on grey wastewater.
4. Reduced insulation in walls, roof and floor; decentral mechanical ventilation; efficient water fixtures.
5. Reduced insulation in walls, roof and floor; decentral mechanical ventilation; roof PV panels.

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 window installation, smaller facade area, smaller foundations and roof when maintaining the same habitable area.

In some countries, 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 building's 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/costly solutions elsewhere in the building and thus lowering the investment costs.

A summary of cost optimisation results from the Danish calculation are shown in **Table 1**.

Life Cycle Cost (LCC) and Life Cycle Environmental Impact Assessment (LCA) calculations

All the identified solution sets are further assessed regarding cost savings using LCC and with respect to the environmental impact using LCA analysis, which both provide a long-term perspective than just the reduced investment costs. The results of the LCC and LCA are compared to those obtained for conventional minimum energy performance (min. EP) buildings, conventionally built NZEBs and buildings that go beyond the NZEB level – zero-energy or even plus-energy houses. For Denmark the beyond NZEB has been defined as a "0-energy building", without including household electricity.

The LCC used for this analysis is resulting in the total net present value (NPV) of the technology solution sets over a fixed period of 30 years. The LCA calculations in this project cover two phases: Production and Use. Generally, the input values/parameters to use for the LCA calculation in both phases are available in each country. An overall decision has been made on how to handle the input to the two phases for each country. For this work, it was agreed to focus the results on two LCA parameters: Non-renewable primary energy (NR-PE) use and global warming potential (GWP), known as CO_2-equivalent emissions. Both NR-PE factors and GWP emissions due to different energy supply options during the use phase have been analysed by each country.

The beyond NZEB, the Typical NZEB and the range of the results from the solution sets are compared to the min. EP building. The range of NZEB solution sets is interpreted as the interval between the best and the worst NZEB solution set result with respect to the LCC and LCA results obtained individually. The two improved technologies that constitute the difference between min. EP and typical NZEB building are the starting

Table 1. *Summary of cost results from analyses of solution sets. Building envelope is the average U-value of the building fabric. GFA is gross floor area.*

	Danish solution sets					
	Typ. NZEB	DK-1	DK-2	DK-3	DK-4	DK-5
Building envelope [W/m^{2}K]	0.26	0.26	0.31	0.21	0.31	0.31
Energy costs$_{(GFA)}$ [€/(m^{2}yr)]	11.8	11.8	11.8	11.7	11.7	11.7
Investment costs$_{(GFA)}$ [€/m^2]	1247	−2.1	−5.5	−18.1	−15.0	−12.6

point to each alternative NZEB solution set. They are: 3-layer windows instead of 2-layer window and a mechanical ventilation system with good heat recovery, instead of one with average recovery. The results are presented in **Figures 1-3** as differences compared to the min. EP building.

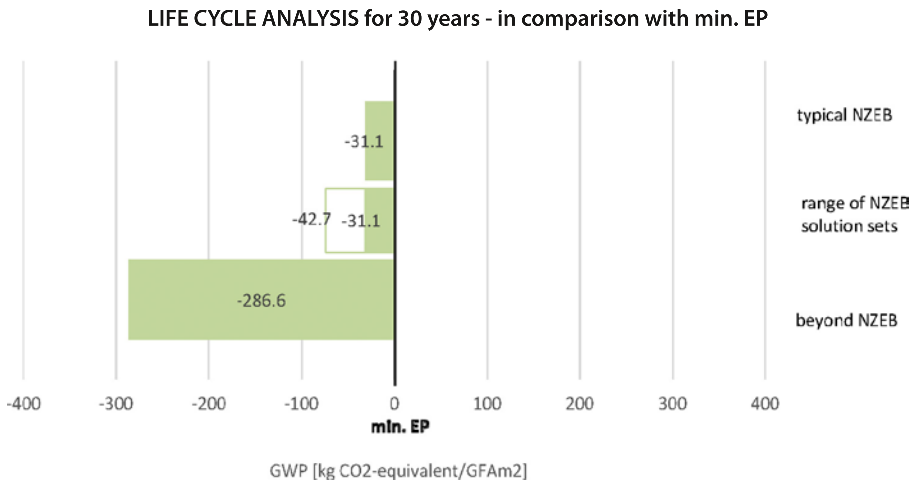

Figure 1. GWP analysis for typical NZEB, range of NZEB solution sets and beyond NZEB in comparison with min. EP.

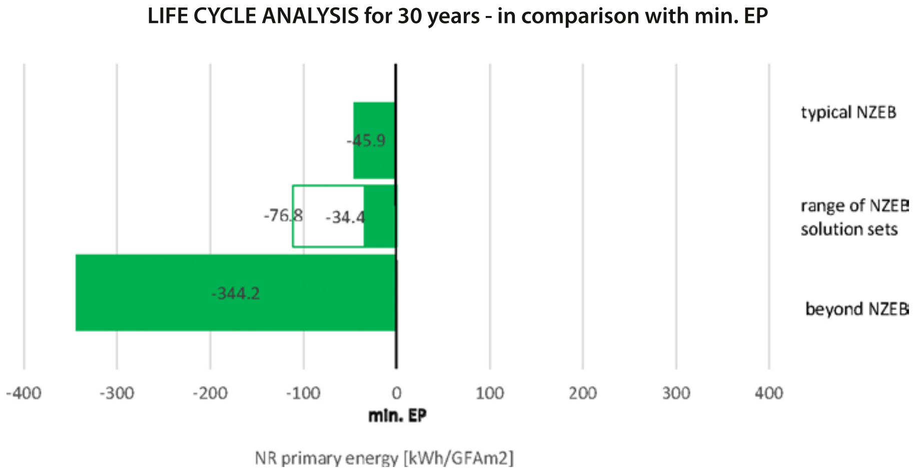

Figure 2. NR-PE energy analysis for typical NZEB, range of NZEB solution sets and beyond NZEB in comparison with min. EP.

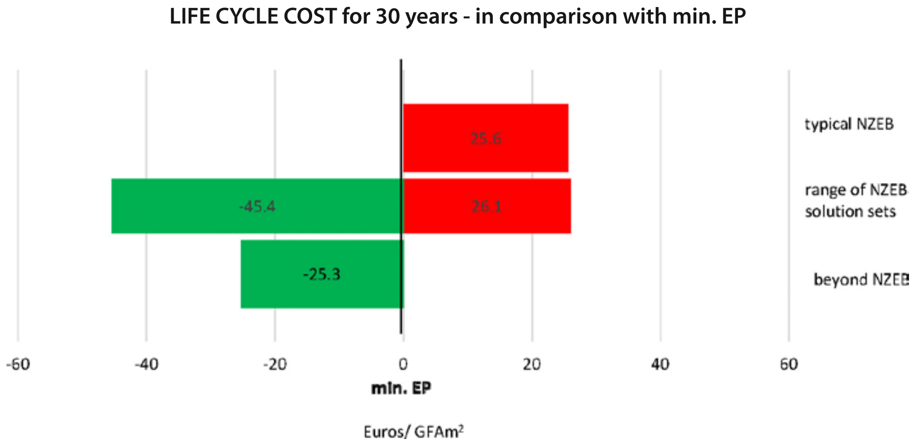

Figure 3. NPV for the different improved energy performance levels compared to minimum EP – Denmark.

Figures 1-3 show that all the alternatives to the min. EP buildings are more environmental friendly, when comparing greenhouse gas emissions in the form of kg CO_2-equiv./m² and nonrenewable primary energy use to the min. EP building. However, from a purely economic perspective, only one of the solution sets and the beyond NZEB building are more cost-effective than the min. EP building. The beyond NZEB building is a more cost-efficient solution than the min. EP building, due to the economic value of larger energy savings than those of the NZEB.

Conclusions

Investment cost reductions in the four countries 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.

One of the main ideas of the CoNZEBs project was to investigate if LCC and LCA analyses conducted over a time-span of minimum 30 years would cast

Figure 4. Illustration of typical multi-family houses used for the CoNZEBs solution set analyses in Denmark, Germany, Italy and Slovenia.

more light over what is the most cost-effective and environmental friendly building energy level – min. EP, NZEB or beyond NZEB.

The analyses are carried out for well-defined reference/typical multi-family buildings in each country (**Figure 4**) for each of the three energy use levels.

One of the overall conclusions, based on the Danish results are: Typical NZEB is less cost-effective than min EP, but beyond NZEB can be more cost-effective. Both NZEB and beyond NZEB can be more environmentally friendly than min. EP. The different solutions for NZEB reduce the CO_2-equivalent emissions by 31 to 43 kg/m^2 over a 30-year period. For the beyond NZEB, the total number is 287 kg/m^2. This compare to the typical total CO_2-equivalent emissions over a 30-year period of a new conventional building in Denmark of 400-500 kg/m^2. Interesting is also that several of the solutions sets show that the insulation levels can be reduced by only adding a solar heating or PV system, or implementing energy efficient water taps - in all cases showing improved GWP compared to the typical NZEB. It needs to be said that reduction of insulation thicknesses are relatively small – about 50 mm – thus these reductions does not compromise the indoor thermal comfort nor diminish the resilience and passive habitability. One of the solutions sets even showing improved cost-efficiency compared to the min. EP building.

So far, the results for Denmark has reached the goal of pointing the way for optimum design of new buildings in the future.

On the project website (www.conzebs.eu) there are information about all the results obtained in the project. Among them is a survey of users' experiences and expectations of low-energy buildings, and a brochure on the benefits of living in low-energy buildings. ■

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