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Life-cycle cost and environmental assessment 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. These buildings 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 Horizon 2020 research project CoNZEBs, identify and assess technology solution sets that lead to significant cost reductions of new NZEBs in four EU member states. The project initially identified baseline costs for minimum energy performance buildings, NZEB and beyond NZEB in the four countries and then a number of solution sets with lower investment costs than those of typical NZEBs. The next step was to carry out life cycle cost and environmental assessment analyses on the identified solution sets and compare these to minimum energy performance, typical NZEB and beyond NZEB buildings. The results of this work for one of the countries – Denmark – is presented below as an example.

1. Introduction

The EU Horizon 2020 (https://ec.europa.eu/programmes/horizon2020/) research project "Solution sets (SS) for the Cost reduction of new Nearly Zero-Energy Buildings – CoNZEBs" (www.conzebs.eu) started in June 2017. The CoNZEBs objectives are to identify and assess technology solution sets that lead to significant cost reductions of new Nearly Zero-Energy Buildings. The focus of the project is on multi-family houses. The project has started by setting baseline costs for conventional new buildings built according to current minimum energy performance (min. EP) requirements (defined by the national building regulations in accordance with the EU Energy Performance of Buildings Directive [1]), currently available NZEBs and buildings that go beyond the NZEB level [2]. It should be noted that until 2021 min. EP requirements are less demanding than what is required for NZEB. After January 2021 min EP and NZEB is to identical.

The second step was to identify NZEB buildings that can be considered typical for the national building tradition for each of the four participating countries. These typical buildings has been designed to meet the national requirements for NZEBs. Thirdly, analyses of possible alternative solutions – constituting solution sets – that show the same calculated energy performance, but have lower investment and potentially lower energy cost were carried out and documented [3]. Some of the typical buildings are selected real buildings, while others are artificial ones (figure 1).

All the identified solution sets are further assessed regarding cost savings using life cycle costs (LCC) analysis and with respect to the environmental impact using life cycle environment assessment (LCA) analysis, which both provide a long-term perspective than just the reduced investment costs. The results of the LCC and LCA analyses are compared to those obtained for conventional min. EP buildings, conventionally built NZEBs and buildings that go beyond the NZEB level – zero-energy or even plus-energy houses.

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

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

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 Net present value (NPV) is calculated as:

NPV = Investment – energy saving + maintenance + replacement (including. residual value) (1)

This is done using a conventional discount calculation.

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 has also been 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 provided by each country.

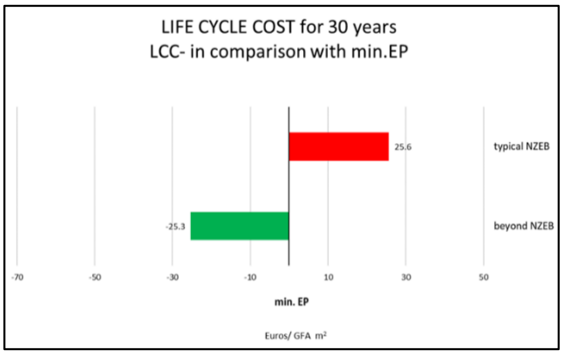
3. Results of the LCC and LCA analyses

As mentioned above the analyses were carried out for the four participating countries – for Italy even in two locations, because of the large climate variations. At the time of writing this paper only calculations for Denmark have been completed. At the conference, results from all four countries and the two locations in Italy will be presented.

The results have been organised in three sections. First Typical NZEB and beyond NZEB is compared to minimum energy performance (min. EP) buildings. Secondly, each of the identified solution set to reach NZEB has been compared to the Typical NZEB and finally, all solution sets, the Typical NZEB and beyond NZEB are compared to min. EP buildings.

3.1 Comparison of Typical NZEB, beyond NZEB to minimum EP buildings

For Denmark the beyond NZEB has been defined as a "0-energy building", without including household electricity. From figure 2 it appears that a NZEB building has higher LCC (illustrated by the red column) than a min. EP building. However, the beyond NZEB building is a more cost-efficient solution than the min. EP building, due to the economic value of the larger energy savings than those of the NZEB building.



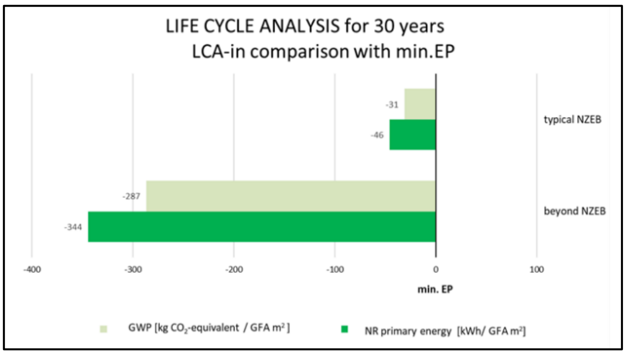


Figure 2 and 3. LCC and LCA analysis.
Typical NZEB and beyond NZEB in comparison with min. EP.

A typical NZEB building is a better solution and the beyond NZEB building is a much better solution from the environmental point of view compared to the min. EP building. The environmental loads are in green color in figure 3. Had they been larger than for min. EP buildings they would have been depicted in red.

3.2 Comparison of the solution sets to Typical NZEB

As mentioned above, a number of solution sets (SS) with lower investment costs than those for a typical NZEB building design were identified in the CoNZEBs project. These are described in detail in the project report [3] and an overview of the Danish SS are shown in Table 1.

Table1. Overview of technology solution sets identified in Denmark.

Building part	REFERENCE BUILDING. TYPICAL NZEB	TECHNOLOGY	DK-SS1	DK-SS2	DK-SS3	DK-SS4	DK-SS5
Envelope	Rockwool insulation, Λ= 0,036 W/mK	Lower lambda value of the insulation	x				
Envelope	3-layer windows	4-layer windows			x		
Envelope	0.15 W/m²	reduced insulation in ext. wall		x		x	x
Envelope	0.1 W/m²K	Reduced insulation in roof		x		x	x
Envelope	0.1 W/m²K	Reduced insulation in floor		x		x	x
Service systems	MVHR[1] Centralized	MVHR – decentralized				x	x
Service systems		Natural ventilation			x		
Service systems	Standard taps water	Energy efficient water taps				x	
Service systems	-	Heat recovery on grey wastewater			x		
Renewables	-	PV-panels on roof					x
Renewables	-	Solar heating		x			

[1]Mechanical Ventilations system with Hear Recovery = MVHR

In the following results of the LCA- and LCC analyses for a couple of these solution set are presented. First SS2 – an addition of a solar heating system, which makes it possible to reduce the insulation thicknesses:

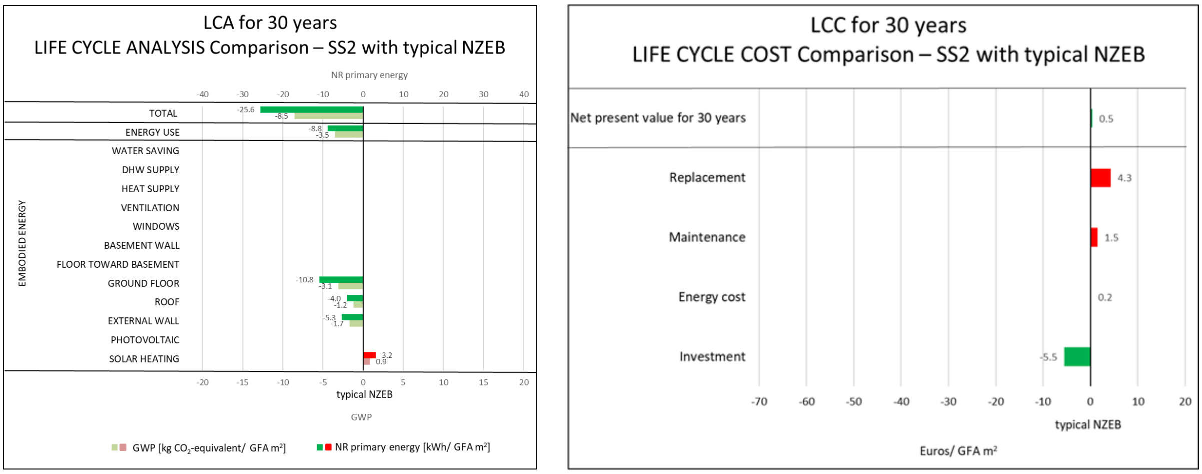


Figure 4 and 5. SS2 compared with typical NZEB.

Figure 4 shows the lower environmental loads due to the lower amount of mineral wool insulation used, however a higher environmental load is generated by the implementation of a new solar heating system. The environmental load-saving is found during the use phase of the building over 30 years, resulting in an overall increased environmentally friendly solution set.

From the economic point of view, this solution set is close to neutral. The investment reduction is balanced by additional maintenance and replacement costs for the solar heating system – see figure 5.

SS3 is a rather simple solution set. Here the 3-layer windows are "replaced" by 4-layer windows and the mechanical ventilation system with heat recovery (MVHR) is removed from the traditional NZEB design and only natural ventilation is used (in spite of the fact that constructing new residential building in Denmark without mechanical ventilation is not presently allowed, it was decided to analyze this solution). The air change rate in this solution set with natural ventilation is the same as for the solutions sets with mechanical ventilation, hence ensuring similar indoor climate. The third change is the installation of a heat recovery system on the grey wastewater.

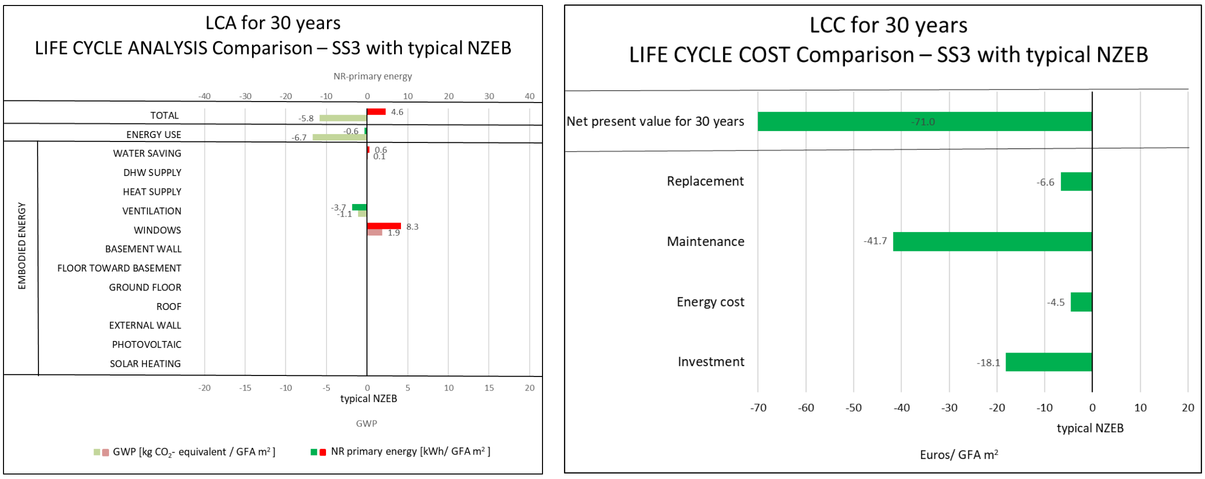


Figure 6 and 7. SS3 compared with typical NZEB.

As it was expected, this gives high cost savings due to the large investment cost reduction for the MVHR system and with the maintenance cost reductions – figure 6. CO_2 emission during the use phase of the building over the 30-year period is also lower, but in contrast, the implementation of this innovative 4-layer window uses more embodied energy during production and thus resulting in an increased total non-renewable primary energy load. The resulting GWP is considerably reduced, though – see figure 7.

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The two next solution sets save energy by either implementing energy efficient water taps or by the installation of a PV-system and balance these savings by reduced insulation thicknesses. The result is both highly improved LCA results and somewhat improved LCC results compared to the typical NZEB in Denmark.

3.3 Comparison of solutions sets, Typical NZEB and beyond NZEB to minimum EP

Here the beyond NZEB, the Typical NZEB and the range of the results from the solution sets are being 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. It is important to note at this point, that the two improved technologies that constitute the difference between min. EP and typical NZEB building are included as the starting 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 8 to 10.

The plots on figures 8 to 10 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 non-renewable primary energy use to the min. EP building. However, from a purely economic perspective, only one of the solution sets (SS3) and the beyond NZEB building are more cost-effective than the min. EP building.

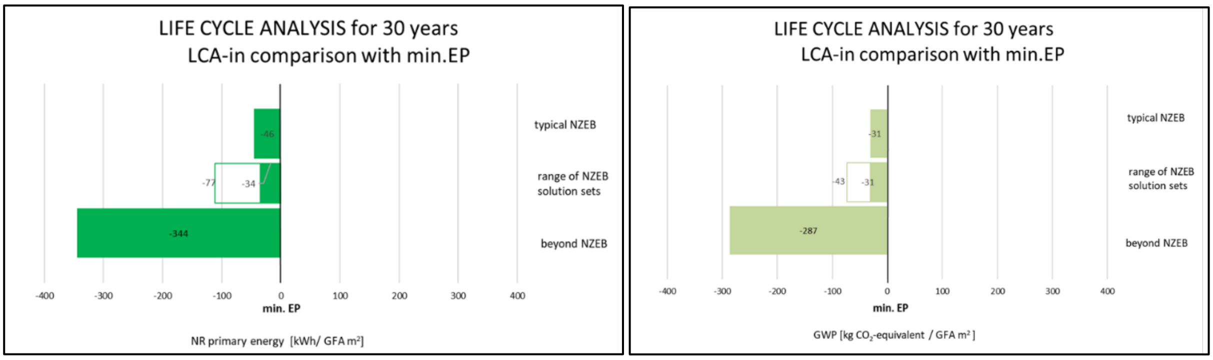

Figure 8 and 9. GWP and NR-PE energy analysis for typical NZEB, range of NZEB solution sets and beyond NZEB in comparison with min. EP.

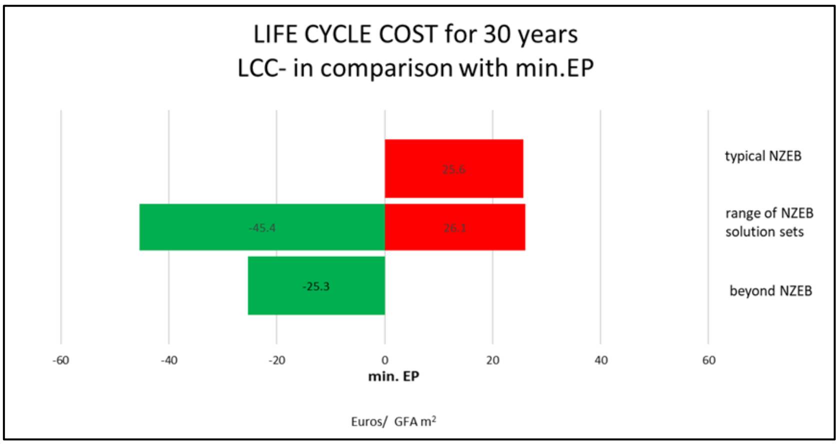

Figure 10. LCC analyses for typical NZEB, range of NZEB solution sets and beyond NZEB in comparison with min. EP.

4. Conclusions

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 more light over what the most cost-effective and environmental friendly building energy level – minimum EP, NZEB or beyond NZEB - are. This work has now been initiated with a complete set of analyses for Denmark. The remaining analyses for the three other countries in the project will soon follow.

The analyses are carried out for well-defined reference/typical multi-family buildings in each country for each of the three energy use levels. The alternative solution sets with lower investment costs to reach the NZEB levels identified earlier were also included in this LCC and LCA analysis. In this paper only the results for Denmark are presented, as the results for the other countries are yet to be produced.

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 between 31 and 43 kg/m² over a 30 year period. For the beyond NZEB this number is as high as 287 kg/m². This may be compared to the typical total CO_2-equivalent emissions over a 30 year period of a new conventional building in Denmark of 400-500 kg/m². 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 results compared to the typical NZEB. It need to be said that the reductions of insulation thicknesses are relatively small – about 5 cm – thus these reductions does not reduce the indoor thermal comfort nor in any considerable way diminish the resilience and passive habitability. One of the solution sets (SS3) 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.

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The authors like to thank our colleagues for their involvement and commitment in the project.

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