Life-Cycle Assessments Of Near Zero Energy Buildings and Beyond In Comparison With Regular New Buildings

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Abstract

Life-cycle costs (LCC) and life cycle environmental impact analyses (LCA) of several alternative technical solution sets identified to reach NZEB and beyond NZEB levels for new multifamily buildings in four European countries (Denmark, Germany, Slovenia and Italy) have been carried out as part of the work of a current EU Horizon 2020 project "Cost reduction of new Nearly Zero-Energy Buildings – CoNZEBs (NZEBs)" (www.conzebs.eu). Some of the 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 results show that both for economic and environmental reasons it pays off to reduce insulation levels and introduce PV-systems and/or solar heating systems for near zero energy buildings. This paper present the main picture of the results achieved.

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

1. Introduction

EU Horizon 2020 (https://ec.europa.eu/programmes/horizon2020) research project "Solution sets for the Cost reduction of new Nearly Zero-Energy Buildings – CoNZEBs" (06.2017-11.2019) (www.conzebs.eu) identifies and assesses technology solution sets (SS) that lead to significant cost reductions of new Nearly Zero-Energy Buildings in Denmark, Germany, Italy and Slovenia. The focus of the project is on multi-family houses. The project started by setting baseline costs for conventional new buildings, currently available NZEBs and buildings that go beyond the NZEB level (Erhorn-Kluttig H, et al. 2017). The second step was to identify multi-family buildings designed and constructed in ways, which are typical for the national building traditions, i.e. buildings that are typically seen in the four countries. The Italian and Slovenian reference typical buildings are based on selected real buildings, while the Danish and the German are purely theoretical buildings (figure 1). The designs are not that different, the differences lies in the ways of construction.

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

These typical buildings has then been designed to meet national requirements for NZEBs. Thirdly, analyses of possible

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alternative sets of solutions that show the same calculated energy performance, but have lower investment and potentially lower energy cost were carried out and documented (Wittchen et al. 2018). The technology solution sets includes approaches that can reduce costs for installations or generation systems, pre-fabrication and construction acceleration, local low temperature district heating including renewable energy systems (RES) in the form of solar heating and photovoltaic solar systems (PV), and hot water saving installations. Obviously, the solutions sets differ substantially between the four participating countries due to differences in prevailing construction technology and climates.

All solution sets have been assessed by life cycle costs (LCC) analysis and life cycle environmental impact analyses (LCA) providing a longer-term perspective than the construction costs. The results of the LCC and LCA analyses are to be compared to those obtained for conventional buildings built according to current building regulations, here referred to as minimum Energy Performance (minimum EP) buildings, conventionally built NZEBs and to buildings going beyond the NZEB levels.

The LCA had primary focus on the Global Warming Potential (GWP) - CO_2 equivalent-emissions (kg CO_{2eq}/m^2) and the use of non-renewable primary energy (NR-PE).

National tools have been used to assess the energy performance of the solution sets, the national tools are shortly listed here. Denmark: ASCOT_LCA (Mørck et al. 2015) based on the ISO EN 13790 standard for energy calculations. Germany: IBP:18599 developed by Fraunhofer IBP based on the DIN V 18599. Italy: EDILCLIMA , version EC700, which is based on relevant CEN standards and adapted for the specific Italian context and legislative framework. Slovenia: KI Energija is a software based on a national technical guideline for efficient energy use, which is prepared based on all relevant EN ISO standards regarding buildings energy efficiency, e.g. SIST EN 13790, SIST EN ISO 13789 , regulations and technical guides. However, the Danish tool, ASCOT_LCA, has been further developed to handle the input from the four countries for the developed solutions sets. Thereafter this tool was used for the LCC and LCA analyses of the developed solution sets in all four countries.

ASCOT_LCA was first developed in a Danish R&D project and then further developed within the EU (FP7) project “School of the Future” (http://www.school-of-the-future.eu) and the IEA EBC Annex 56 - Cost Effective Energy and Carbon Emissions Optimization in Building Renovation (http://www.iea-annex56.org).

2. Assumptions and prerequisites

The factors (see Table 1) used to calculate global warming potential (GWP) and NR-PE from the calculated energy demands are quite different among the four countries. These factors reflect the present energy supply mix in each country.

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Tab 1: NR-PE and GWP factors used for the use phase LCA calculation for each country. Sources are be found in Gutierrez et al. (2019) at www.conzebs.eu

Country	Energy source	NR-PEF [kWh/kWh]	GWP, CO_2.Equivalent [kg/kWh]
Denmark	District heating	0.46	0.248
	Electricity	0.86	0.649
Germany	District heating	0.7	0.1517
	Natural gas	1.1	0.24
	Electricity	1.8	0.55
Slovenia	District heating	1.0	0.254
	Natural gas	1.1	0.237
	Electricity	2.5	0.602
Italy	Natural gas	1.05	0.200
	Electricity	1.95	0.445

3. The identified solution set with lower investment costs

Identified solution sets for NZEB presenting lower investment costs than the typical national NZEB are been presented in detail in the report of the CoNZEBs project (Wittchen et al. 2018). In this paper, the solution sets are briefly presented in each national (for Italy two climates) chapter. The solutions (technical and/or constructional) constituting the selected solution sets are quite different for each location. The solution sets in each country has been numbered, for example DK1-DK5 in Denmark.

For Denmark, they comprise:

DK1. High efficiency insulation in exterior walls resulting in lower construction cost for foundations, window fittings and roofs.

DK2. Reduced insulation in walls, roof and floor; DHW solar heating.

DK3. Four-layer windows; Heat recovery on grey wastewater; Natural ventilation (illegal in current legislation).

DK4. Reduced insulation in walls, roof and floor; decentral mechanical ventilation; energy efficient water fixtures.

DK5. Reduced insulation in walls, roof and floor; Decentral mechanical ventilation; PV-panels on the roof .

The German solution sets are based on alternative heating and ventilation systems instead of the typical system of a condensing gas boiler with solar thermal support and mechanical exhaust ventilation and include:

DE1. 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.

DE2. 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.

DE3. Central combined heating and DHW system with district heating, central exhaust ventilation system and reduced insulation level.

DE4. 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.

Due to the better efficiency and/or lower primary energy factor of the alternative systems, the insulation level of the building envelope could be reduced, while still fulfilling the NZEB requirements.

In Italy – two climates: Rome and Turin – other new technologies are:

ITR1. Cheaper construction of external walls and windows. Condensing boiler for both heating and DHW production.

ITR2. Cheaper construction of external walls and windows. Heat pump for both heating and DHW supply. No use of solar thermal collectors.

ITR3. Cheaper construction of external walls and windows. Electric radiators for space heating mainly supplied by the PV panels.

ITR4. Cheaper construction of external walls and windows. Condensing boiler for both heating and DHW production. Reduction of PV panels based on real needs.

ITT1. Cheaper construction of external walls and windows. Condensing boiler for both heating and DHW production. Combined use of solar collectors both for heating and DHW.

ITT2. Cheaper construction of external walls and windows and extra insulation in the envelope. Condensing boiler for both heating and DHW production. Combined use of solar collectors both for heating and DHW. Mechanical extract ventilation.

ITT3. Cheaper construction of external walls and windows. Air water heat pump for both heating and DHW supply. No solar collectors.

ITT4. Cheaper construction of external walls and windows and extra insulation in the envelope. Air water heat pump for both heating and DHW supply. No solar collectors. Mechanical extract ventilation.

ITT5. Cheaper construction of external walls and windows and extra insulation in the envelope. Electric radiators for space heating mainly supplied by the PV panels.

In Slovenia new technologies taken into consideration are:

SK1. District heating as generation for heating and DHW; use of mechanical ventilation with 85% heat recovery; better airtightness.

SK2. Air heat pump as generation for heating and DHW; use of mechanical ventilation with 85% heat recovery; triple glazing windows; better airtightness

SK3. 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.

SK4. Air heat pump as generation for heating and DHW; roof PV panels; use of hygro-sensible ventilation system; triple glazing windows; better airtightness

There is thus quite a large variation of technologies combined into different solution sets. Solar heating and PV are among the technologies used in all countries. The other technologies differ significantly and seen together with the different GWP and NR-PE factors it becomes clear why no attempt has been made to compare results between the countries. Representative GWP and NR-PE results

To illustrate the main results of this work some of the plots from the different national parts have been selected to be presented here in this paper. These are comparison (minimum energy performance (EP) as basis) plots for the LCA and LCC results for the typical NZEB, the range obtained for the NZEB solution sets and for beyond NZEB buildings.

The first selection of plots shows the comparison of the GWP for Denmark and Rome – figure 2 and figure 3. These two plots are representative for all five plots from the national parts. All improved energy performance level buildings show decreased GWP numbers. The ranges are different, as explained above due to both the different conversion factors used and to the different construction traditions and finally to different energy requirements in the countries.

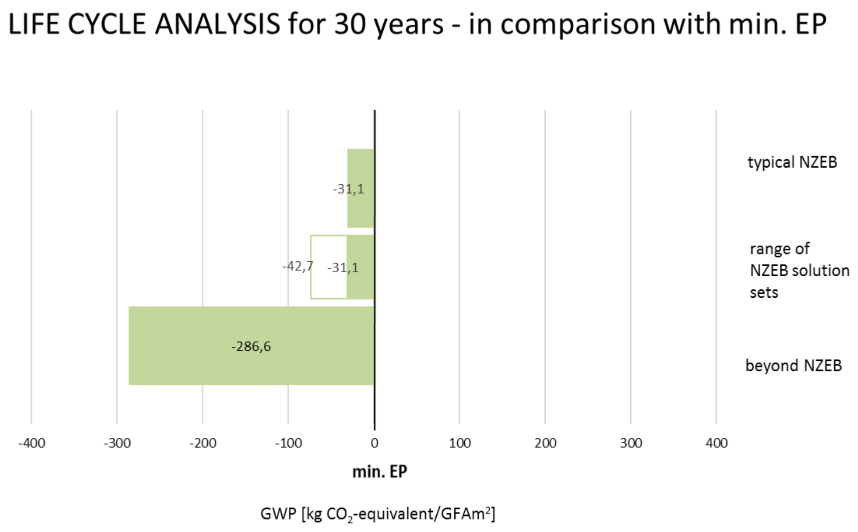

Fig. 2: GWP for the different improved energy performance levels compared to minimum EP – Denmark

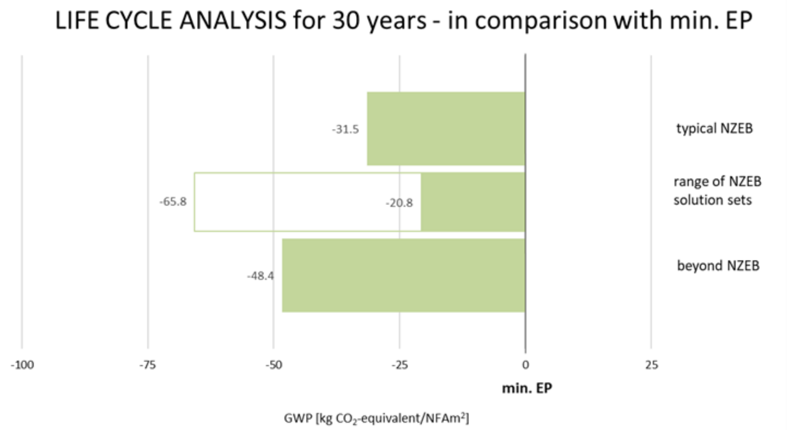

Fig. 3: GWP for the different improved energy performance levels compared to minimum EP – Rome, Italy

Similarly, the next two plots represent the results for non-renewable primary energy (NR-PE) from all the five climates (for Italy, the calculations were made fort two climates: Rome and Turin). Here results have been selected from Germany – figure 4 and Slovenia – figure 5. Again, the plots show that from an environmental point of view all the buildings with improved energy performance exhibit very good results. Same reasons for the differences in the ranges between the countries as mentioned above for the GWP.

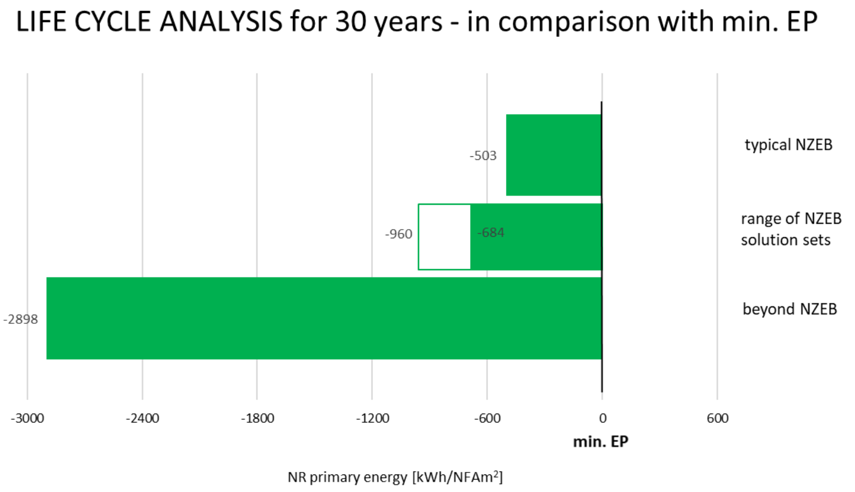

Fig. 4: NR-PE for the different improved energy performance levels compared to minimum EP – Germany

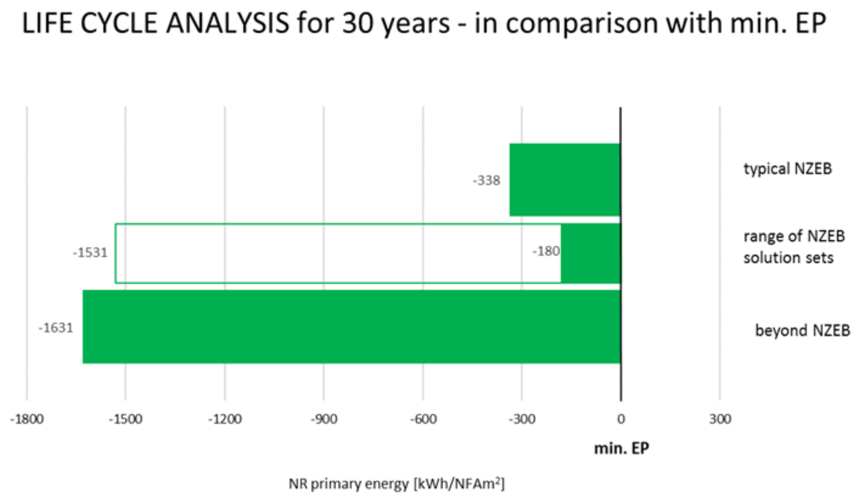

Fig. 5: NR-PE for the different improved energy performance levels compared to minimum EP – Slovenia

It needs to be emphasised at this point that the GWP and NR-EP calculations **do** take into account the energy use at the production stage of the energy saving and renewable energy producing measures. The plots show that these "investments" are outbalanced by the reduced energy use over the building's lifetime compared to the minimum EP building levels.

4. Representative LCC results

Looking at the LCC results – expressed in net present value (NPV) - there are larger differences between the five locations. Two countries, Germany (figure 6) and Slovenia (represented by figure 6), show increased expenses (NPV) for all the improved building levels. As it can be seen on figure 6 the results for typical NZEB and for the range of the solution sets show that the NZEB level in Germany can be reached at almost the same NPV costs as that of minimum EP buildings. The costs of reaching the beyond NZEB level is however too high to be balanced by the financial value of the energy savings. It should be noted, though, that for Germany the beyond NZEB level is a plus-energy house including household electricity consumption. For Slovenia, the NPV is significantly above that of the minimum EP for all the improved building types.

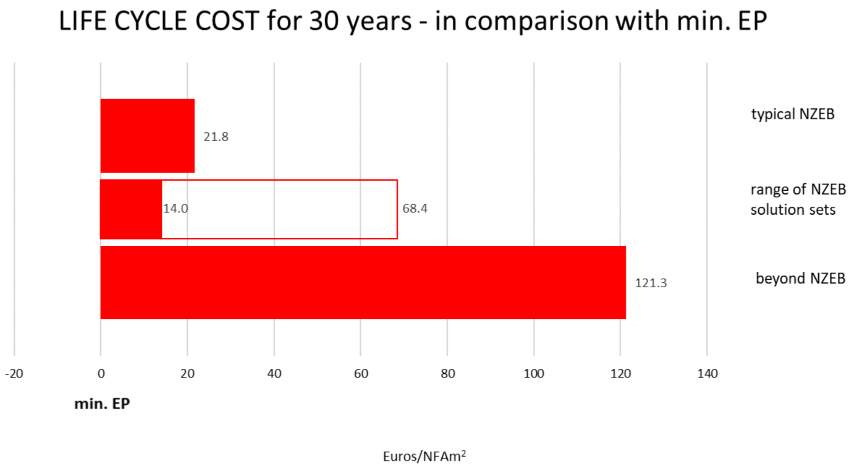

Fig. 6: NPV for the different improved energy performance levels compared to minimum EP – Germany

Denmark represents the picture in between. Here one of the solutions sets and the building built beyond the NZEB level have lower total costs (NPV) than a minimum EP building- see figure 7. However, the typical NZEB and the other solutions sets show higher costs.

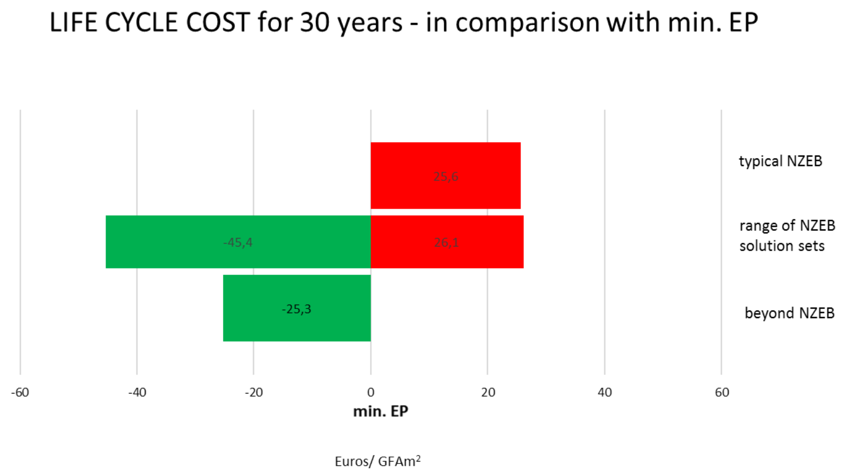

Figure 7: NPV for the different improved energy performance levels compared to minimum EP – Denmark

The two Italian climates show quite different results. In Rome all the solution sets and the beyond NZEB building show reduced total costs (NPV) compared to the minimum EP and the typical NZEB almost the same cost – see figure 8. For the Turin situation, only the analysed solution sets show lower total costs than the minimum EP building. Both the typical NZEB and the beyond NZEB buildings have higher costs – see figure 9.

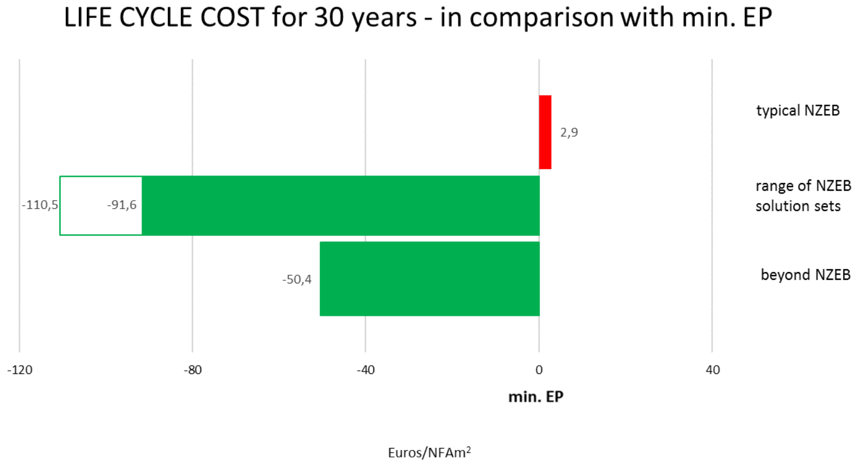

Fig. 8: NPV for the different improved energy performance levels compared to minimum EP – Rome, Italy

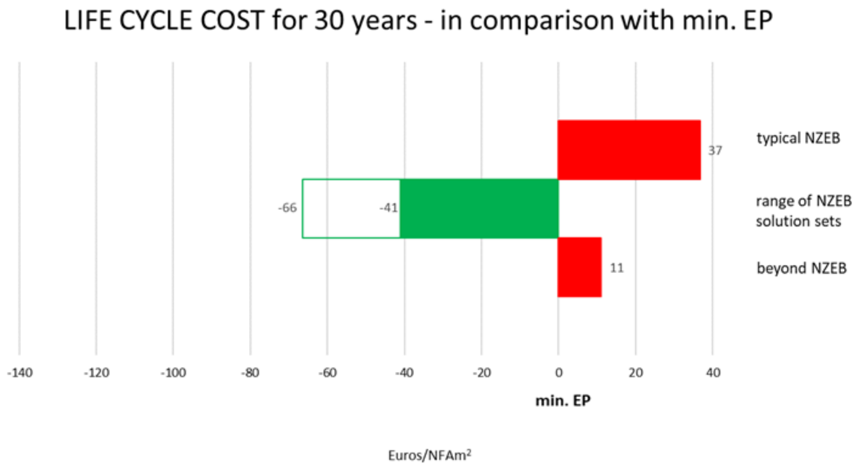

Fig. 9: NPV for the different improved energy performance levels compared to minimum EP – Turin, Italy

All improved energy performance levels show clearly improved environmental results compared to the minimum EP building levels in all locations. The picture is more varied when looking at the total costs from the LCC analysis. For Slovenia and Germany, it does not pay off to aim at a better energy performance than the minimum energy performance level at this moment, whereas in the other three countries some of the solution sets also show good financial results.

5. Conclusions

Summary of the results for each climate

Denmark

All solution sets show improved NPV compared to the typical NZEB. However, when comparing them to the minimum EP level only one of the solution sets (DK3 – based on natural ventilation) comes out with a lower NPV. It is very interesting that the buildings designed and built to the beyond NZEB level actually show better LCC than the buildings built to minimum EP due to the financial value of the large energy savings of a 0-energy house.

When comparing greenhouse gas emissions in the form of kg CO_2,eq./m² and non-renewable primary energy over the 30 year period of the LCA analyses all solution sets, the typical NZEB and the beyond NZEB all show improved environmental results compared the minimum EP building.

The right choice for the future will depend on the local energy infrastructure. If the building is located outside a district heating area , the best solution may be to design and build beyond the NZEB level, whereas in the situation where a CO_2-neutral supply within relatively few years can be expected a DK3 NZEB would be the right choice, provided special care is taken to assure adequate ventilation rates.

Germany

The results of the LCA analyses for Germany show that the typical NZEB, the range of solution sets and the beyond NZEB level are more environmental friendly than the minimum EP building. This is true for both the examined parameters (global warming potential and non-renewable primary energy use). Thanks to the changes in heat generation, ventilation and the huge PV system, the beyond NZEB has a much lower environmental impact than the typical NZEB, since the savings during the use phase dominate the higher embodied energy for these building levels.

None of the alternative NZEB solution set was able to generate a lower net present value than the minimum EP level, but three solution sets only result in a slightly higher net present value of about 20 €/m² (net floor area) or lower. This means additional costs of 0.055 €/m² per month or 3.67 €/month per average apartment. These rather low additional costs should be accepted when building a new multi-family house, even more when carbon taxes might be introduced in the EU member states in the near future.

Italy – Rome

The LCA results show that the best performing solution in the long term perspective of 30 years is ITR2 with a reduction of non-renewable primary energy up to 335 kWh/m^2 and a reduction of greenhouse gas emissions up to 2 kg CO_2eq./m^2 compared to a typical NZEB.

LCC results show that the most profitable solution is ITR4, both in terms of investment costs (up to 93 €/m^2 less than the typical NZEB) and net present value over 30 years (up to 113 €/m^2 less than the typical NZEB). These savings are even larger if compared to a minimum EP building.

Additionally, it has to be noted that the beyond NZEB solution achieved the best environmental results compared to the minimum EP level for non-renewable primary energy (468.6 kWh/m^2) within the 30 years period. The beyond NZEB is also more profitable than the minimum EP due to the large energy cost reduction over 30 years. Savings in running costs do indeed compensate for the higher investment costs.

Italy – Turin

The LCA results show that the best performing solution in a long-term perspective of 30 years is ITT1 with a reduction of non-renewable primary energy up to 302 kWh/m^2 and a reduction of greenhouse gas emissions up to 33.3 kg CO_2-eq./m^2 compared to a typical NZEB.

LCC results show instead that the most profitable solution is SS2, with a reduction in the NPV up to 103 €/m^2 compared to the typical NZEB. Regarding the investment costs, all solutions are in the same range with a maximum difference of 15%.

As in Rome, the beyond NZEB configuration showed very good environmental results compared to the minimum EP, namely reductions of 98 kg CO_2eq./m^2 and of 663 kWh/m^2 of non-renewable primary energy. Thanks to savings in the energy costs during the operating phase, the beyond NZEB is also more profitable than the typical NZEB.

As a conclusion, both in Rome and Turin, the alternative solution sets and the beyond NZEB are more environmental friendly and cheaper in the long term than the typical NZEB. These results pave the way for a wider development of high-efficient buildings in the Italian market; reaching optimal environmental and economic results if optimized design strategies are applied.

Slovenia

Looking at the greenhouse gas emissions in the form of kg CO_2eq./m² and the non-renewable primary energy use over the 30 year period of the LCA analyses, all solution sets, the typical NZEB and the beyond NZEB houses show improved environmental results in comparison with the minimum EP building.

None of the solution sets was cheaper in the 30-years lifetime than the building fulfilling the minimum EP level, due to implementation of the technologies with higher investment costs in all solution sets. However, both the investment costs, and the net present value over 30 years is lower than that of the typical NZEB for all solution sets.

General findings

The overall results indicate that a balance point between energy saving measures and renewable energy (solar thermal or PV) supply has been crossed. In other words, the LCC and LCA results show that both for economic and environmental reasons in most countries and climates it pays off to reduce insulation levels and introduce PV-systems and/or solar heating systems for nearly zero energy buildings.

Reductions of GWP and NR-PE are difficult to comprehend; here we try to illustrate the importance by comparing to:

- the GWP and NR-PE due to the embedded energy in constructing new NZEB buildings in Denmark,
- the emissions from different transportations means and
- the CO_2-reductions from planting trees.

Two of the new low energy buildings (also used in the first work phases of the CoNZEBs project to establish the references) have been analysed in Denmark as part of a Sustainable Certification according to the Danish DGNB-DK certification scheme (www.dk-gbc.dk/english/). From this, the total GWP emissions and the NR-PE from the construction phase were identified. To serve as a reference here the average for these have been calculated. For the construction itself the GWP was 262.5 kg CO_2eq./m² and the NR-PE: 1,350 kWh/m² (calculated over a 30 year period). As the GWP- and NR-PE factors of the different countries are so varied it is meaningful only to compare the results of the Danish LCA analysis with these numbers. Here we see that the GWP reductions are between 50 and 300 kg CO_2eq./m² and the NR-PE reductions between 50 and 350 kWh/m². In other words the GWP reductions of the beyond NZEB building compared to the minimum EP in Denmark are of the same size as that from the embedded energy in the construction (incl. the technical building systems). This corresponds very well with the general understanding in Denmark today that the energy used for new construction is at the same level as the energy used over a 30-year period. The reduced NR-PE is about one fourth of the used NR-PE under construction of new buildings.

The next comparison is to the GWP of different transportation means. Figure 10 shows the GWP for 1000 person-km using different transportation means.

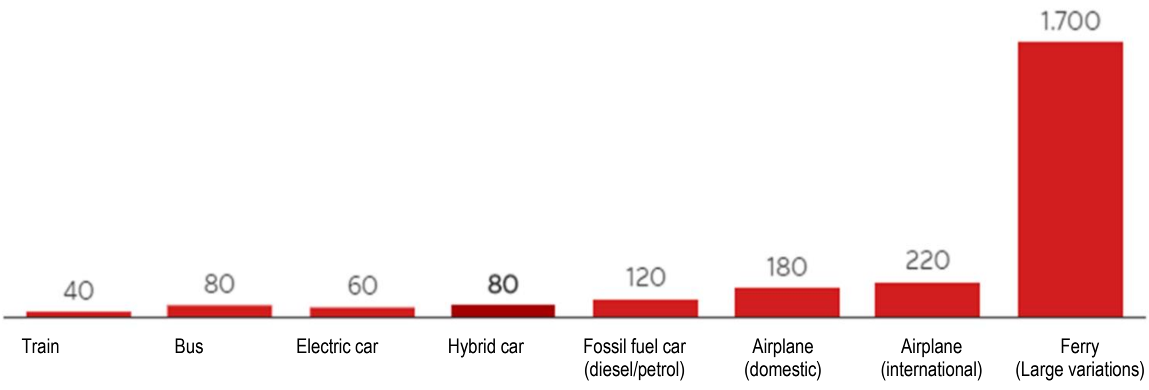

Fig. 10: GWP (kg CO_2eq./1000 person-km) for different transportation means (source: CONCITO)

From figure 10 it can be seen that 1000 person-km in a traditional fossil fuel-car results in the emission of 120 kg CO_2 eq. The annual GWP reductions from the Danish beyond NZEB example building (12 flats) thus corresponds to 6369 person-km in a fossil fuel car.

The third comparison is to the growing of trees. 1,000 m² forest results in GWP reductions of approx. 1,000 kg CO_2eq./year or 1 m² ~ 1 kg CO_2eq./year. So, the 286.6 kg CO_2eq./m² reductions of the Danish beyond NZEB houses over 30 years could also have been obtained by increasing the forest area by 286.65/30 = 9.55 m² * 80 (size of the flat, m²) =764 m² of forest for 30 years..

Looking at the LCC results, they show – as mentioned above – large variations. From 30 year NPV savings of about 100

€/m² to no additional costs. Annually, this is around 240 € for an 80 m² flat (20 €/month) – still a considerable amount. But in some cases the additional cost (NPV) is rather limited and in the light of potential new carbon taxes being introduced soon in EU member states, these low additional costs should be acceptable when building new multi-family houses.

The impact of evolving factors like changing primary energy factors, technology efficiencies, technology costs and possible carbon taxes were studied in another task of the CONZEBs project and has been documented in a project report https://www.conzebs.eu/index.php/thinking-ahead.

6. Acknowledgements

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7. References

Erhorn- Kluttig H, Erhorn H, Utesch B, Wittchen KB, Thomsen KE, Mørck O, Baslev- Olsen O, Jungshoved M, Zinzi M, Mattoni B, Šijanec- Zavrl M, Varšek D. 2017. Overview of Cost Baselines for three Building Levels. Located at: www.conzebs.eu.

Gutierrez MSM, Mørck O, Thomsen KE, Wittchen KB, Illner M, Erhorn-Kluttig H, Erhorn H, Mattoni B, Zinzi M, Jaćimović M, Šijanec-Zavrl M. 2019. Life cycle assessment of typical multi-family with different energy performance levels. Located at: www.conzebs.eu.

Mørck O, Romeo R. & Zinzi M. 2015. On the implementation of an innovative energy/financial optimization tool and its application for technology screening within the EU-project School of the Future. 6th International Building Physics Conference, IBPC 2015.

Wittchen KB, Thomsen KE, Mørck O, Gutierrez MSM, Balslev-Olesen O, Illner M, Erhorn-Kluttig H, Erhorn H, Zinzi M, Mattoni B, Šijanec-Zavrl M, Jačimović M, Gjerkeš H. 2018. Solution sets and technologies for NZEBs. Located at: www.conzebs.eu.