Solution sets for the Cost reduction of new Nearly Zero-Energy Buildings – CoNZEBs

EU H2020-EE-2016-CSA

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Life cycle assessment of typical multi-family houses with different energy performance levels

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CoNZEBs
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Content

About CoNZEBs

This report is one of the outcomes of the work within CoNZEBs. CoNZEBs is a EU Horizon 2020 project on the topic 'Cost reduction of new Nearly Zero-Energy buildings' (call H2020-EE-2016-CSA, topic EE-13-2016). As such it receives co-funding by the European Union under the Grant Agreement No. 750046. The project period is from 01/06/17 to 30/11/19.

The planned work can be summarised as follows:

CoNZEBs identifies and assesses 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. Close cooperation with housing associations allows for an intensive interaction with stakeholders and tenants. The project starts by setting baseline costs for conventional new buildings, currently available NZEBs and buildings that go beyond the NZEB level based on the experience of the consortium. It analyses planning and construction processes to identify possible cost reductions.

An investigation of end-users' experiences and expectations together with a guide on co-benefits of NZEBs promotes living in these buildings and enhances the energy performance by conducive user behaviour.

The technology solution sets include approaches that can reduce costs for installations or generation systems, pre-fabrication and construction acceleration, local low temperature district heating including RES, and many more. All solution sets are assessed regarding cost savings, energy performance and applicability in multi-family houses. A life cycle assessment of different building levels and NZEBs using the solution sets provides a longer term perspective.

Communication to stakeholders and dissemination of the project results includes events and discussions with the national housing associations.

The CoNZEBs project team consists of 9 organisations from 4 different countries:

Table 1: Project partners within the CoNZEBs consortium

Project partner		Country	Website
1	Fraunhofer Institute for Building Physics (Coordinator)	Germany	www.ibp.fraunhofer.de
2	Aalborg Universitet	Denmark	www.sbi.aau.dk
3	Kuben Management AS	Denmark	http://kubenman.dk
4	Agenzia Nazionale per le Nuove Tecnologie, l'Energia e lo Sviluppo Economico Sostenibile (ENEA)	Italy	www.enea.it/en
5	Gradbeni Institut ZRMK doo	Slovenia	www.gi-zrmk.si/en
6	ABG Frankfurt Holding Wohnungsbau- und Beteiligungsgesellschaft mit beschränkter Haftung	Germany	www.abg-fh.com
7	Boligselskabernes Landforening (BL)	Denmark	www.bl.dk/in-english
8	Azienda Casa Emilia Romagna della Provincia die Reggio Emilia (ACER Reggio Emilia)	Italy	www.acer.re.it
9	Stanovanjski Sklad Republike Slovenije, Javni Sklad (SSRS)	Slovenia	http://ssrs.si/

1. Executive summary

This report presents the results of further analyses carried out for the solution sets identified in the previous work of the CoNZEBs project [1]. The solutions sets have been analysed to establish their life cycle costs (LCC) and life cycle environmental impact assessment (LCA). The solution sets have been assumed implemented for NZEB buildings and the results of the LCC and LCA analyses compared to those obtained for conventional buildings built according to current national building regulations (BR) (minimum energy performance requirements = min. EP), conventional built NZEB and buildings beyond NZEB (ZEB and plus-energy buildings).

In short the objectives of this work has been to provide essential life cycle performance (LCC and LCA) comparisons and results in addition to the energy and investment cost information obtained in the previous work [1]. For this work we have selected the global warming potential (GWP) parameter $CO_{2equivalent}$-emissions (kg $CO_{2eq.}$/m²) and the non-renewable primary energy (NR-PE) use in kWh/m² over a 30 years period as the essential LCA-parameters to compare. For the LCC calculations the results have been expressed in net present values (NPV) in Euros/m². For the square meters used there is a difference between the four countries based on national traditions. In Germany, Slovenia and Italy the net floor area (NFA) is used and for Denmark the gross floor area (GFA).

Results have been obtained for a considerable number of combinations and comparisons. All solution sets have been compared to as well min. EP and typical NZEB buildings. Beyond NZEB buildings have been compared to min. EP and typical NZEB and also to the range of results of the calculations of the solution sets. All calculations have been carried out for 5 climates representing Denmark, Germany, Slovenia, Italy –Rome and Italy –Turin. Most of the results are presented in the national (climate specific for Italy) chapters, but the individual comparisons, where the typical NZEB, solutions sets and beyond NZEB are compared to the min. EP buildings are presented in the Appendix 9.2 without comments.

The solution sets for NZEB buildings presenting lower investment costs than the typical NZEB in each location have been presented in detail in the previous report of the CoNZEBs project [1]. In this report they are briefly presented in each national/climate chapter. The solutions constituting the selected solution sets are quite different for each location. For Denmark they comprise: change of insulation material, shift to 4-layer windows, reduced insulation in the building envelope, energy efficient water taps, heat recovery from the grey waste water, natural ventilation, PV- and solar heating systems. The German solution sets are based on alternative heating and ventilation systems compared to the base system gas condensing boiler with solar thermal support and mechanical exhaust ventilation and include: decentral direct electric heating and DHW system, central air heating system by air-to-air heat pump, district heating and a combination of exhaust-air water heat pump and gas condensing boiler. 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 Slovenia new technologies taken into consideration are: air/water heat pump, decentralised hygro-sensible ventilation and opposite to Denmark and Germany: additional insulation in the building envelope. In Italy – Rome and Turin – other new technologies are: autoclaved concrete brick with increased insulation in the façade and monoblock 2-layer windows. This is quite a large variation of technologies combined in different solution sets. Therefore, to really understand the background of the results it is recommended to study each national/climate chapter carefully.

Before presenting a selection of results from the national chapters it is necessary to mention that the factors used to calculate GWP and NR-PE are quite different for the four countries in question. These factors primarily reflects the present energy supply mix in each country. They can be seen in Table 2 in paragraph 2.2, which also holds a detailed description of how the LCA calculations were performed. From the table is can be seen that the NR-PE factor (NR-PEF) for electricity varies between 0.86 (for Denmark) to 2.5 (for Slovenia) – in between lies 1.8 (for Germany) and 1.95 (for Italy). Likewise the used GWP factor for district heating varies between 0.15 kg/kWh (Germany) and 0.25 kg/kWh (Slovenia). This means it becomes additional difficult to compare the results. To begin with it is almost impossible because of the very different construction traditions and different requirements to low-energy buildings (here NZEB) in the different countries. Therefore there has been no attempt to compare the results from the different countries, but the idea is to present some overall conclusions in this chapter. Also the energy prices used for the LCC analysis varies among the countries – what is actually used can be found at the beginning of each chapter.

To illustrate the main results some of the plots from the national chapters have been selected to be presented here. These are comparison plots for the LCA and LCC results for the typical NZEB, the range obtained for the NZEB solution sets and for beyond NZEB buildings with the min. EP as basis.

The first selection of plots shows the comparison of the GWP for Denmark and Rome – Figure 1 and Figure 2. These two plots are representative for all five plots from the national chapters. All the improved energy performance level buildings show decreased GWP numbers. The ranges are different, as explained above due to both the different factors used and to the different construction traditions and finally to different energy requirements.

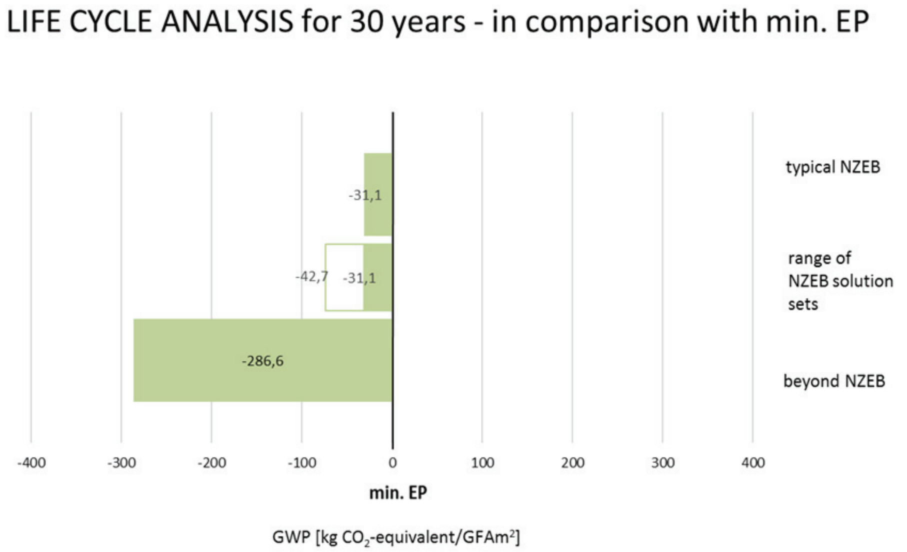

Figure 1: **GWP for the different improved energy performance levels compared to min. EP – Denmark**

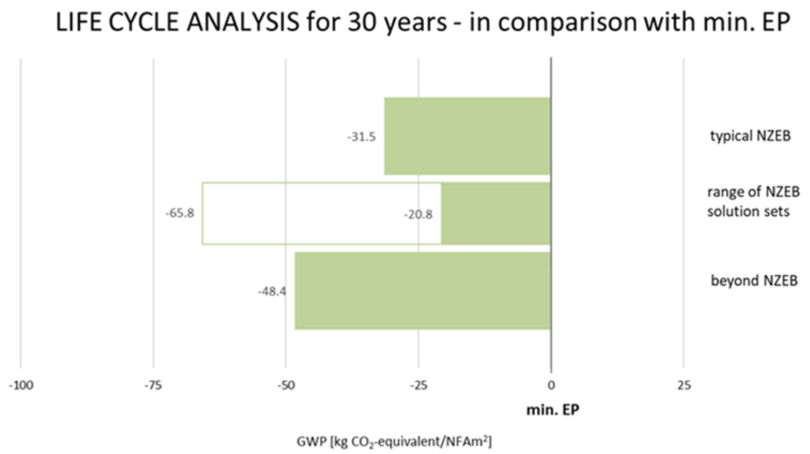

Figure 2: **GWP for the different improved energy performance levels compared to min. EP – Rome**

Similarly, the next two plots represent the results for non-renewable primary energy (NR-PE) from all the five climates. Here results have been selected from Germany - Figure 3 and Slovenia - Figure 4. 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.

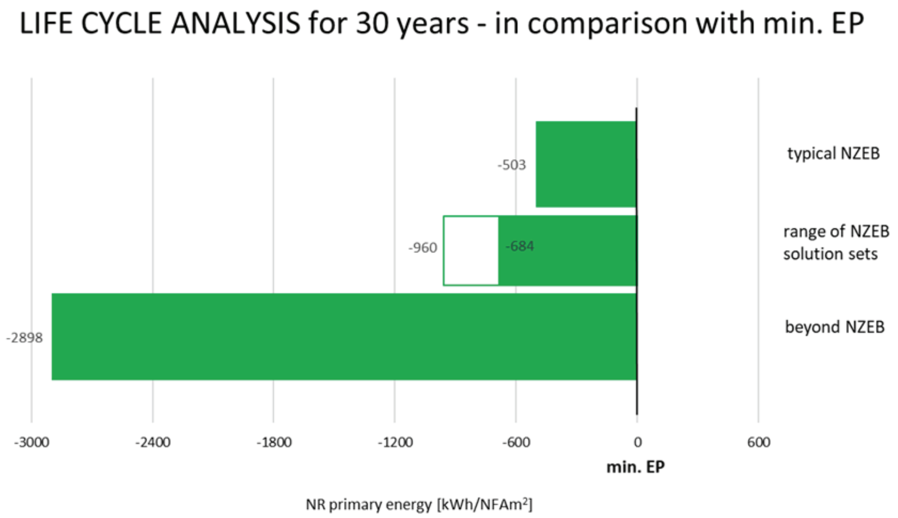

Figure 3: **NR-PE for the different improved energy performance levels compared to min. EP – Germany**

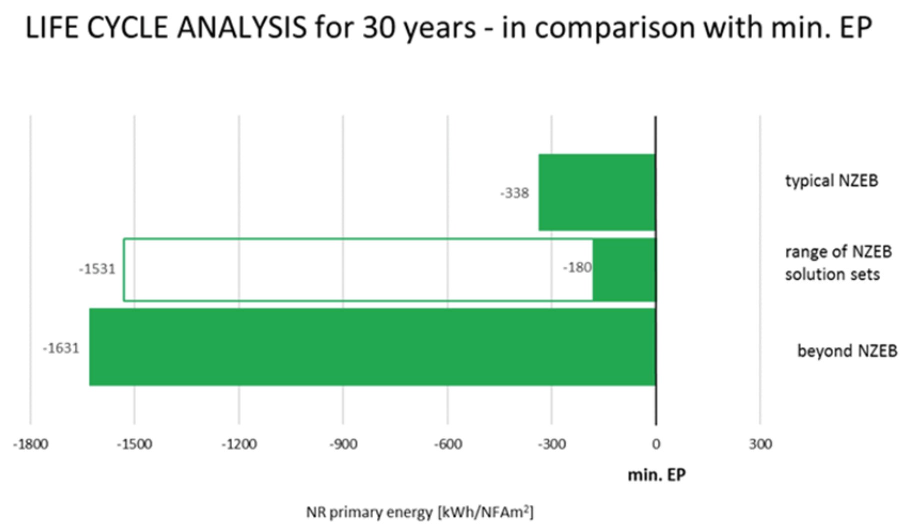

Figure 4: **NR-PE for the different improved energy performance levels compared to min. EP – Slovenia**

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 consumptions compared to the min. EP building levels.

Looking at the LCC results – expressed in net present value (NPV) - there are larger differences between the five locations. Two countries show increased expenses (NPV) for all the improved building levels. They are Slovenia and Germany – see Figure 5. As it can be seen on this figure 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 min. EP buildings, whereas the costs of reaching the beyond NZEB level is too high to be balanced by the financial value of the energy savings. It should be noted here 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 min. EP for all the improved building types (see Figure 63 in chapter 6).

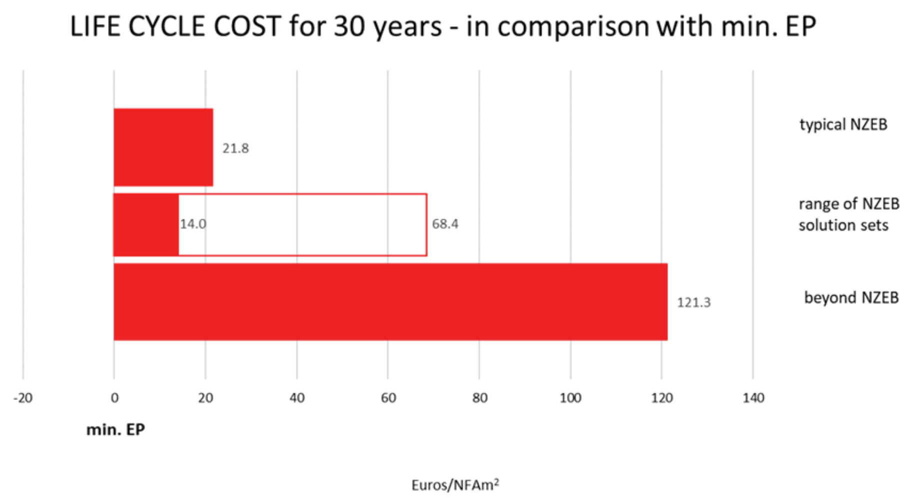

Figure 5: NPV for the different improved energy performance levels compared to min. EP – Germany

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 min. EP building- see Figure 6. However, the typical NZEB and the other solutions sets show higher costs.

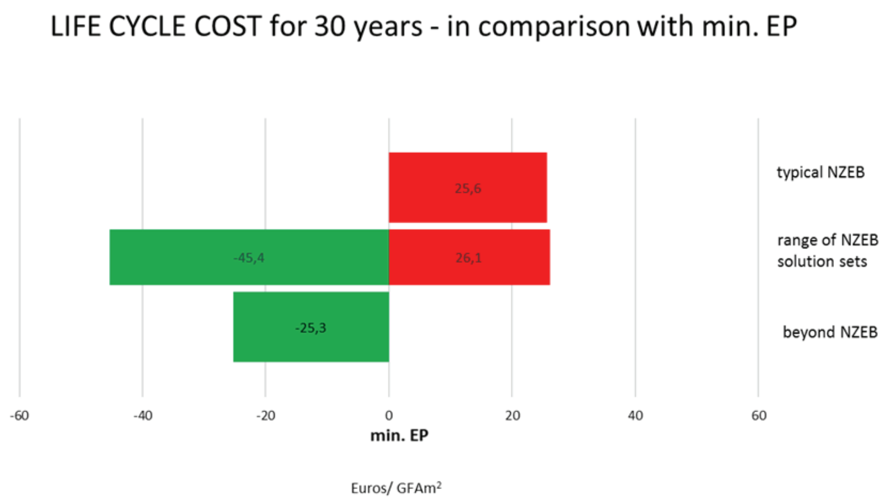

Figure 6: NPV for the different improved energy performance levels compared to min. EP – Denmark

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 min. EP and the typical NZEB almost the same cost – see Figure 7. For the Turin situation only the solution sets show lower total costs than the min. EP building. Both the typical NZEB and the beyond NZEB buildings have higher costs – see Figure 8.

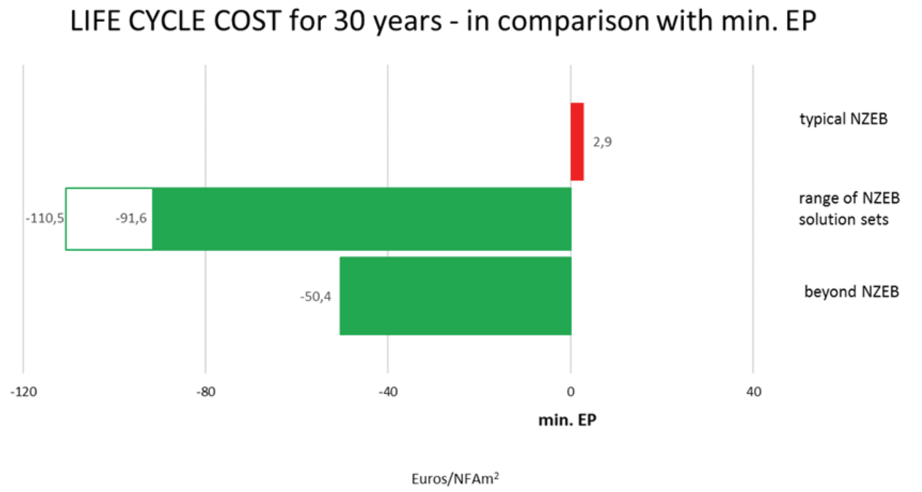

Figure 7: **NPV for the different improved energy performance levels compared to min. EP – Rome**

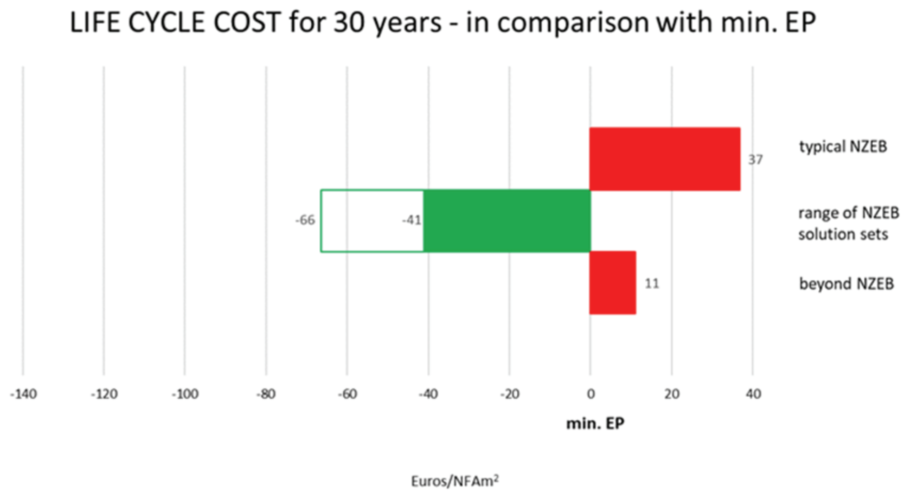

Figure 8 NPV for the different improved energy performance levels compared to min. EP – Turin

To summarise: All improved energy performance levels show clearly improved environmental results compared to the min. EP building levels in all locations. The picture is more varied looking at the total costs from the LCC analysis. For Slovenia and Germany it doesn't pay off at this moment, whereas in the other three locations some of the solutions also show good financial results.

How much does it mean?

The reductions of GWP and NR-PE are difficult to relate to. Here we will try to illustrate the importance by comparing to:

1. The GWP and NR-PE due to the embedded energy in constructing new NZEB buildings in Denmark,
2. The emissions from different transportations means and

3. 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 DGNB-DK certification scheme. From this the total GWP emissions and the NR-PE from the construction phase was found. To serve as a reference here the average for these have been calculated. For the construction itself the GWP was 262.5 $kgCO_{2eq.}/m^2$ and the NR-PE: 1,350 kWh/m^2 (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 $kgCO_{2eq.}/m^2$ and the NR-PE reductions between 50 and 350 kWh/m^2. In other words the GWP reductions of the beyond NZEB building compared to the min. 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 9 shows the GWP for 1000 person-km using different transportation means.

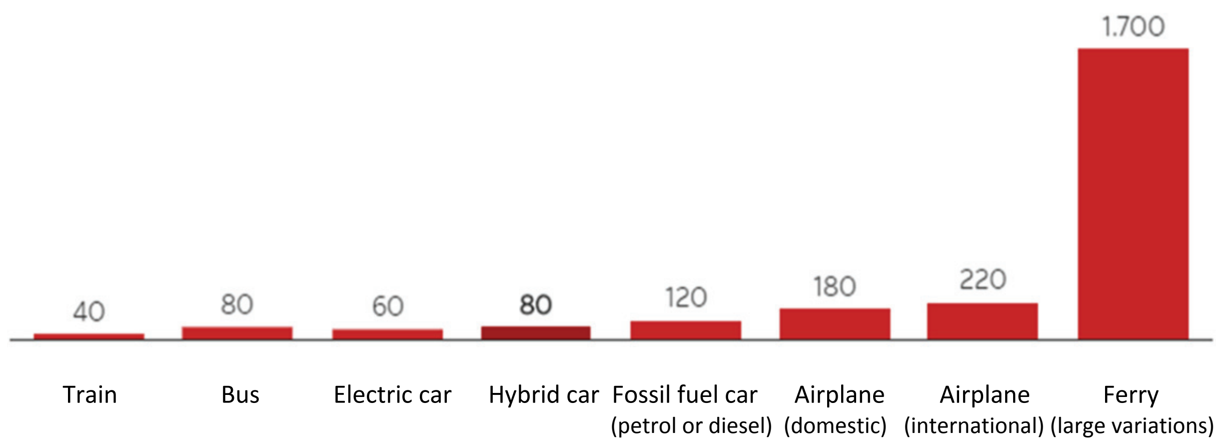

Figure 9: GWP (kgCO2eq./1000 person-km) for different transportation means.

From the figure it can be seen that 1000 person-km in a traditional fossil fuel-car results in the emission of 120 $kgCO_{2eq}$. The yearly GWP reductions from the Danish beyond NZEB example thus corresponds to 6369 person-km in a fossil fuel car.

The third comparison is to the growing of trees. 1,000 m^2 forest results in GWP reductions of approx. 1,000 kg $kgCO_{2eq}/yr$ or 1 m^2~1 $kgCO_{2eq}/yr$. So, the 286.6 $kgCO_{2eq.}/m^2$ reductions of the Danish beyond NZEB houses over 30 years could also have been obtained by having a forest of 286.65/30 = 9.55 m² * 80 (size of the apartment, m²) =764 m² of forest for 30 years.

Looking at the LCC results they show – as mentioned above – large variations. From savings of about 100 €/m² to additional costs of the same size. We are speaking of NPV over 30 years. Per year this is around 240 € for an 80 m² apartment (20 €/month) – still a considerable amount. But in some cases the additional cost (NPV) is rather limited and in light of new carbon taxes potentially being be introduced soon in the EU member states these low additional costs should be accepted when building new multi-family houses.

The impact of evolving factors like changing primary energy factors, technology efficiencies, technology costs and possible carbon taxes are studied in another task of the CONZEBs project and will be documented in another project report.

2. Introduction

This report presents the results of further analyses carried out for the solution sets identified in the previous work of the CoNZEBs project [1]. The solutions sets have now been analysed to establish their life cycle costs (LCC) and life cycle environmental impact assessment (LCA). The solution sets have been assumed implemented for NZEB buildings and the results of the LCC and LCA analyses compared to those obtained for conventional buildings built according to current national building regulations (minimum energy performance requirements = min. EP), conventional built NZEB and buildings beyond NZEB (ZEB and plus-energy buildings).

In short the objectives of this work has been to:

- Provide essential life cycle performance (LCC and LCA) comparisons and results in addition to the energy and investment cost information obtained in the previous work in the CoNZEBs project.

2.1. Description of the work and the tools used

The work comprised LCC and LCA assessments of the four different typical buildings identified for the four countries. This work has been carried out using the ASCOT_LCA tool that combines the energy performance assessment as defined in the Danish implementation of the EPBD with LCC and LCA assessments. For Denmark ASCOT_LCA has been used in full both for the energy performance assessments and for the LCC and LCA assessments. For the other countries, the energy performance calculations have been performed using national tools and then these results have been used further for the operation phase LCC and LCA calculations in ASCOT_LCA.

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).

2.2. LCA calculations method

The LCA calculations in this report cover the two most important phases out of the five phases a building component can be considered to have: Production and use – framed with red on Figure 10.

Product Stage			Construction Process Stage		Use Stage							End-of-Life				Next Product System
Raw material supply	Transport to manufacturer	Manufacturing	Transport to building site	Installation into building	Use /application	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction /demolition	Transport to EoL	Waste processing	Disposal	Reuse, recovery or recycling potential

Figure 10: **LCA phases [2]**

Generally, the input values/parameters to use for the LCA calculation in these phases are available in each country. Below is an overview of how the input to the two phases has been handled for each country.

<u>Product stage</u>: The material production.

- Germany: Öbaudat (German database), accessible via https://www.oekobaudat.de/en.html) and manufacturer information
- Denmark: Ökobaudat is directly used in the Danish implementation of DGNB, so in a way adopted as a “Danish” database.
- Italy: European values (EU28) and ökobaudat (German database for the material not found in EU28)
- Slovenia: European values (EU28) and ökobaudat (German database for the material not found in EU28)

<u>Use stage</u>: Building use in 30 years.

Final and NR-PE values: National calculation results as presented in [1], provided by the national teams. These are presented in each national chapter below.

Environmental loads analyzed

In a life cycle analysis, the following environmental loads are generally assessed. However, for this work it has been decided to focus on two of these: Non-renewable primary energy (NR-PE) consumption and global warming potential, known as $CO_{2,\ eq.}$ emissions – marked with a red frame below.

- Resource consumption – primary energy (PE):

- Non-renewable primary energy consumption (NR-PE), kWh/m²
- Renewable primary energy consumption (PE), kWh/m²

- Environmental loads from emission to air, soil and water
  - Global warming potential (GWP), kg CO_2-Equivalent emissions
  - Ozone depletion potential (ODP), kg R11-Equiv.
  - Photochemical ozone creation potential (POCP), kg Ethene-Equiv.
  - Acidification potential (AP), kg SO_2-Equiv.
  - Eutrophication potential (EP), kg Phosphate-Equiv.
  - Abiotic Depletion (ADP elements), kg Sb-Equiv.

Both the NR-PE factor (NR-PEF) and GWP emission during the use phase are provided by national CoNZEBs team. An overview of these factors is presented in Table 2.

Table 2: NR-PE factor and GWP values used for the use phase calculation for each country

Energy source	NR-PEF [kWh/kWh]	GWP $CO_{2\text{-Equivalent}}$ [kg/kWh]	Source	Comments
District heating. DK	0.46	0.248	Statens Byggeforsk-ningsinstitut - SBi	https://sbi.dk/Pages/Energifaktorer-ved-energiberegning.aspx#s=aggerholm
Electricity. DK	0.86	0.649		
District heating. DE	0.7	0.1517	DIN V 18599	NR-PE taken from DIN V 18599 GWP is taken from GEMIS (100% CHP made of natural gas)
Natural gas. DE	1.1	0.24	DIN V 18599	
Electricity. DE	1.8	0.55	DIN V 18599	
District heating. SI	1.0	0.254	PURES 2010	https://ceu.ijs.si/izpusti-co2-tgp-na-enoto-elektricne-energije/
Natural gas. SI	1.1	0.237	PURES 2010	
Electricity. SI	2.5	0.602	PURES 2010	
Natural gas. IT	1.05	0.200	DM 26/05/2015	NR-PE taken from DM 26/05/2015 GWP is taken from ISPRA https://www.google.com/search?q=cache:wc9y7MW3CJwJ:www.sinanet.isprambiente.it/it/sia-ispra/serie-storiche-emissioni/fattori-di-emissione-per-la-produzione-ed-il-consumo-di-energia-elettrica-in-italia/at_download/file+&cd=3&hl=it&ct=clnk&gl=it http://www.sinanet.isprambiente.it/it/sia-ispra/serie-storiche-emissioni/fattori-di-emissione-per-le-sorgenti-di-combustione-stazionarie-in-italia/view
Electricity. IT	1.95	0.445	DM 26/05/2015	

The NR-PE factor (NR-PEF) should not be confused with the Primary Energy (PE) factor, which for some countries e.g. Denmark is used in the national building regulations to define the maximum energy demand according to the implementation of the EU Energy Performance Directive. In the previous work [1] of the CoNZEBs project Denmark used the PE factor for the calculations of the primary energy demand.

2.3. LCC calculation method

The life cycle analysis as calculated for this work is resulting in the total net present value (NPV) of the implementation of the solutions over a fixed period of 30 years using a macro-economic perspective.

The total NPV is calculated by the following formula:

Total NPV = Investment –Energy savings + Maintenance + Replacement (incl. residual value)

Where:

- Investment is the investment cost of the implementation of the technologies
- Energy savings is NPV of savings over 30 years by the implementation of the technologies.
- Maintenance is the NPV of the maintenance cost of the technologies as represented by a percentage of each individual technology investment cost. Maintenance cost includes servicing and inspections.
- Replacement is the NPV of the replacement cost of the technologies as represented by a percentage of each individual technology investment cost plus the residual value of the technology after 30 years into its life time.

The LCA and LCC results evaluated in a 30 years period are presented for each CoNZEBs country in the following chapters. In the national chapters of the main report all solution sets are compared to the typical NZEB. Also buildings beyond NZEB are compared to the typical NZEB and in Appendix 9.2 all solutions sets, typical NZEB and buildings beyond NZEB are compared to the min. EP. Thus in the national chapters the typical NZEB is the reference value and in the appendix the min. EP is the reference value. The results given for the NZEB solution sets or the beyond NZEB buildings are higher or lower values comparing to the reference value. This means that a lower result than the reference value is presented as negative value (-) – meaning either a lower environmental load for the LCA-calculations or lower life-cycle costs for the LCC-calculations. Oppositely, higher results are presented as plus values (+), which means higher environmental loads or higher life cycle costs, respectively. The green colours show better results, and red colours show worse results compared to the reference values.

The input used for LCA & LCC analyses for each country can be found in detail in Appendix 9.1.

3. The basis for the calculations and the approach used for presenting the results

The calculations have been performed for typical multifamily houses in the four participating countries for the following three building energy performance levels:

- Minimum energy performance requirements (min. EP)
- Nearly zero-energy building (NZEB): typical NZEB plus identified alternative NZEB solution sets
- Beyond NZEB: net zero energy buildings for Denmark, Italy and Slovenia, net plus energy building incl. user electricity for Germany (Efficiency House Plus standard)

For each country the results are presented in the same order:

1. For typical NZEB and beyond NZEB with min. EP as basis for the comparison
2. For each NZEB solution set with typical NZEB as basis
3. For typical NZEB and NZEB solution sets with min. EP as basis
4. For typical NZEB, range of NZEB solution sets + beyond NZEB with min. EP as basis.

4. Buildings in Denmark

The typical Danish multi-family house is a building of four floors with two flats at each floor in a stairwell and a minimum of three stairwells. The typical flat has a size of 80 m² heated gross floor area (GFA) (incl. external walls and stairwells) (~72.05 m² NFA). The building envelope comprises a prefabricated concrete inner facade leaf with substantial insulation, and an external brick shell. The roof is flat (sloping minimum 4 °) with roofing felt and there is no basement. Most multi-family residential buildings in Denmark are connected to a district-heating grid for both space heating and domestic hot water and without local production of renewable energy. All energy values and cost values in the Danish buildings are related to the gross floor area.

The min. EP version of this building fulfills the legal requirement for maximum primary energy use, U-values and transmission losses of building envelope, and other requirements for airtightness, installations and indoor climate conditions.

4.1. Building energy levels with parameters

Energy requirements covers the building's total energy need for heating, ventilation, cooling and hot water. The energy requirement is weighted according to the primary energy used. In Denmark the Danish Building Regulations (BR18) prescribes primary energy factors of 1.90 and 0.85 for electricity and district heating, respectively. The maximum primary energy use for residential buildings is given by this expression: 30 + 1000/GFA kWh/(m²yr).

In BR18 there is also a limitation on the electricity production from renewable energy plants such as solar cells and wind turbines, corresponding to a reduction in the energy building needs. The allowed maximum primary energy contribution from renewable energy generated electricity into the energy calculations is 25 kWh/m² per year.

In Denmark, it has been decided to define a NZEB building class as a voluntary low energy class (lavenergiklasse) in the BR18. The maximum energy performance requirement for this low energy building class is 27 kWh/(m²yr) primary energy.

For Denmark beyond NZEB is defined in this context as “0” energy building demand without considering household electricity. A selection of solutions from the solution set for NZEB has been used to step up to the beyond NZEB building. Additional electricity production from photovoltaic panels balances the heating energy demand resulting in a “0” yearly primary energy building demand.

In this case, the limitation of the electricity production is not taken into account.

The following tables gives an overview of the technologies implemented for each building level:

Table 3: Technologies set overview for each building level

Technologies		Min. EP	Typical NZEB	SS1	SS2	SS3	SS4	SS5	Beyond NZEB
Envelope	Lower lambda value of the insulation			x					
	2-layer windows	x							
	3-layer windows		x	x	x		x	x	x
	4-layer windows					x			
	Reduced insulation in external wall				x		x	x	x
	Reduced insulation in roof				x		x	x	x
	Reduced insulation in floor				x		x	x	x
Technical Building systems	MVHR – centralized with heat recovery, 80%	x							
	MVHR – centralized with heat recovery, 90%		x	x	x				
	MVHR – decentralized with heat recovery, 85%						x	x	x
	Natural ventilation					x			
	Energy efficient water taps						x		x
	HR of gray waste water					x			
Renewable energy systems	PV panels on roof							x	x
	Solar heating				x				

Table 4: Environmental load used for LCA calculation

Energy	PE non-renewable [kWh/kWh (or MJ/MJ)]	GWP, CO_2,eq. [kg/kWh]
District heating, DK	0.464	0.248
Electricity, DK	0.864	0.649

Table 5: Final energy demand used for LCA and LCC calculation

	Final electricity demand [kWh/yr]	Final district heating demand [kWh/yr]	Total final energy demand [kWh/yr]	Total final energy demand [kWh/(GFAm^2 yr)]
min. EP	4,181	59,199	63,379	33.0
typical NZEB	3,068	52,651	55,719	29.0
SS1	3,068	52,651	55,719	29.0
SS2	3,478	50,680	54,158	28.2
SS3	895	56,611	57,506	30.0
SS4	3,085	51,707	54,792	28.5
SS5	331	58,007	58,338	30.4
beyond NZEB	-23,132	51,707	28,549	14.9

Table 6: Non-renewable primary energy demand used for LCA

	Non-renewable primary energy demand: electricity [kWh/yr]	Non-renewable primary energy demand: district heating [kWh/yr]	Total non-renewable primary energy demand [kWh/yr]	Total non-renewable primary energy demand [kWh/(GFAm^2 yr)]
min. EP	3,612	27,468	31,081	16.2
typical NZEB	2,651	24,430	27,081	14.1
SS1	2,651	24,430	27,081	14.1
SS2	3,005	23,516	26,521	13.8
SS3	773	26,268	27,041	14.1
SS4	2,665	23,992	26,657	13.9
SS5	286	26,915	27,201	14.2
beyond NZEB	-19,986	23,992	4,006	2.1

Table 7: Energy cost data used for LCC calculation

Energy cost	Euros/kWh
District heating	0.059
Electricity	0.300

Table 8: Financial figures to calculate the net present value in LCC analyses

Financial figures	Value
Discount rate	5%
Tax of interest income	0%
Inflation of energy: • District heating • Electricity	 0.8%/yr 1.9%/yr
Inflation of maintenance	2%/yr
Expected economic lifetime	30 years

4.2. LCA and LCC analyses comparison of the three building levels

In the following two plots the LCA and LCC assessments of the typical NZEB and the beyond NZEB levels are compared to the min. EP level. From Figure 11 and Figure 12 is appears that the typical NZEB is a good solution from the environmental point of view, but not from the economic point of view, when compared to the results for the min. EP level. The environmental loads (GWP and NR-PE) are in green color, which means that they are lower than those found for the min. EP building. However, the beyond NZEB building is both a more environmentally friendly and a more cost-efficient solution than the min. EP building, due to the economic value of the large energy savings over 30 years for a “zero energy building”.

LIFE CYCLE ANALYSIS for 30 years - in comparison with min. EP

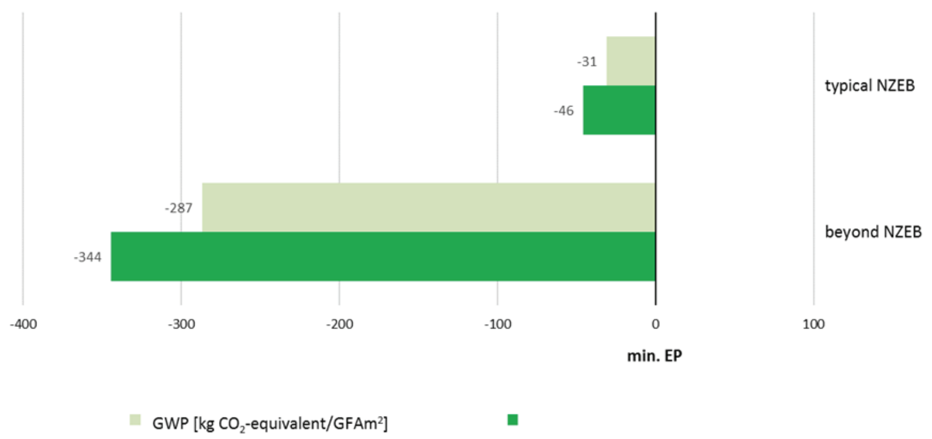

Figure 11: LCA analysis. Typical NZEB and beyond NZEB in comparison with min. EP in a 30 years period.

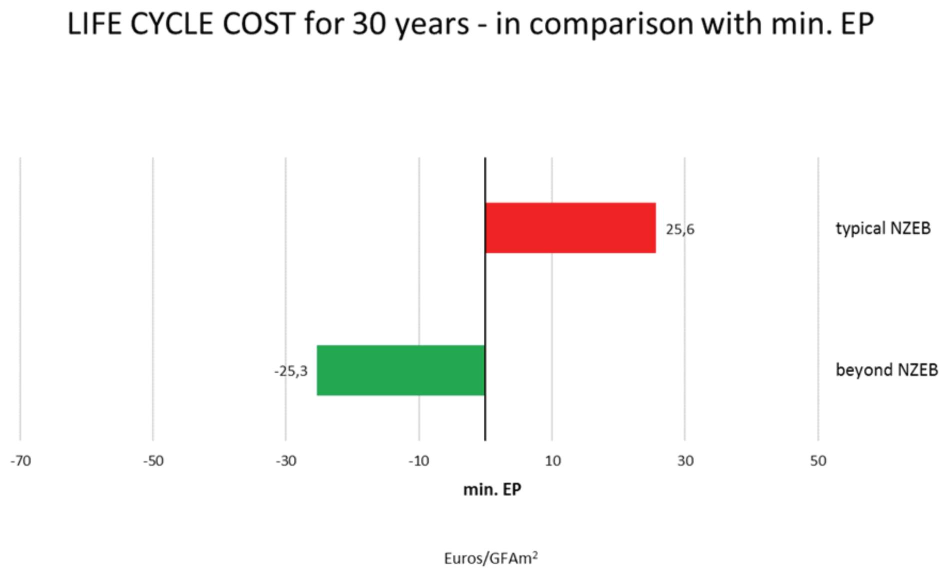

Figure 12: LCC analysis. Typical NZEB and beyond NZEB in comparison with min. EP in a 30 years period (NPV).

4.3. LCA and LCC analyses for each solution set in comparison with typical NZEB

In the previous phase of the CoNZEBs project, it was the goal to find more affordable energy technology solution sets regarding investment costs, than used in a typical NZEB building design. Five solution sets (SS) were identified, which are described in detail in a report [1] and summarised in Table 3. In the following paragraphs the results of the LCA and LCC analyses for each solution set in comparison to the typical NZEB building are presented in detail.

4.3.1. Comparison of SS1 with typical NZEB

For solution set 1, it is suggested to insulate the external walls with phenolic foam insulation, which has a lambda value of 0.02 W/m^{2}K instead of using traditional mineral wool insulation with a lambda value of 0.036 W/m^{2}K. This has no impact on the building energy needs, however it affects the environmental load. See Figure 13 and Figure 14.

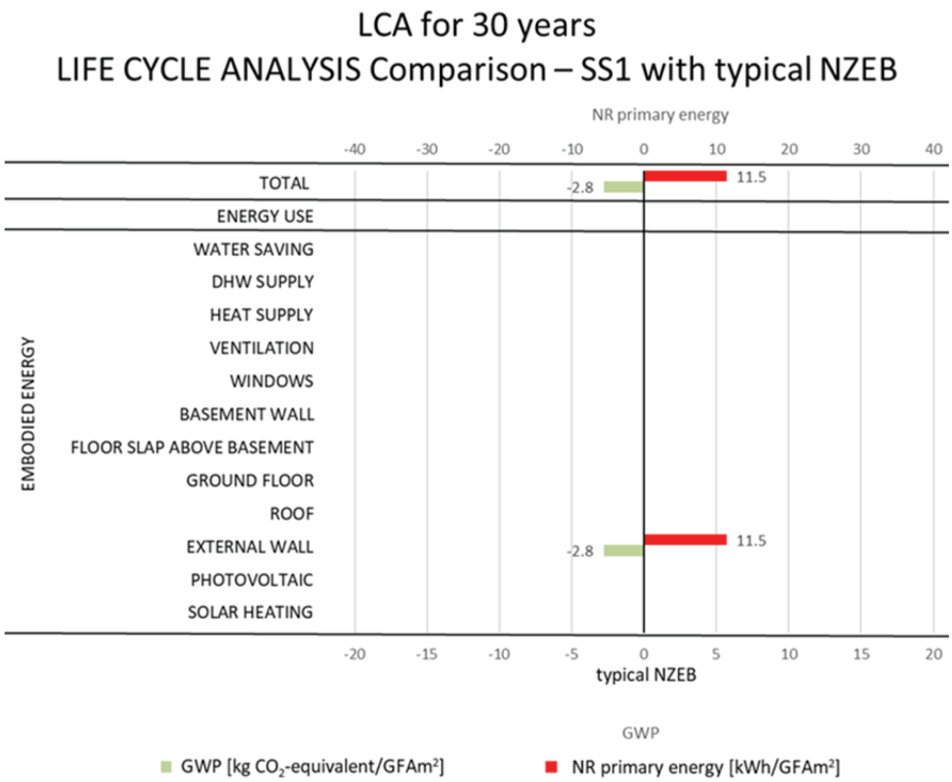

Figure 13: LCA comparison of SS1 with typical NZEB

Summary of the LCA results for SS1:

1. GWP: Phenolic foam insulation generates lower $CO_{2,\,eq.}$ emissions, but it results in higher non-renewable primary energy, due to the way it is produced.
2. Energy use in the operation phase: Identical to that of the typical NZEB

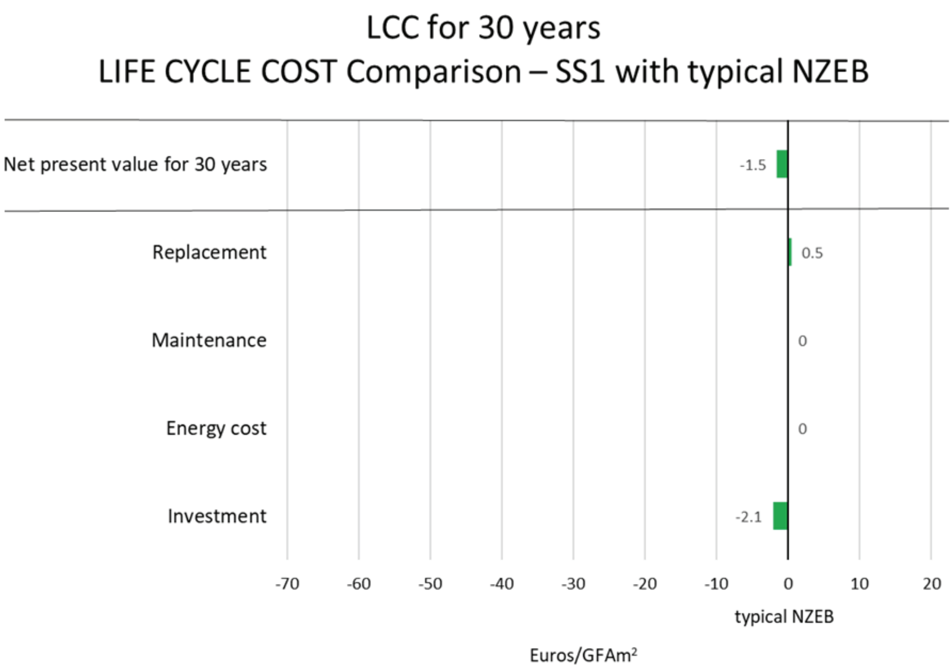

Figure 14: LCC comparison of SS1 with typical NZEB

Summary of the LCC results for SS1:

The use of this product shows improved cost-efficiency, primarily due to the decreased wall thickness, which leads to investment saving for the external wall and foundation of that. Another benefit is that is results in an increased living area.

4.3.2. Comparison of SS2 with typical NZEB

The second solution set is based on the installation of a solar heating system, which makes it possible to reduce the insulation thickness in the building envelope. Overall this solution set leads a good environmental friendly result (see Figure 15).

Summary of the LCA results for SS2:

1. The lower the amount of mineral wool insulation the lower environmental loads are produced at the building envelope components, however a higher environmental load is generated by the implementation of a solar heating system.
2. Additionally, environmental load-saving occurs during the use phase of the building due to reduced energy (NR-PE) use during the 30 years of operation.

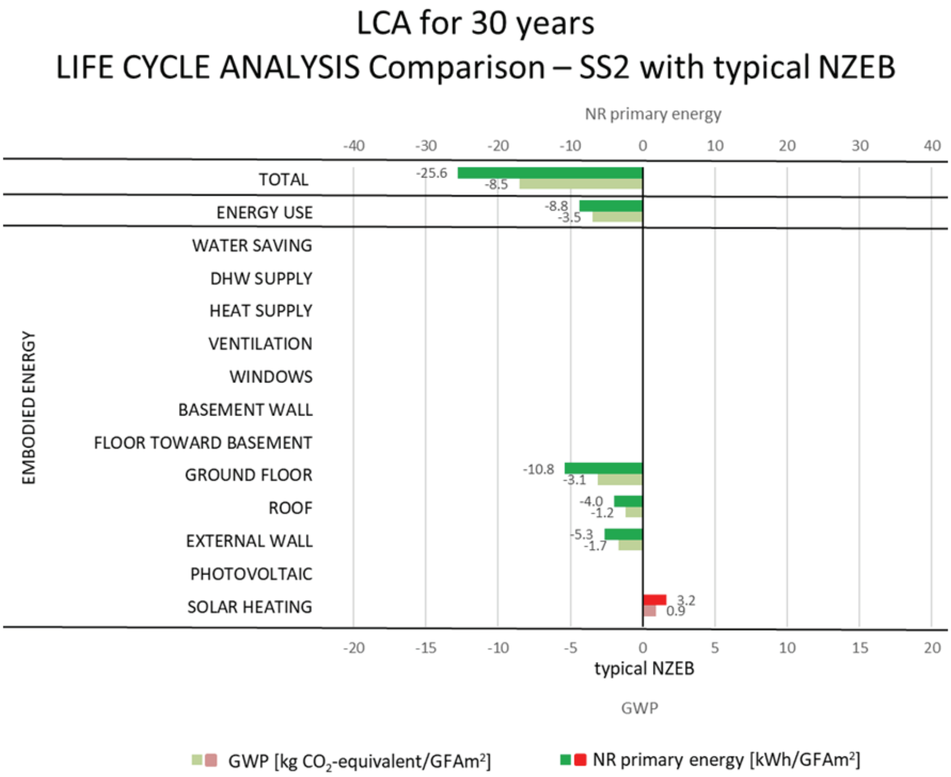

Figure 15: LCA comparison of SS2 with typical NZEB

From the economic point of view, this solution set has a slightly higher NPV. This is due to the following factors:

1. The investment is reduced compared to the typical NZEB
2. However, this reduction is counterbalanced by additional maintenance and replacement costs for the solar heating system (see Figure 16).

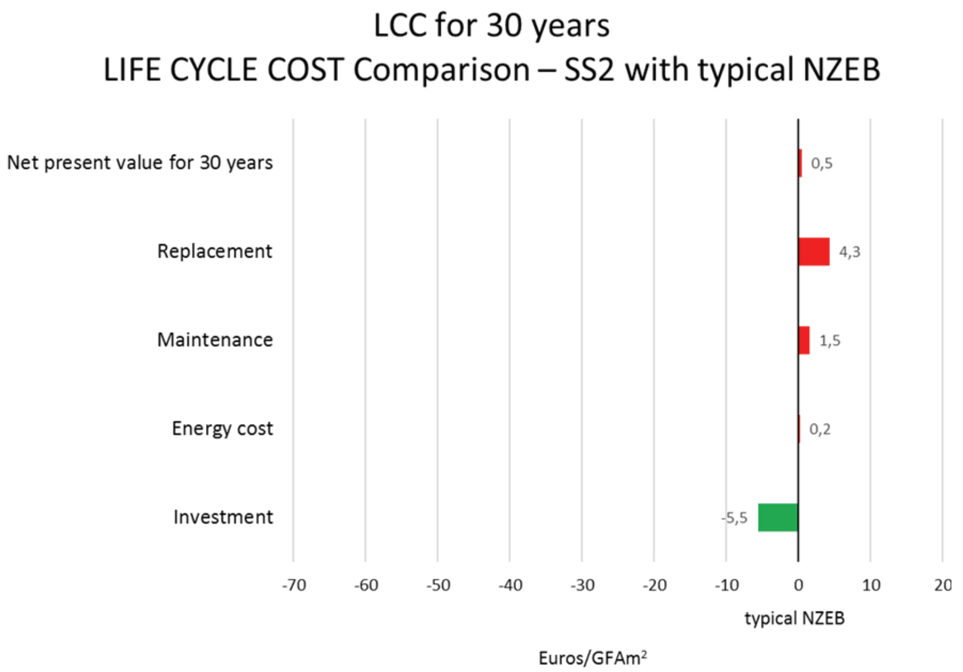

Figure 16: LCC comparison of SS2 with typical NZEB

4.3.3. Comparison of SS3 with typical NZEB

A four-layer window glazing and a non-mechanical (natural) ventilation system primarily define SS3 in relation to the typical NZEB. In spite of the fact that the construction of new residential building in Denmark without mechanical ventilation is not allowed, it was decided to analyse the impact of the MVHR absence.

Summary of the LCA results of SS3:

1. The $CO_{2,eq.}$ emission during the use phase of the building in a 30 year period is lower than for the typical NZEB
2. The implementation of the innovative window gives a negative environmental impact during its production
3. And the absence of mechanical ventilation with heat recovery increase the heating energy use, resulting in an increased total NR-PE load, see Figure 17.

Summary of the LCC results of SS3, see Figure 18:

1. The absence of a MVHR results in high cost savings due to the large investment cost reduction
2. And also maintenance reductions

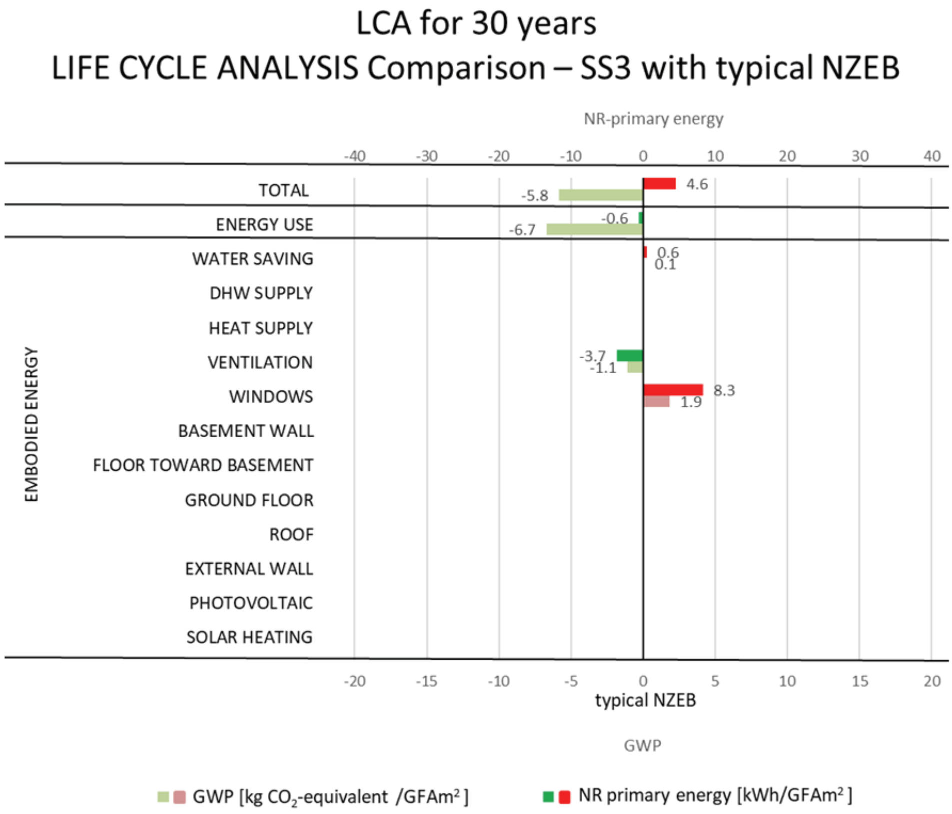

Figure 17: **LCA comparison of SS3 with typical NZEB**

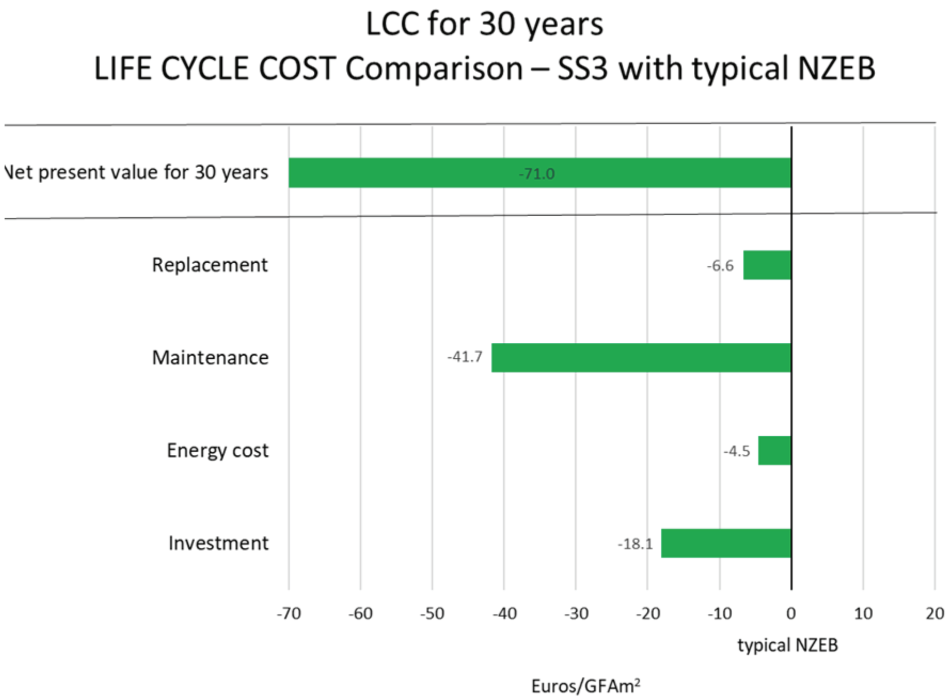

Figure 18: **LCC comparison of SS3 with typical NZEB**

4.3.4. Comparison of SS4 with typical NZEB

SS4 is defined by insulation reductions in the building envelope, water saving taps and the use of decentralized mechanical ventilation systems with heat recovery instead of a traditional centralized system.

Summary of the LCA results of SS4, see Figure 19:

1. The water saving taps has the same environmental loads as conventional taps. Therefore there is no additional load from the production of these.
2. There is considerable reductions in the environmental loads (GWP and NR-PE) from the reduced insulation thicknesses in the building envelope.
3. Thus, in combination both GWP and NR-PE are deduced significantly

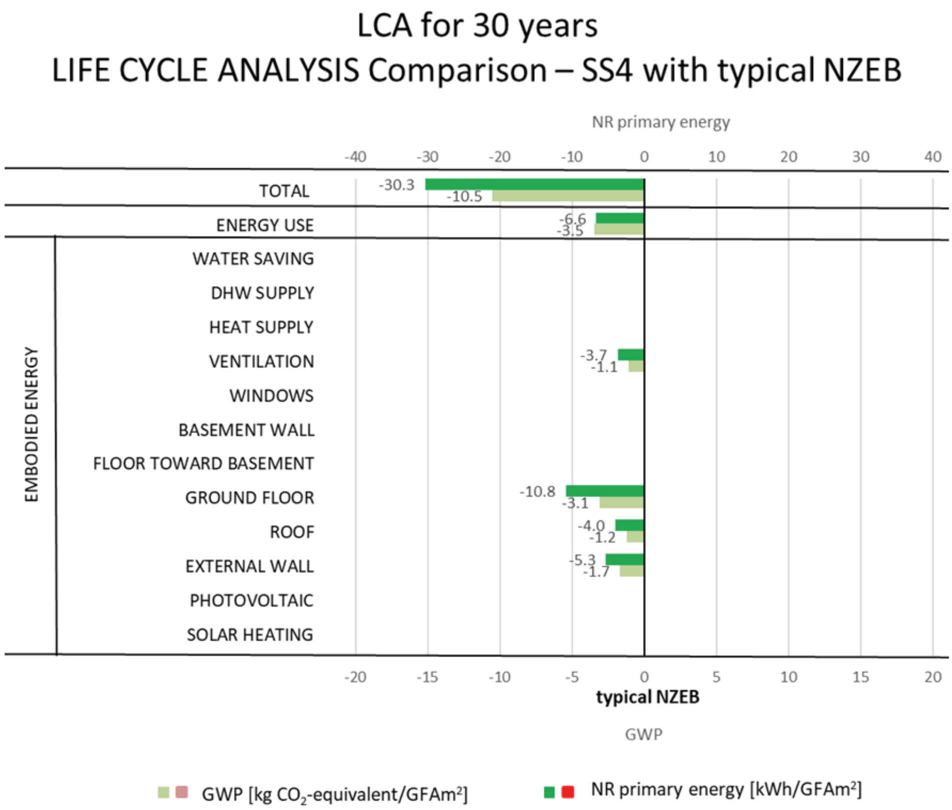

Figure 19: LCA comparison of SS4 with typical NZEB

Summary of the LCC results of SS4, see Figure 20:

1. In spite of the fact that the maintenance cost of decentralized ventilation systems is higher than that of the centralized system, the overall cost are significantly reduced in comparison to a typical NZEB building.

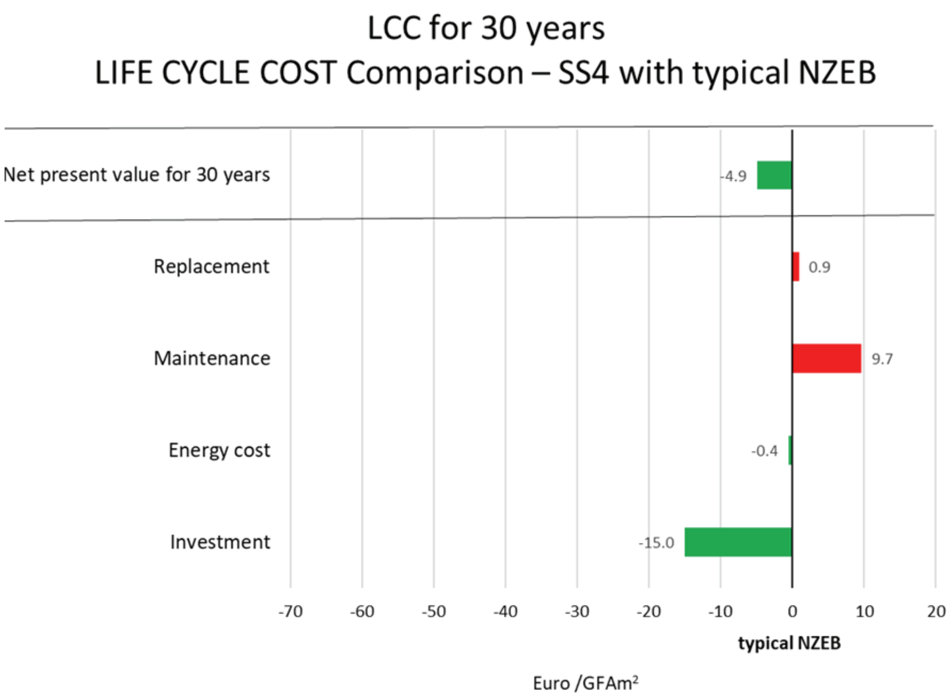

Figure 20: **LCC comparison of SS4 with typical NZEB**

4.3.5. Comparison of SS5 with typical NZEB

The energy supply from the implementation of photovoltaic solar panels (PV) in SS5 is used to lower the insulation thicknesses in the building envelope.

Summary of the LCA results for SS5, see Figure 21:

1. The PV system has a negative environmental impact from its production.
2. The heating demand is higher than for the typical NZEB due to the insulation reductions.
3. However, the insulation reductions in the building envelope gives a positive influence in the environmental loads resulting in an overall reduction of the environmental loads.

Summary of the LCC results for SS5, see Figure 22:

1. The investment costs are reduced
2. The energy use costs are reduced due to the higher price of electricity than that of heating
3. The maintenance and replacement costs (of the PV) are increased,
4. The result is overall reduced costs for this solution set.

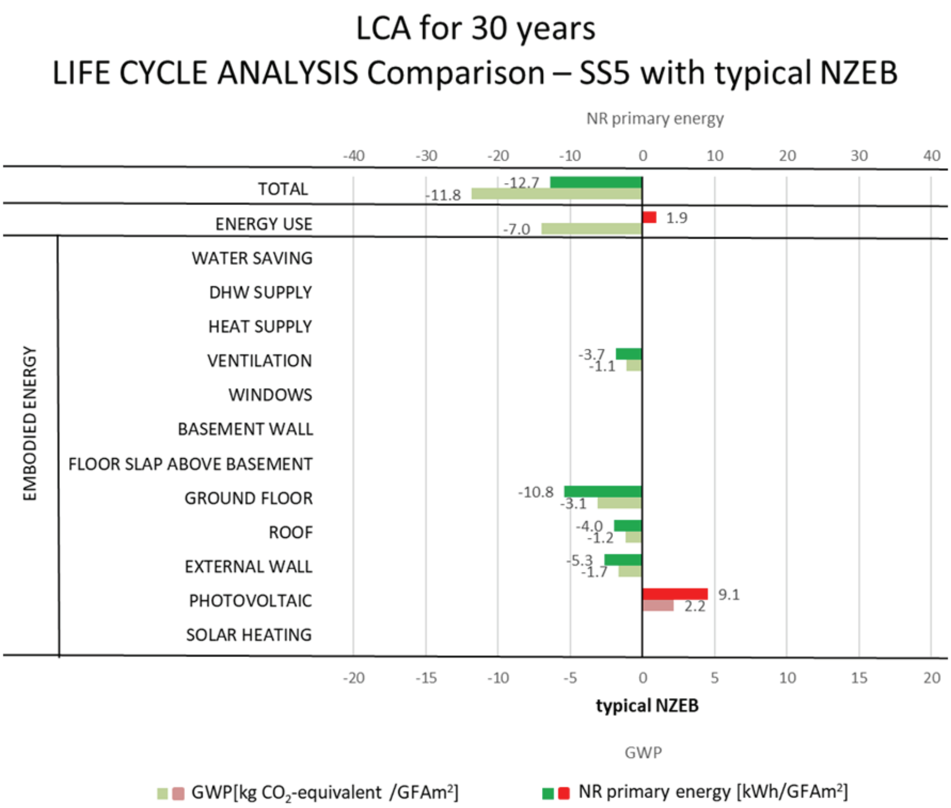

Figure 21: LCA comparison of SS5 with typical NZEB

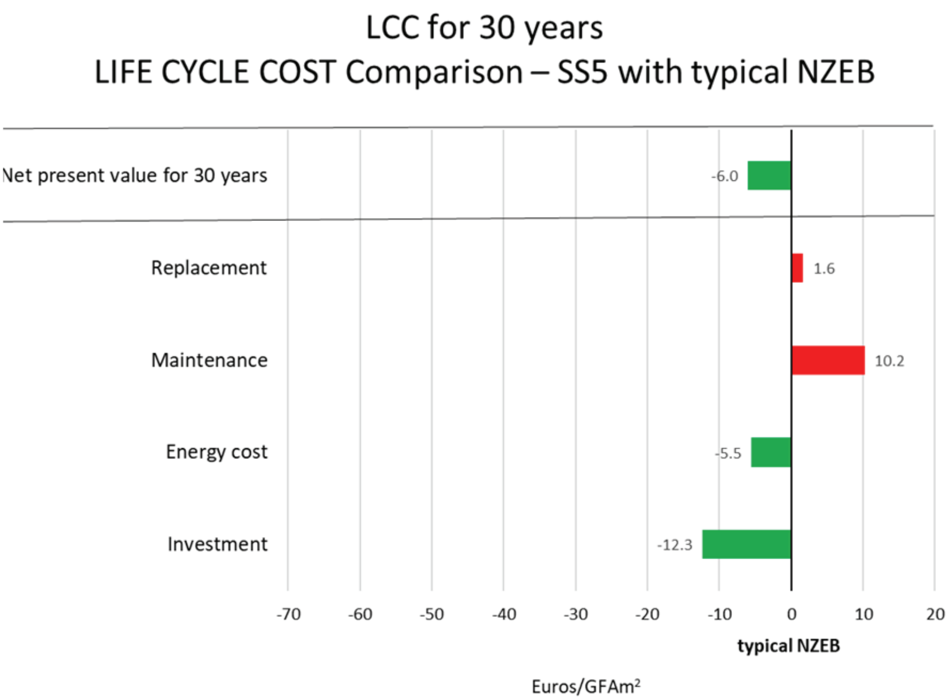

Figure 22: LCC comparison of SS5 with typical NZEB

4.3.6. Summary of investment costs and net present value – in comparison with the typical NZEB

The main objective of this project was to identify alternative solution sets that reduce the investment cost compared to a typical NZEB design. The investment costs and net present value plot in Figure 23 shows that this goal was achieved. The investment costs of all solution sets are lower than the investment cost for the typical NZEB (shown as the reference). The total NPV of four of the solution sets is also better than that of the typical NZEB, which means that all solution sets but SS2 are profit-earning and thus to be preferred by the building owners/tenants.

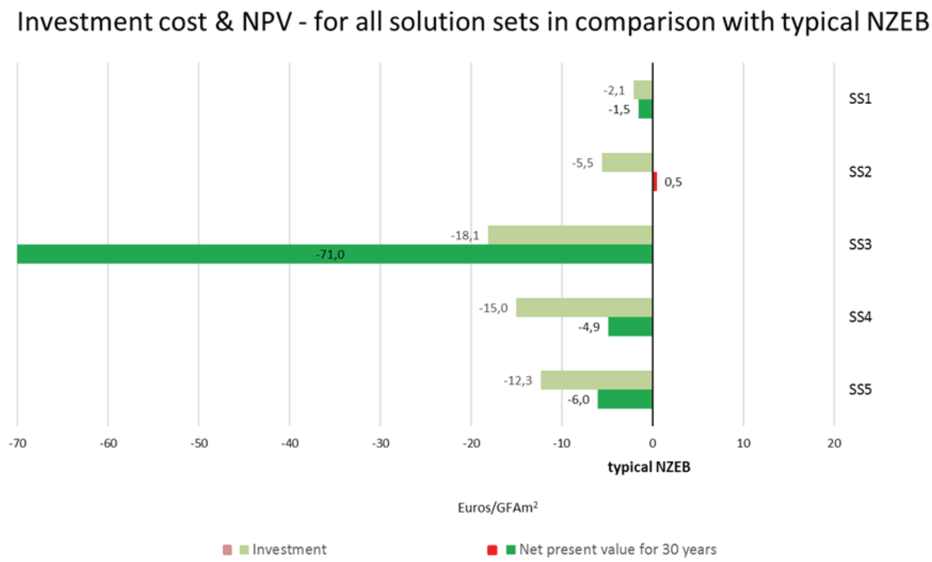

Figure 23: Summary of investment cost and net present value of all solution sets in comparison to typical NZEB

Looking solely at the investment costs the result is shown on Figure 24. This plot shows the same as Figure 23, but includes also the investment costs of buildings built as the min. EP and the beyond NZEB levels.

It appears from this figure that one solution set is has lower investments costs than the min. EP level and the rest, the typical NZEB and the beyond NZEB buildings have higher.

In a way this plot illustrates why it is necessary to perform both the LCA and the LCC analyses to get the full picture. As it was shown on Figure 11 and Figure 12 the beyond NZEB building showed both reduced NPV and environmental loads compared to the min. EP buildings.

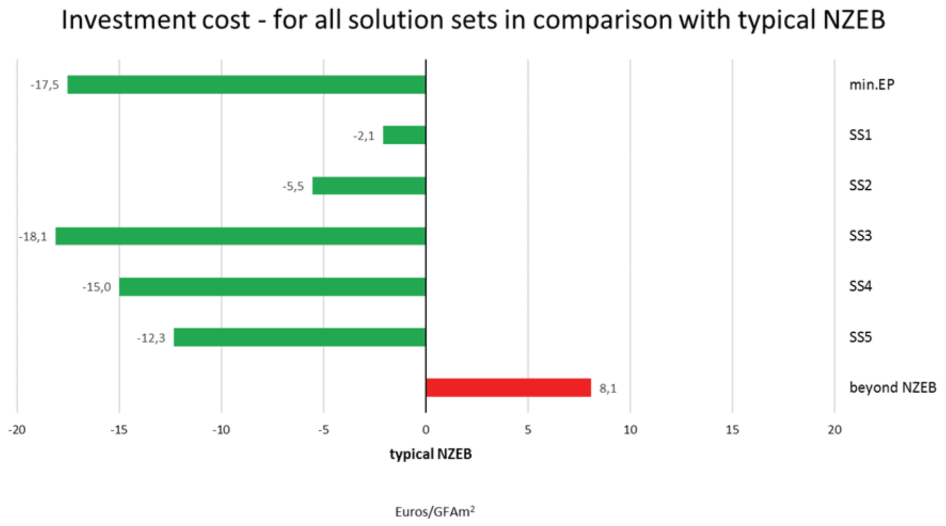

Figure 24: Investment cost overview in comparison with the typical NZEB

4.4. LCA and LCC analyses for the typical NZEB and the alternative NZEB solution sets in comparison with the min. EP building level

In this section the typical NZEB and the more cost-efficient solution sets as alternatives to the typical NZEB are being compared to buildings built according to the current minimum energy performance requirements (min. EP).

It is important to note at this point that the two technologies, implemented to improve the min. EP to the typical NZEB building, are included as the starting point to each alternative NZEB solution set. Table 4 shows these two technologies.

Table 9: Overview of the difference between the min. EP building and the typical NZEB.

	Min. EP	Typical NZEB
Windows	2-layer glazing	3-layer glazing
Ventilation system	MVHR centralized. 80% heat recovery. SEL=1.5 kJ/m³	MVHR centralized. 90% heat recovery. SEL=1.2 kJ/m³

From Figure 25 it can be seen that both the typical NZEB and all solution sets as alternatives to the typical NZEB are more environmental friendly solutions (regarding both GWP and NR-PE) than the min. EP building.

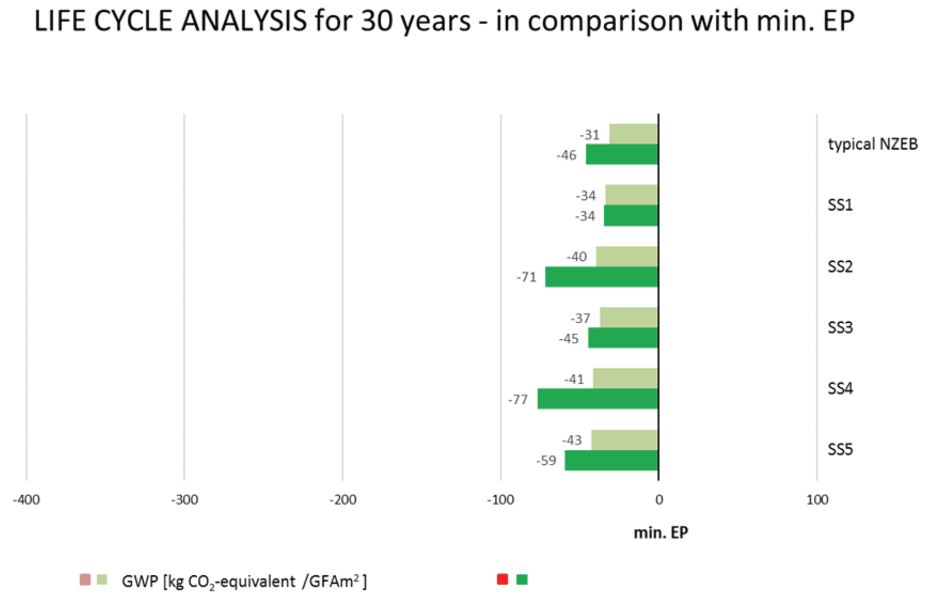

Figure 25: **LCA analyses. Comparison of the typical NZEB and the alternative NZEB solution sets in comparison with the min. EP level**

All NZEB solutions sets were designed to achieve lower investment cost keeping approximately the same primary energy demand as the typical NZEB. All solution sets have higher NR-PE savings of approximately 4 kWh/GFAm² in comparison with the min. EP. The investment cost of the NZEB solutions set are higher than the investment cost of a min. EP building.

Figure 26: **LCC analysis (NPV). Comparison of the typical NZEB and the alternative NZEB solution sets to the min. EP level**

The result, see Figure 26, is that the NPV of each solution set except SS3 is lower (better) than that of the typical NZEB, but still higher (worse) than for the min. EP building.

4.5. LCA and LCC analyses for the typical NZEB, the range of NZEB solution sets and the beyond NZEB in comparison with the min. EP level

In this chapter the typical NZEB, the range of the NZEB solution sets and the beyond NZEB are compared to a min. EP building. The range of NZEB solution sets is the interval between the best and the worst NZEB solution set results. The results are presented in Figure 27 to Figure 29.

These plots show that all the alternatives to the min. EP buildings are more environmental friendly, when comparing greenhouse gas emissions in the form of kg $CO_{2,eq.}/m^2$ and non-renewable primary energy. However, from a purely economic perspective only one of the solution sets – 4-layer windows, natural ventilation and energy saving water taps - (SS3) and the beyond NZEB building are more cost-effective than the min. EP building.

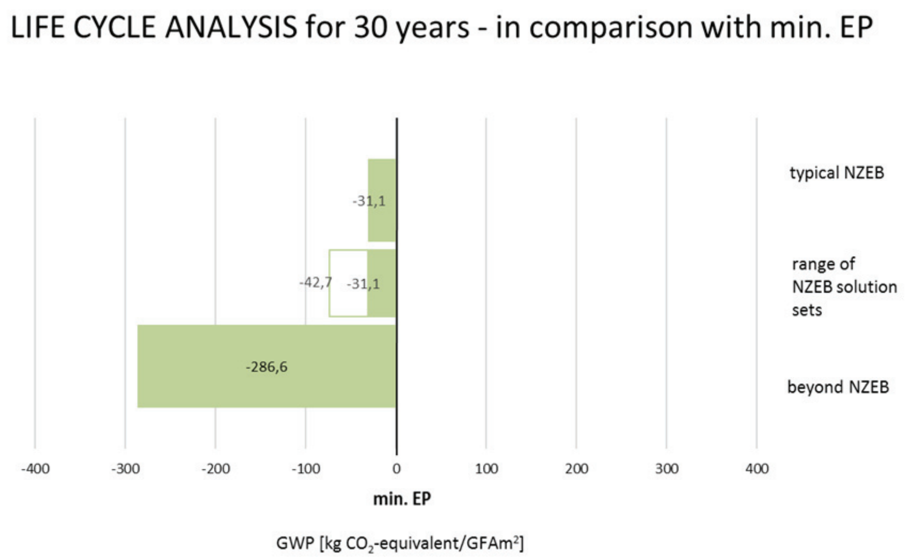

Figure 27: **GWP analysis for the typical NZEB, the range of NZEB solution sets and the beyond NZEB level in comparison with the min. EP level**

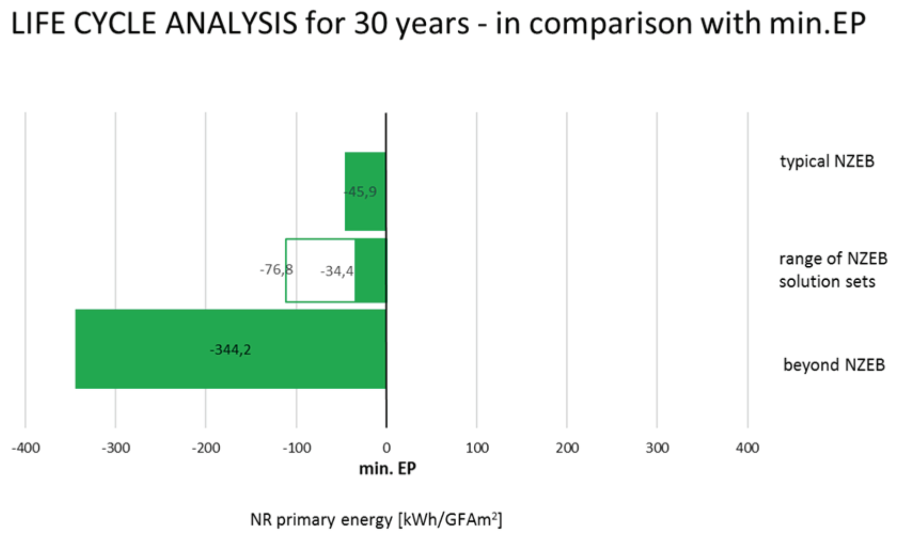

Figure 28: **Non-renewable primary energy analysis for the typical NZEB, the range of NZEB solution sets and the beyond NZEB in comparison with the min. EP level.**

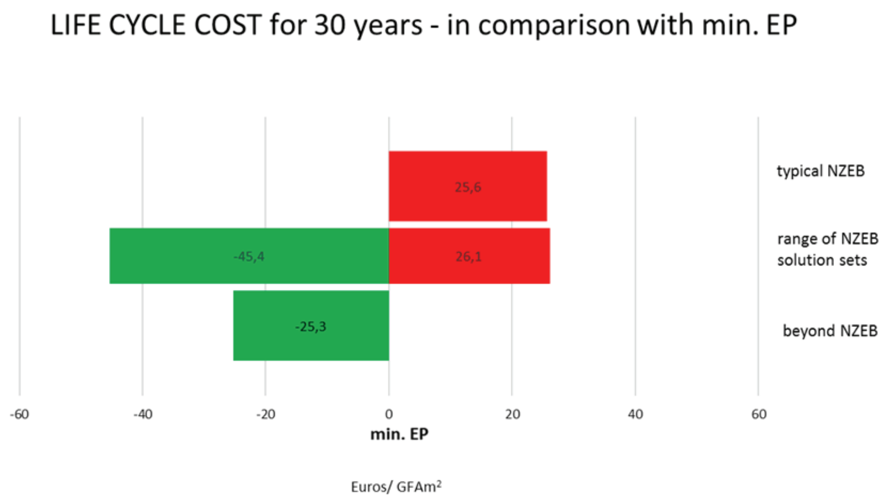

Figure 29: **LCC analyses (NPV) for the typical NZEB, the range of NZEB solution sets and the beyond NZEB level in comparison with the min. EP level**

4.6. Summary

The lower investment costs of the identified solution sets for NZEB compared to the typical NZEB constructions in Denmark found in the previous work of the CoNZEBs project also show up in the results of the LCC calculations above. All solution sets show improved NPV compared to the typical NZEB. However, when comparing them to the min. EP level only one of the solution sets (SS3) comes out with a lower NPV. Very interesting is it the buildings designed and built to the beyond NZEB level actually shows better LCC than the min. 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 $CO_{2,eq.}/m^2$ and non-renewable primary energy over the 30 year period of the LCA analyses all solution sets, the typical NZEB and the beyond NZEB houses all show improved environmental results.

The right choice for the future will depend on the greater context: If the building is located in an area with no common supply (generally district heating) it may be the best solution to design and build to the beyond NZEB level, whereas in the situation where a CO_2-neutral supply within relatively few years can be expected a SS3 NZEB would be the right choice, provided special care is taken to assure adequate ventilation rates.

5. Buildings in Germany

The different NZEB and beyond solutions that are under investigation in this report have been applied to a typical multi-family house, which in the case of Germany includes 5 storeys, 15 apartments and in total 1,010.8 m² living area or a net floor area of 984,8 $m^2_{NFA.}$ The storey height is 2.78 m and the total building height 15.7 m. There are three different apartment sizes on all storeys with flat #1 having a living area of 54.9 m² (2-room flat), flat #2 of 48.5 m² (2-room flat) and flat #3 of 105.0 m² (4-room flat). A cellar is located below the whole building. The (unheated) traffic area incl. the staircases is outside on the north side of the building.

Economical information about the building and HVAC components like depreciation period and effort for maintenance has been primarily taken from the standard VDI 2067 [DE 1]. Cost data has been acquired from the MODER District Energy Concept Advisor [DE 2].

The energy calculations have been performed according to the standard DIN V 18599 [DE 3], which is one of the mandatorily prescribed calculation methods to issue energy performance certificates for residential buildings and the mandatorily prescribed method for non-residential buildings in Germany.

Due to the long time missing detailed German application of the NZEB definition, the German CoNZEBs team defined the national NZEB requirement for the project to be the KfW Efficiency House 55, which translates to be about 27% more tight than the legal minimum energy performance requirement for new buildings.

All area related data for the German building energy levels is related to the net floor area (NFA).

5.1. Building energy levels with parameters

Table 10: Technologies set overview for each building level

	Technologies	Min. EP	Typical NZEB	SS2	SS3	SS7	SS8	Beyond NZEB
Envelope	Reduced insulation, facade	x		x	x	x	x	x
	Reduced insulation, roof	x		x	x	x	x	x
	Reduced insulation, ground floor	x		x	x	x	x	x
	2-layer windows	x		x	x	x	x	
	3-layer windows		x					x
Technical building systems	Mechanical exhaust, demand –controlled	x	x			x		
	Mechanical exhaust						x	
	Reversing air flow with heat recovery			x				x
	Central MVHR 75%				x			
	Exhaust air heat pump				x			
	Gas condensing boiler, 63 KW	x	x					
	Gas condensing boiler, 58 KW						x	
	Thermal storage, 3.17 m^3	x	x			x		
	Thermal storage, 0.8 m^3						x	x
	Heating distribution, emission and chimney	x	x			x	x	x
	Electric heating system			x				
	Electric reheaters				x			
	District heating					x		
	District heating connection cost and cost subsidy					x		
	Exhaust-air-water heat pump						x	
	Air-water heat pump							x
	Single room control heating							x
	Hot water distribution with circulation	x	x			x	x	x
	Electric DHW heater			x	x			
Renewable energy systems	PV panels on roof			x			x	x
	Shower waste water heat recovery			x	x			
	Solar heating	x	x					

Table 11 to Table 15 show the input parameters used for the LCA and LCC calculation.

Table 11: Environmental load used for LCA calculation

Energy	DE: DIN V 18599 PE non-renewable [kWh/kWh (or MJ/MJ)]	DE: DIN V 18599 GWP, $CO_{2,eq.}$ [kg/kWh_{Hi}]	Comments
District heating, DE	0.7	0.1517	GWP not included in DIN V 18599, calculations with GEMIS [X], based on 100% CHP made of natural gas
Natural gas, DE	1.1	0.2400	-
Electricity, DE	1.8	0.5500	-

Table 12: Final energy demand used for LCA and LCC calculation

	Final electricity demand: normal [kWh/yr]	Final electricity demand: heat pumps [kWh/yr]	Final energy demand: gas [kWh/yr]	Final energy demand: district heating [kWh/yr]	Final energy: feed in electricity [kWh/yr]	Final energy: self-use PV-electricity [kWh/yr]
min. EP	3,460		60,369			
typical NZEB	3,263		42,628			
SS2	22,484				2,799	15,945
SS3	12,826	13,763				
SS7	2,282			62,205		
SS8	2,173	9,603	25,917			
beyond NZEB	1,065	9,861			31,997	14,518

Table 13: Non-renewable primary energy demand used for LCA

	Non-renewable primary electricity demand: normal [kWh/yr]	Non-renewable primary electricity demand: heat pumps [kWh/yr]	Non-renewable primary energy demand: gas [kWh/yr]	Non-renewable primary energy demand: district heating [kWh/yr]	Primary energy: feed-in electricity [kWh/yr]	Total non-renewable primary energy demand [kWh/yr]	Total non-renewable primary energy demand [kWh/(NFAm²yr)]
min. EP	6,228		66,406			72,634	73.8
typical NZEB	5,873		46,891			52,764	53.6
SS2	40,471				5,038	35,433	36.0
SS3	23,087	24,773				47,860	48.6
SS7	4,108			43,544		47,652	48.4
SS8	3,911	17,285	28,509			49,705	50.5
beyond NZEB	1,917	17,750			57,595	-37,928	-38.5

Table 14: Energy cost data used for LCC calculation

Energy cost	Euros/kWh	Energy inflation in 30 years
Gas	0.05425	1.06%/yr
District heating	0.1	1.06%/yr
Electricity	0.2942 (normal) 0.22 (for heat pumps)	0.19%/yr
Electricity feed in tariff	0.2942 (SS2) 0.144 (beyond NZEB)	0%/yr
Share of the EEG-surcharge for self-used PV-electricity	0.02562	0%/yr

Table 15: Financial figures to calculate the net present value in LCC analyses

Financial figures	Value
Discount rate	1.89%
Tax of interest income	0%
Inflation of energy • Gas • District heating • Electricity	 1.06%/year 1.06%/year 0.19%/year
Inflation of maintenance	1.19%/year
Expected economic lifetime	30 years

5.2. LCA and LCC analyses comparison of the three building levels

In this chapter the life cycle assessment (LCA) and the life cycle cost analysis (LCC) are compared between the levels minimum energy performance requirements (min. EP), typical NZEB and beyond NZEB. The only difference between the min. EP and the typical NZEB building is the better thermal envelope quality of the typical NZEB. The list of differences between the min. EP and the beyond NZEB level is much longer as presented below:

- Improved thermal envelope
- Air-water heat pump instead of gas condensing boiler
- Floor heating with single room control instead of radiators
- Decentral mechanical ventilation system with heat recovery (reversing airflow)
- DHW is heated with fresh water stations (domestic hot water heat exchangers). No separate hot water distribution.
- The solar heating system is replaced by a 300 m² PV system

The results of the LCA is shown in Figure 30, which shows that the typical NZEB as well as the beyond NZEB level are more environmental friendly than the min. EP building. This is true for both 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.

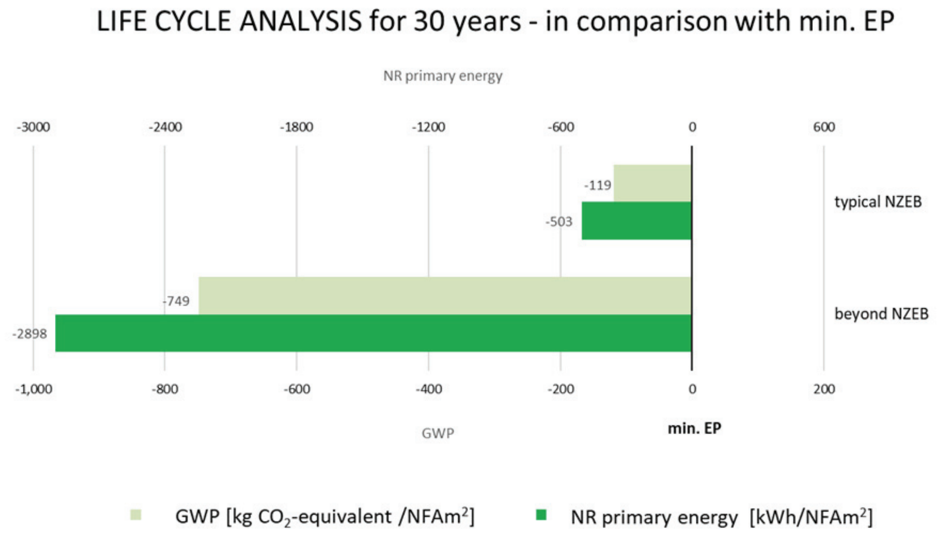

Figure 30: LCA analysis. Typical NZEB and Beyond NZEB in comparison with min. EP in a 30 years period.

In contrast, constructing a typical NZEB or a beyond NZEB is not economically profitable compared to constructing a standard (min. EP) building (see Figure 31). Moreover, constructing a beyond NZEB level is more costly than designing a typical NZEB due to higher maintenance and replacement costs of the technologies implemented in the beyond NZEB level.

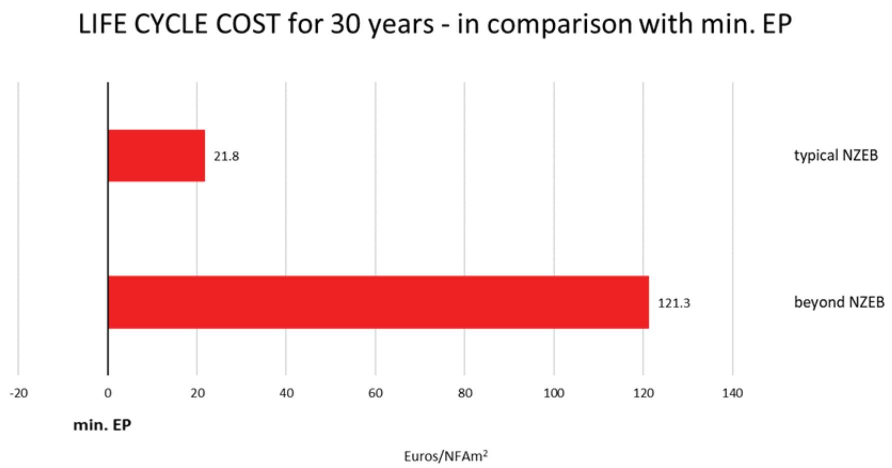

Figure 31: LCC analysis. Typical NZEB and Beyond NZEB in comparison with min. EP in a 30 years period.

5.3. LCA and LCC analyses for each solution set in comparison with typical NZEB

The German CoNZEBs team has assessed nine alternative NZEB solution sets i comparison with the typical NZEB. Only four solution sets proved to be cost-saving regarding investment costs (SS2, SS3, SS7 and SS8) and are therefore presented in the earlier CoNZEBs report and are also analysed here concering the LCA and LCC results.

5.3.1. Comparison of SS2 with typical NZEB

SS2 includes a decentralized mechanical ventilation system with heat recovery (decentral MVHR). Heating is provided via electric heating plates in each room and domestic hot water is generated with one electric DHW heater per flat. To reduce the DHW demand for the shower a decentral gray water heat exchanger is connected to the shower drain which preheats the cold freshwater flowing towards the shower. The solar heating system of the typical NZEB is replaced in this solution set by a 130 m² PV system. The energy produced by the PV is mostly self-used and the rest is sold to the grid. Due to the changes at the technical building systems the building envelope insulation level could be reduced down to the specific building envelope requirement for KfW 55 buildings (used here as NZEB level).

As a result of the changes done in this solution set, the global warming potential (GWP) and the non-renewable primary energy consumption (NR primary energy – NR-PE) shown in the LCA results (see Figure 32) change. The installation of the 130 m² PV system increases the embodied energy more than all the other technical changes in the solution set combined are able to reduce it. The reduced building envelope insulation level on the one hand leads to reduced values of GWP and NR-PE for the embodied energy because of less material use. On the other hand, it has a negative impact on the energy use, which is superimposed by the energy savings through the installation of the decentral MVHR (compared to an exhaust ventilation system in the typical NZEB) and the positive impact of the large PV system. In total the changes decrease the final energy demand, which results (grid feed-in considered) in a GWP reduction of 36.5 kg/(NFAm²) over a period of 30 years.

Summary of the LCA results for SS2:

1. Material use (embodied energy): The GWP and the NR-PE due to the embodied energy use are higher for solution set 2 if compared to the typical NZEB, largely due to the PV installation.
2. Energy use during the operation phase: The GWP and NR-PE due to the energy use are significantly lower thanks to the PV system and the decentral MVHRs, although the envelope insulation level is reduced.

3. The sum of the partial results (embodied energy and energy use) leads to the total LCA of SS2 which shows a significant reduction of GWP (13 kg $CO_{2,eq.}$/NFAm²) and NR-PE (454 kWh/NFAm²).

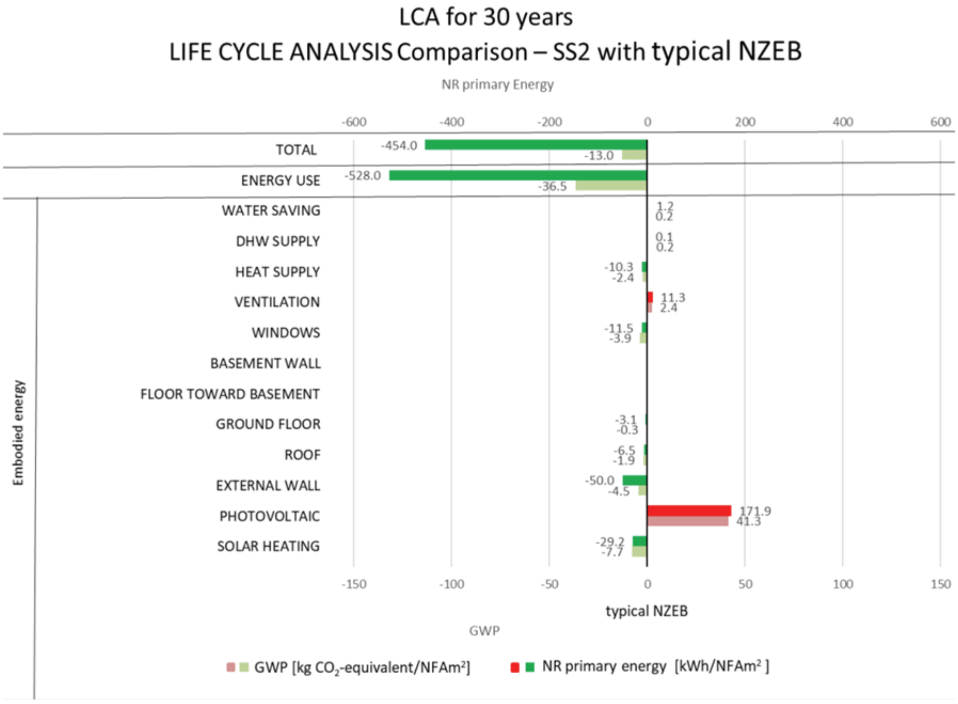

Figure 32: LCA comparison of SS2 with typical NZEB

The life cycle cost (LCC) of the solution set SS2 in comparison with the typical NZEB (shown in Figure 33) are higher. Three major influences on the total net present value (NPV) for 30 years can be observed:

1. Investment costs: The lower investment costs of the solution set reduces its net present value. The biggest investment cost savings are possible because there is no need for the domestic hot water and heating distribution, its emission and the chimney.
2. Energy costs: The energy costs are much higher. Since the solution set is providing heat (heating and domestic hot water) via direct electrical generation, the kilowatthour of heating energy is pretty expensive (electricity price is 0.294 €/kWh with a yearly inflation of 0.19%). The final energy price for SS2 is in comparison to the typical NZEB 0.225 €/kWh (or a factor of 4.2) higher. Even though the final energy consumption of SS2 is reduced by 23,400 kWh/yr (23.7 kWh/(NFAm²yr)) or a factor of 2.05, this is not enough to compensate for the much higher energy prices, leading to the results shown in Figure 33.
3. Replacement costs: The replacement costs of the solution set SS2 are considerably higher. According to the national standard used for the definition of the depreciation period (VDI 2067 Blatt 1) two rather expensive components of the solution set (electric

DHW heaters and decentral MVHR) have a relatively short depreciation period of 15 or 18 years respectively. This increases the replacement costs compared to the typical NZEB.

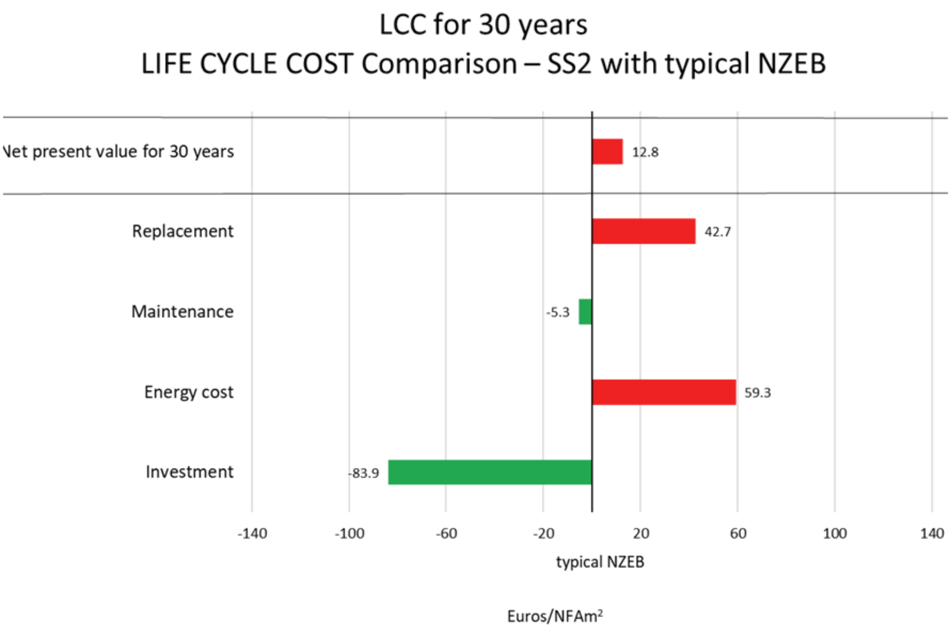

Figure 33: LCC comparison of SS2 with typical NZEB

5.3.2. Comparison of SS3 with typical NZEB

The difference between the typical NZEB and solution set SS3 consists in the following changes in the HVAC and in a reduced building envelope insulation level:

- Central exhaust air heat pump for heating instead of a gas boiler
- Central mechanical ventilation system with heat recovery (central MVHR). The ventilation system is connected to the exhaust air heat pump and distributes the heat in the building (i.e. an air heating system) instead of central exhaust air ventilation
- Decentral electrical domestic hot water generation (one DHW heater per flat) instead of a central generation by a gas condensing boiler
- Decentral gray water heat exchanger that is connected to the shower drain which preheats the cold freshwater flowing towards the shower
- The solar heating system of the typical NZEB is removed in this solution set
- Reduced building envelope insulation level

Because of the changes in SS3, the global warming potential (GWP) of the solution set is higher and the non-renewable primary energy consumption (NR-PE) shown in the LCA results (see Figure 34) are lower because:

1. Material use (embodied energy): The constructional and technical system changes to the building and the resulting changes in material use have only a minor influence on the changes in the GWP or NR-PE regarding embodied energy use. The reduced building envelope insulation level and the removal of the solar thermal system lead on the one hand to reduced values of GWP and NR-PE because of a reduced material use.
2. Energy use during the operation phase: On the other hand, the reduced building envelope insulation level and the removed solar thermal system have a negative impact on the energy use.
3. To understand why the GWP of the solution set is higher and the NR-PE is lower we have to take a look at the energy consumption of the compared solutions and the primary energy factors and $CO_{2,eq.}$ emission factors of the energy carriers used. The typical NZEB uses 42,628 kWh of gas per year with a primary energy factor of 1.1 and a $CO_{2,eq.}$ emission factor of 0.24 kg/kWh_{Hi} as well as 3,263 kWh of electricity with a primary energy factor of 1.8 and a $CO_{2,eq.}$ emission factor of 0.55 kg/kWh. This leads to a primary energy demand of 52.764 kWh/yr and a $CO_{2,eq.}$ emission of 16.392 kg/yr. Looking at the primary energy factors of gas and electricity, the one of electricity is 1.6 times bigger. In contrast the $CO_{2,eq.}$ emission factor of electricity is 2.3 times bigger. Therefore from the NR-PE point of view one kilowatthour of electricity has to replace at least 1.6 kWh of gas to reduce the primary energy use in the LCA calculations. From the GWP point of view one kilowatthour of electricity has to replace at least 2.3 kWh of gas to reduce the GWP of solution set 3. In SS3 the only energy carrier is electricity and its demand amounts to 26,589 kWh/yr, which, in simplified terms, results in a replacement of 42,628 kWh of gas or 1.8 $kWh_{gas}/kWh_{electricity}$. This indicates that in SS3 the replacement of gas through electicity is efficient enough to reduce the NR-PE but not the GWP.

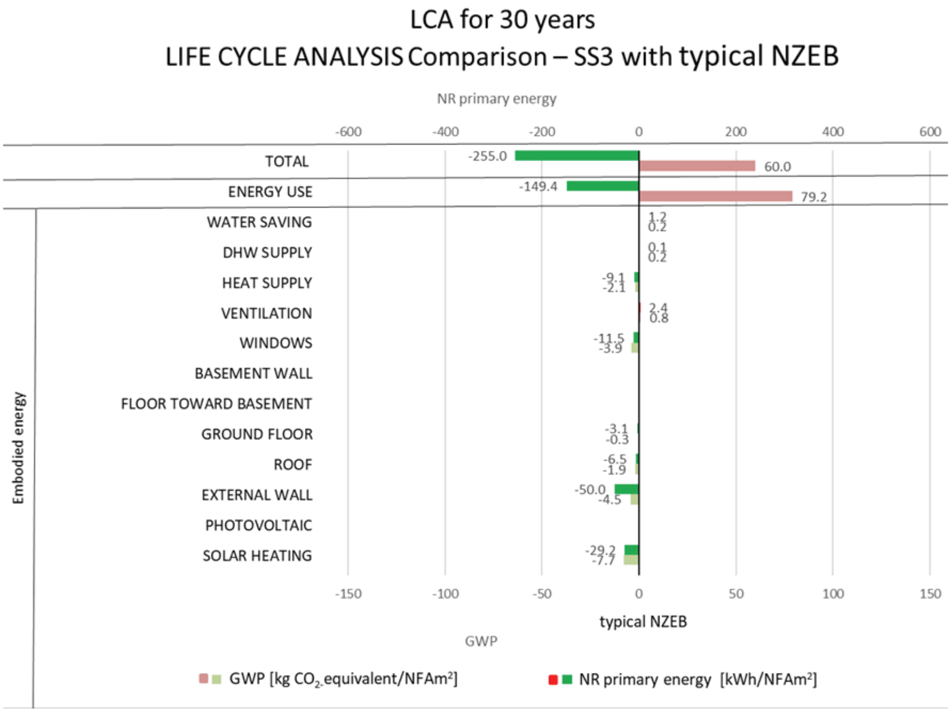

Figure 34: LCA comparison of SS3 with typical NZEB

The assessment of the life cycle costs of solution set SS3 over 30 years (displayed in Figure 35) shows, that the solution set results in a higher net present value than the typical NZEB. The overall life cycle costs over 30 years are in total 46.7 €/NFAm² more expensive. This can be divided into:

1. Investment costs: According to the main aim - identifying NZEB solution sets with lower investment costs if compared to the typical NZEB - SS3 is able to save investment cost.
2. Replacement & maintenance: The costs for replacement and maintenance for the HVAC are increased compared to the typical NZEB due to the shorter depreciation periods and the higher maintenance efforts of the technical systems used in SS3. The central mechanical ventilation system with heat recovery attributes to a huge part of the replacement costs.
3. Energy costs: The energy costs are increased due to the much higher electricity than gas price.

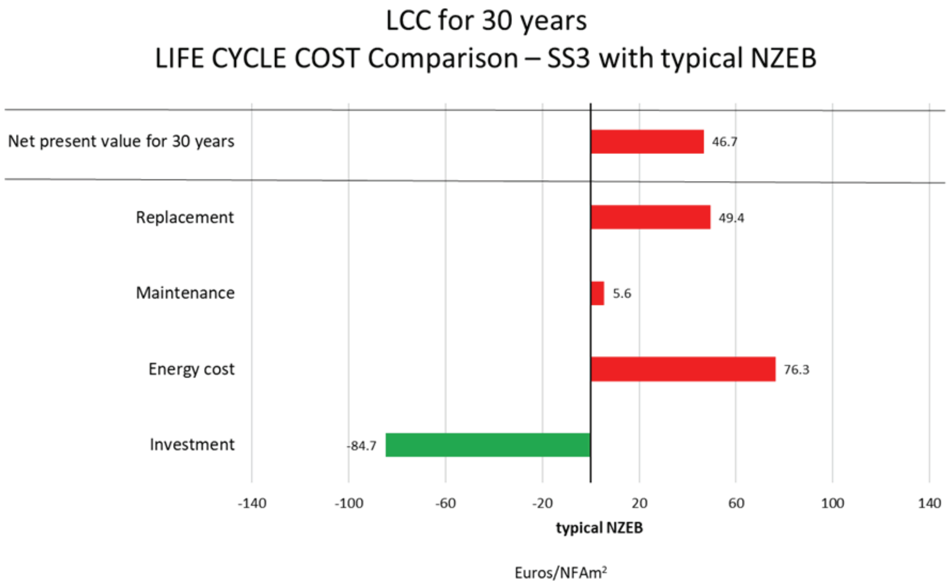

Figure 35: LCC comparison of SS3 with typical NZEB

5.3.3. Comparison of SS7 with typical NZEB

Solution set SS7 differs from the typical NZEB by the following two major changes in the HVAC and by the reduced insulation level of the envelope:

- Connection to the district heating instead of using a gas condensing boiler
- The solar heating system of the typical NZEB is removed in this solution set

The life cycle assessment calculation (shown in Figure 36) leads to 263 kWh/NFAm² less non-renewable primary energy use and 60.6 kg $CO_{2,eq.}$/NFAm² less global warming potential than the typical NZEB. This can be divided into:

1. Material use (embodied energy): The reduced insulation level of the envelope leads to savings in NR-PE and GWP due to a lower material input in the ground floor, roof, windows and external opaque walls insulation. For the HVAC section, savings occur due to the replacement of the gas boiler towards a less material consuming district heating substation and the removal of the solar heating system.
2. Energy use during the operation phase: The biggest impact in the LCA comes from the energy use, where the district heating replaces the gas boiler. The district heating used for the calculation is based on 100% CHP made of natural gas, resulting in a lower non-renewable primary energy factor and global warming potential than natural gas usage for boilers (compare to Table 11).

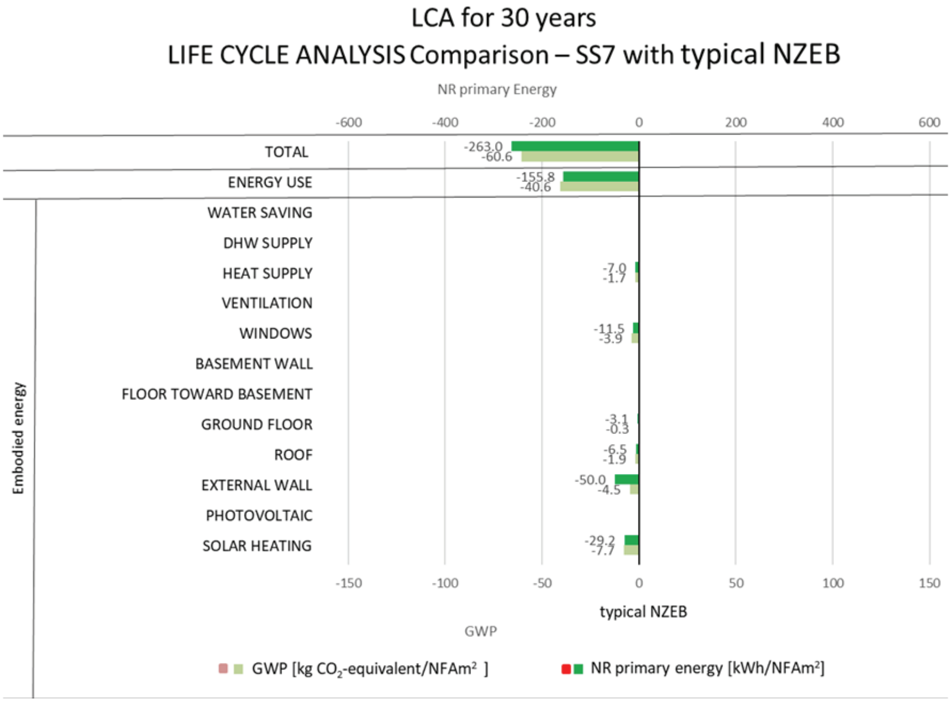

Figure 36: LCA comparison of SS7 with typical NZEB

Looking on the economics of the solution set SS7 the life cycle cost analysis (displayed in Figure 29) shows that over the 30 years period a total net present value of 7.8 €/NFAm² can be saved in comparison to the typical NZEB, which is the total impact based on:

1. Investment costs: The reduced HVAC complexity and the lower insulation levels of the envelope lead to a huge investment saving.
2. Maintenance and replacement costs: They also reduce the maintenance and replacement costs.
3. Energy costs: The higher energy prices for district heating result in a negative influence on the LCC.

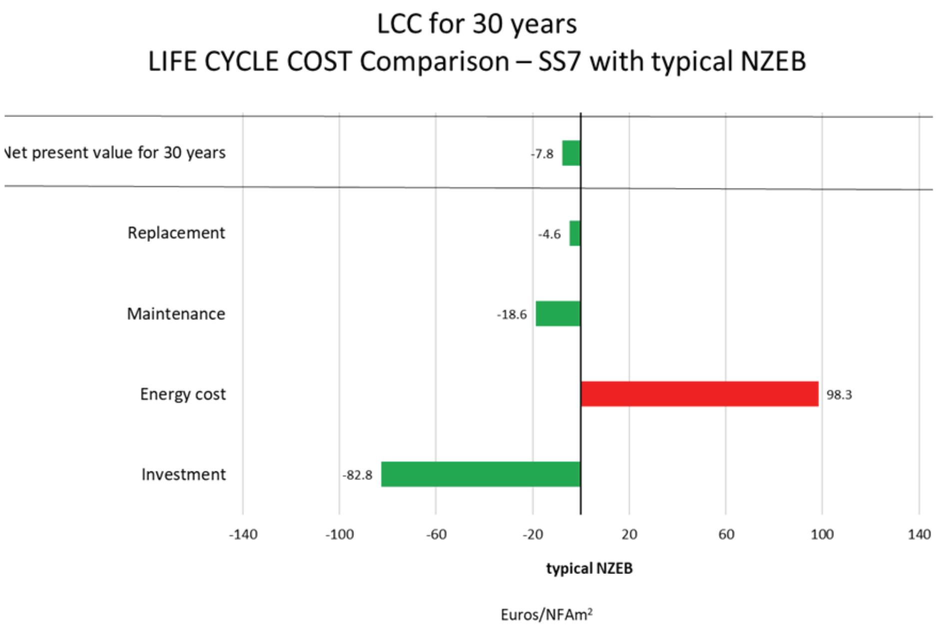

Figure 37: LCC comparison of SS7 with typical NZEB

5.3.4. Comparison of SS8 with typical NZEB

The changes in solution set SS8 in contrast to the typical NZEB are numerous:

- Two types of heat generators (gas boiler and exhaust air heat pump) instead of only one gas boiler. Most of the heating is done by the gas boiler whilst most of the domestic hot water (DHW) is generated by the exhaust air heat pump.
- Since the DHW is heated with fresh water stations (domestic hot water heat exchangers) no separate hot water distribution is necessary and is therefore removed in this solution set.
- The solar heating system of the typical NZEB is replaced with a small PV system (10 m²) in this solution set.
- Reduced building envelope insulation level

The effects of the changes on the life cycle assessment are shown in Figure 38. In total the changes of SS8 result in a non-renewable primary energy saving of 176.1 kWh/NFAm² and an increase of the global warming potential of 6.4 kg $CO_{2,eq.}$/NFAm² over 30 years. More detailed the impact can be described as follows:

3. Material use (embodied energy): Like in the other solution sets the reduced insulation level results in lower NR-PE and GWP for the building components window, ground floor, roof and external wall. The change from the solar heating system to a small PV system also leads to savings. In contrast the changes done to the heating and DHW supply result in a small increase in the embodied energy.

4. Energy use during the operation phase: For this solution set, like for all other solution sets, the energy use has the biggest impact on the LCA results. The shift away from gas towards electricity through the implementation of the exhaust air heat pump for DHW generation leads to a divided LCA result for energy use (positive for the NR-PE, negative for the GWP. The reason for this is explained in detail in chapter 5.3.2 for the similar situation in SS3.

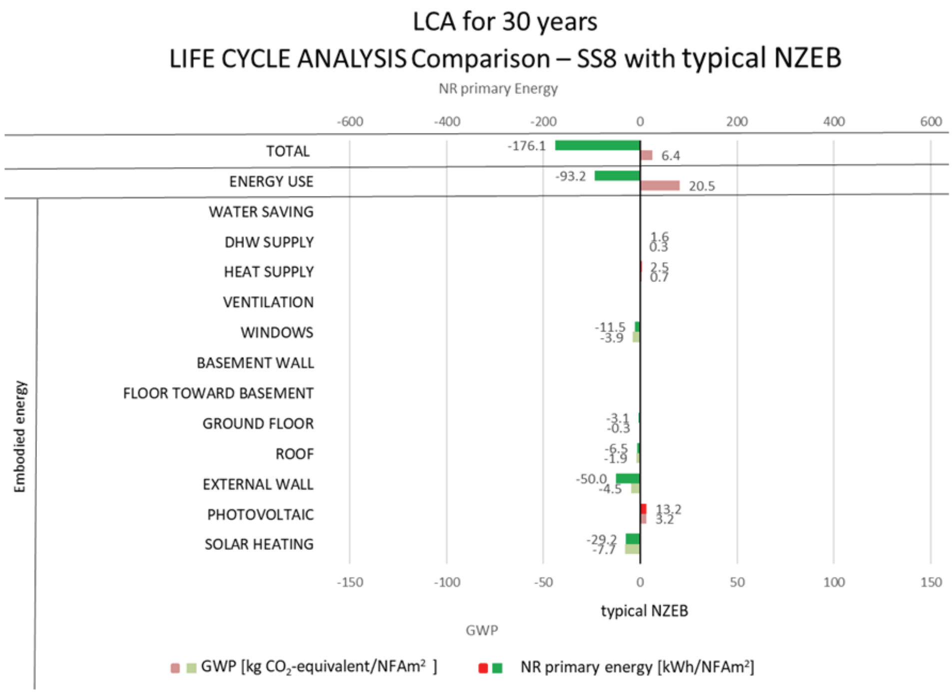

Figure 38: LCA comparison of SS8 with typical NZEB

According to the results of the life cycle cost analysis (LCC) for 30 years shown in Figure 39, the changes of SS8 lead to a net present value reduction of 5.4 €/NFAm² over 30 years.

1. Investment costs: As with all alternative NZEB solution sets the new combination of technical building systems and reduced building envelope insulation results in reduced investment costs.
2. Maintenance and replacement costs: The higher replacement and maintenance costs originate from the increased complexity of the heating and DWH supply system. Especially the domestic hot water heat exchangers contribute 1/3 of the total costs for maintenance.
3. Energy costs: Due the use of electricity for DHW generation the energy costs for this solution set are higher than those for the typical NZEB.

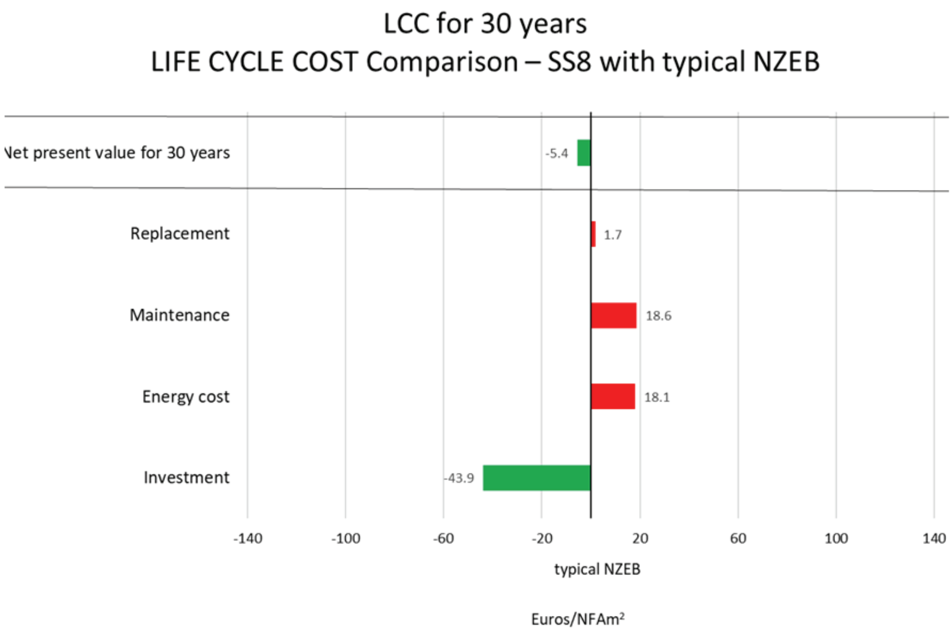

Figure 39: **LCC comparison of SS8 with typical NZEB**

5.3.5. Summary of investment costs and net present value in comparison with the typical NZEB

The main goal of the project was to identify alternative NZEB solution sets that reduce the investment cost compared to a typical NZEB design. The combined investment cost and net present value (NPV) graph in Figure 40 shows, that all presented NZEB solution sets are able to save investment costs (dark green bars) in comparison to the typical NZEB but this does not automatically mean that the NPV also results in negative values. Sadly, the solutions sets SS2 und SS3 are not able to reduce the NPV. Therefore, the solution sets SS7 and SS8 are to be preferred from the point of view of the client and the tenant.

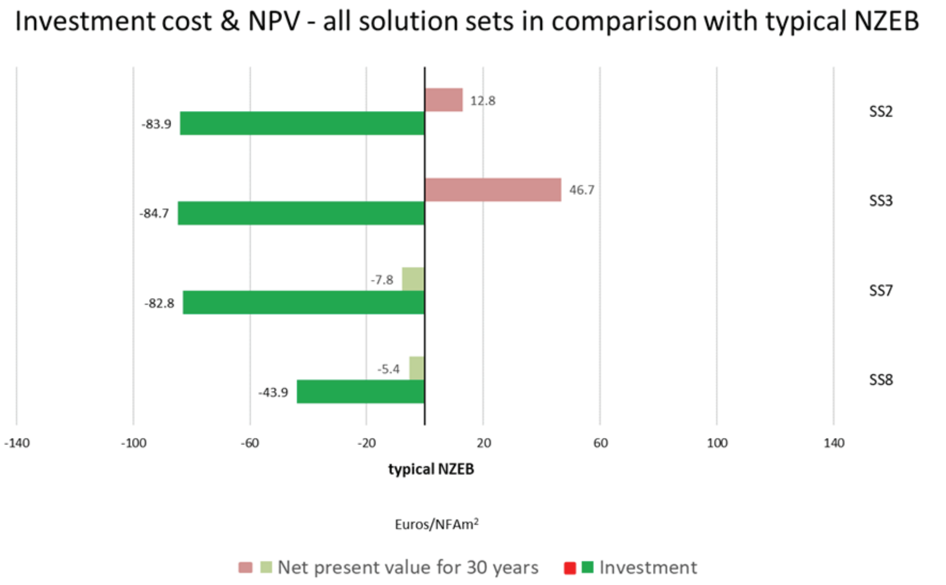

Figure 40: Summary of investment costs of all solution sets in comparison to the typical NZEB level

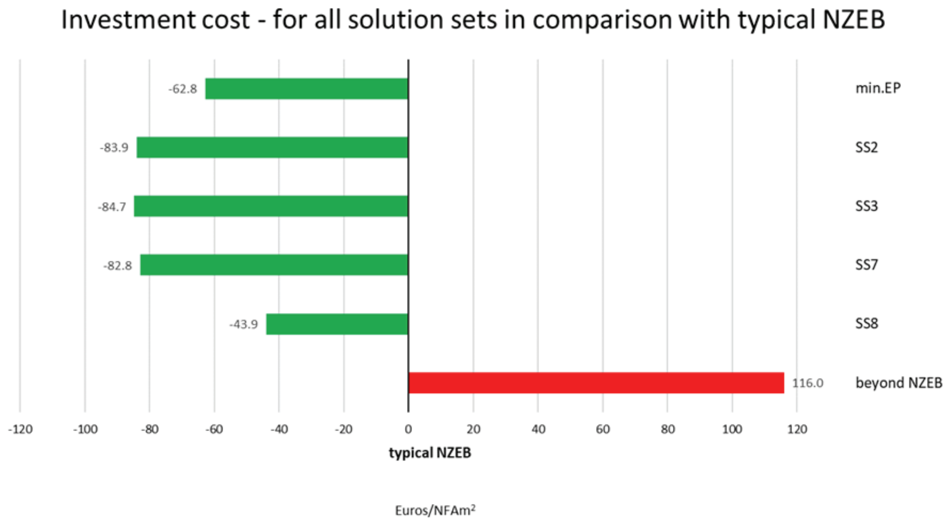

Figure 41: Investment cost overview in comparison with the typical NZEB

5.4. LCA and LCC analyses for the typical NZEB and the alternative NZEB solution sets in comparison with the min. EP level

The LCA and LCC performance of the typical NZEB and the developed solution sets in comparison to the current minimum energy performance requirements (min. EP) are shown in Figure 42. The typical NZEB and all alternative NZEB solution sets are more environmentally friendly (regarding both, NR-PE and GWP) than the min. EP level.

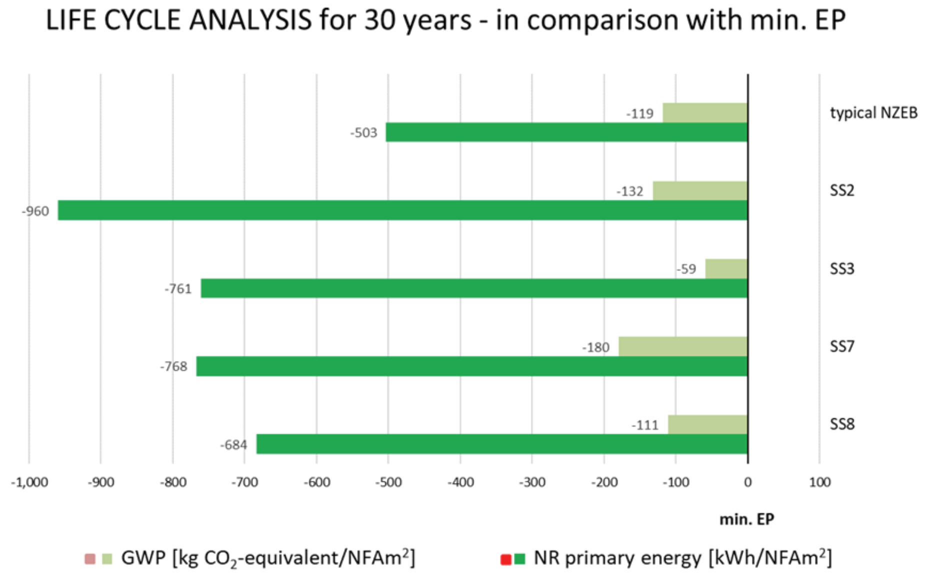

Figure 42: **LCA analyses. Comparison of the typical NZEB and the alternative NZEB solution sets in comparison with the min. EP level**

In contrast, as shown in Figure 43, all NZEB variants (typical NZEB and alternative NZEB solution sets) are more costly in comparison to the min. EP level when using the net present value over a period of 30 years as criterion. SS7 and SS8 are cheaper solutions in comparison to the typical NZEB. However, they are not cheaper than the min. EP level.

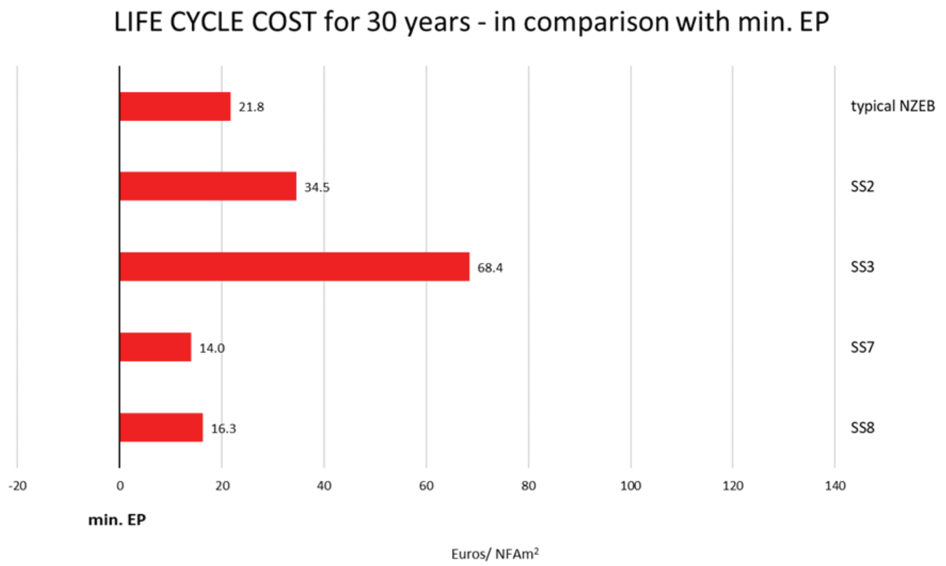

Figure 43: **LCC analyses. Comparison of the typical NZEB and the alternative NZEB solution sets in comparison with the min. EP level.**

Looking at the investment cost in comparison to a building that just fulfils the minimum energy performance requirements, it is 62.8 €/NFAm² more costly to invest in a typical NZEB (see Figure 43). The alternative NZEB solution sets SS2 and SS7 result in 21.1 €/NFAm² respectively 20.0 €/NFAm² lower investment costs than the min. EP level. The NZEB solution sets SS3 and SS8 and especially the beyond NZEB cause higher investment costs with 5.1 €/NFAm² (SS3), 19.0 €/NFAm² (SS8) and 178.9 €/NFAm² (beyond NZEB = efficiency house plus).

The existing funding measures to support the creation of NZEBs or beyond NZEBs available in Germany are not considered in the LCC calculation because they can change rapidly. At the moment the construction of a KfW efficiency house 55 (here used for the NZEB level) is supported by 5,000 € per apartment repayment subsidy in combination with a cheaper loan. With a mean apartment size in the typical German multi-family house of 66 NFAm² the funding amounts to 75 €/NFAm², which is sufficient to cover the additional investment costs of the typical NZEB.

5.5. LCA and LCC analyses for the typical NZEB, the range of NZEB solution sets and the beyond NZEB in comparison with the min. EP level

In this chapter the typical NZEB, the range of NZEB solution sets and the beyond NZEB are compared to the min. EP level. The range of NZEB plots solution sets is interpreted as the interval between the best and the worst NZEB solution set results. The results of this comparison are presented in

Figure 44 to Figure 46.

The plots below show that all alternative solution sets to the min. EP level are more environmental friendly than the min. EP level, when comparing greenhouse gas emissions in the form of kg $CO_{2,eq.}$/NFAm² and non-renewable primary energy. However, from a purely economic perspective no NZEB solution set is more cost-effective according to the NPV within a 30 year period than the min. EP level.

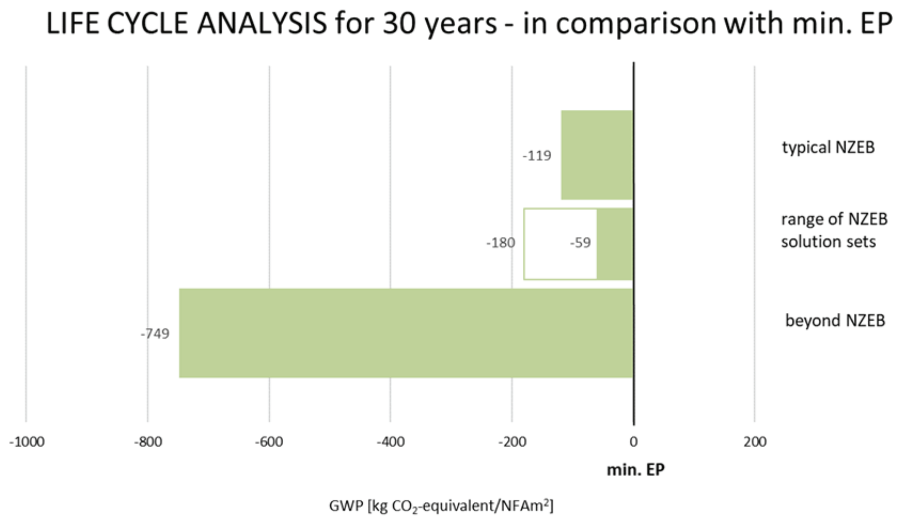

Figure 44: GWP analysis for the typical NZEB, the range of NZEB solution sets and the beyond NZEB in comparison with the min. EP level

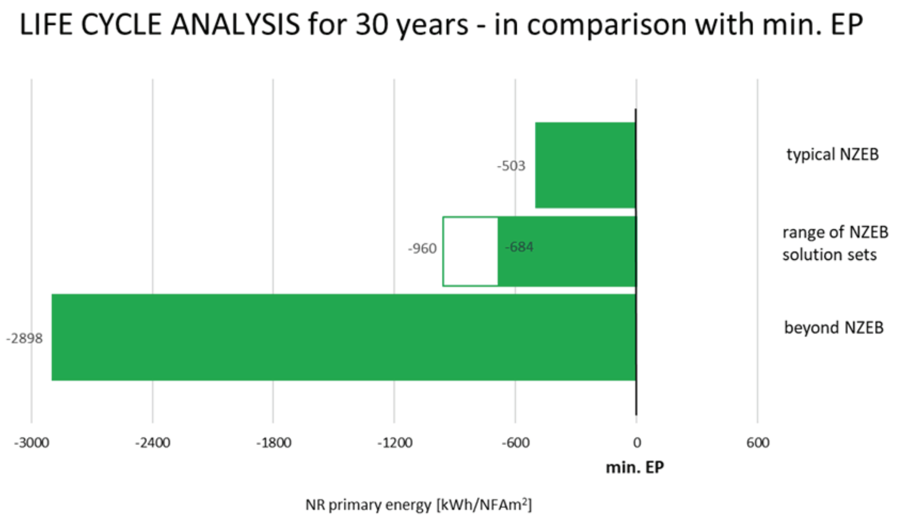

Figure 45: Non-renewable primary energy analysis for the typical NZEB, the range of NZEB solution sets and the beyond NZEB in comparison with the min. EP level

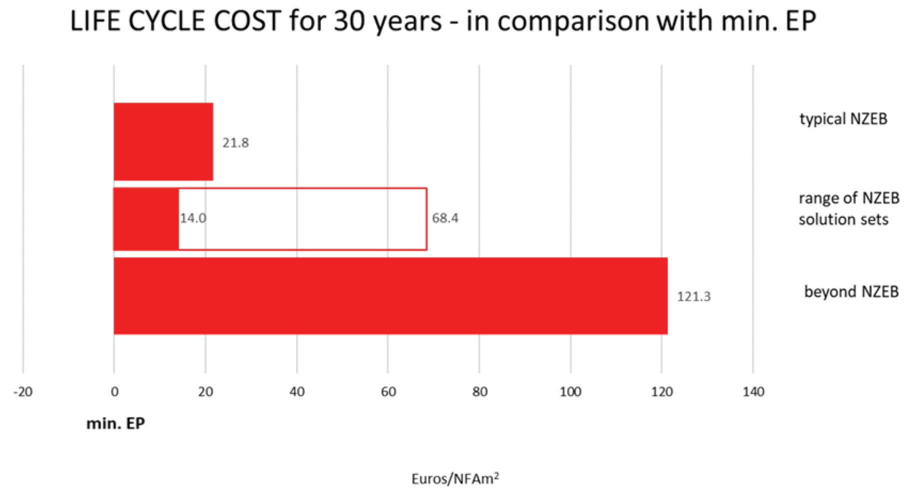

Figure 46: **LCC analysis for the typical NZEB, the range of NZEB solution sets and the beyond NZEB in comparison with the min. EP level**

5.6. Summary

The detailed calculations for the German situation have shown that there are energy concepts (solution sets) for nearly zero-energy multi-family houses existing that result in lower investment costs not only in comparison with the typical NZEB configuration but even with the typical building fulfilling the minimum energy performance requirement level (min. EP). Most of them go in the direction of using electricity for heating, either as direct electrical heating or via heat pumps. Savings are partly based on fewer costs for distribution and emission (radiators). Alternatively the change to district heating with a low primary energy factor (here based on CHP) as heat source can be an efficient choice with the focus on investment costs. Both ways the technical building system is more efficient than the standard system used for the min. EP level and the typical NZEB, the gas condensing boiler with solar thermal support. Therefore a reduced insulation level at the building envelope leads to further investment cost savings.

Unfortunately no alternative NZEB solution set was able to generate a lower (mind: macro-economic) net present value than the min. EP level, even though three solution sets result in an only slightly higher net present value of about 20 €/NFAm² or lower in a period of 30 years. This means additional costs of 5.5 Ct./NFAm² 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 soon in the EU member states. The impact of evolving factors like changing primary energy factors, technology efficiencies, technology costs and possible carbon taxes are studied in another task of the CONZEBs project and will be documented in another project report.

Using the currently available support programme for efficiency houses plus (here the beyond NZEB building) it is advisable to construct this higher level of energy performance. The available support is 15,000 € per apartment repayment subsidy in combination with a cheaper loan. Recalculated to the net floor area (66 $NFAm^2$/apartment) this means a support of 227 €/$NFAm^2$ which is higher than the (macro-economic) increased net present value of 121,3 €/$NFAm^2$ in 30 years compared to the min. EP level.

The environmental results are positive for the typical NZEB, all alternative NZEB solution sets and very positive for the beyond NZEB building if compared to the min. EP level for both GWP and non-renewable primary energy within the 30 year period.

6. Buildings in Slovenia

The typical Slovenian multi-family building is a compact building with two-side orientated dwellings that offer diverse views and good daylighting. The building is contains also several terraces and balconies. It has 5 floors and 21 apartments with the total net floor area 1486 m² and average net floor area of 70,8 m². The storey height is 2,88 m, while the total building height is 14,80 m. Apartments are positioned around the central stairway/hallway zone. The typical building envelope consists of reinforced concrete for structure use and contact façade, which includes a layer of thermal insulation.

The energy calculations have been performed according to the national calculation methodology provided in Slovenian technical guide for energy efficiency use [SI1], which is the key document supplementing Slovenian Building code PURES 2010 [SI2]. Mentioned documents are the basis of the software that was used for performing energy calculations and is used for issuing national energy performance certificates.

Information about the building components, such as life time and standard maintenance have been taken from Slovenian Rules on standards for the maintenance of apartment buildings and apartments [SI3], Rules on the methods for determining energy savings [SI4] and life cycle cost analyses from Kuben Management [SI5]. Building cost data has been primarily gathered from the actual project designs of used typical Slovenian multi-family house.

For Slovenian NZEB definition and requirements has been used Action Plan for Nearly Zero-Energy Buildings Up [SI6].

All area related data for the Slovenian building energy levels is related to the net floor area (NFA).

6.1. Building energy levels with parameters

Table 16: Technologies set overview for each building level

	Technologies	Min. EP	Typical NZEB	SS1	SS2	SS3	SS4	Beyond NZEB
Envelope	Increased insulation, facade		x	x	x	x	x	x
	Increased insulation, roof		x	x	x	x	x	x
	Increased insulation, floor slab above basement		x	x	x	x	x	x
	2-layer windows	x	x	x				
	3-layer windows				x	x	x	x
Technical building systems	Decentralized hygro-sensible ventilation system	x	x				x	
	Decentralized MVHR 85%			x	x	x		x
	Gas condensing boiler, 50 kW		x					
	Gas condensing boiler, 30 kW					x		
	Thermal storage, 0,8 m3		x			x		
	Heating distribution, emission and chimney, floor heating	x	x	x	x	x	x	x
	District Heating	x		x				
	Air/water heat pump 30 kW					x		
	Air/water heat pump 50 kW				x		x	x
	Thermal storage, 2 m^3	x	x	x	x		x	x
	Thermal storage, 1.5 m^3		x			x		
Renewable energy systems	PV panels on roof						x	x
	Solar heating		x					

Table 17: Environmental load used for LCA calculation

Energy	SI: PURES 2010 PE non-renewable [kWh/kWh (or MJ/MJ)]	GWP, $CO_{2,eq.}$ [kg/kWh]
District heating, SI	1	0.254
Natural gas, SI	1.1	0.237
Electricity, SI	2.5	0.602

Table 18: Final Energy building demand considered for LCA &LCC calculation

	Final gas demand [kWh/yr]	Final district heating demand [kWh/yr]	Final electricity demand (lighting, ventilation, heating, DHW) [kWh/yr]	Solar heating / PV contribution [kWh/yr]	Total final energy demand after RES contribution [kWh/yr]	Total final energy demand after RED contribution [kWh/ (NFAm^2 yr)]
min. EP	0	63704	10124	0	73828	49.68
typical NZEB	60936	0	11208	25252	46892	31.56
SS1	0	48095	12542	0	60637	40.81
SS2	0	0	23693	0	23693	15.94
SS3	14068	0	19135	0	33203	22.34
SS4	0	0	26201	24193	2008	1.35
beyond NZEB	0	0	23693	24193	0	0.0

Table 19: Non-renewable primary energy demand used for LCA

	Non-renewable primary energy demand: gas [kWh/yr]	Non-renewable primary energy demand: district heating [kWh/yr]	Non-renewable primary electricity demand [kWh/yr]	Total non-renewable primary energy demand [kWh/ yr]	Total non-renewable primary energy demand [kWh/ (NFAm^2 yr)]
min. EP	0	63704	25310	89014	59.90
typical NZEB	39252	0	28020	67272	45.27
SS1	0	48095	31355	79450	53.47
SS2	0	0	59233	59233	39.86
SS3	15474	0	47837	63312	42.61
SS4	0	0	5020	5020	3.38
beyond NZEB*	0	0	0	0	0.0

*Only electricity is used in beyond NZEB, PV electricity production is somewhat higher from the demand. Accounting is done on the annual basis and limited with building net energy demand.

Table 20: Energy cost data used for LCC calculation

Energy cost	Euros / kWh	Energy inflation
Gas	0.05	0.69%
District heating	0.068	-1.6%
Electricity	0.16	0.234%
El-PV production fee	0.0603	0.234%

Table 21: Financial figures to calculate the net present value in LCC analyses

Financial figures	Value
Discount rate	4%
Tax of interest income	0%
Inflation of energy • Gas • District heating • Electricity	 0.69%/year -1.6%/year 0.23%/year
Inflation of maintenance	1.7%/year
Expected economic lifetime	30 years

6.2. LCA and LCC analyses comparison of the three building levels

This chapters presents the comparison of LCA and LCC assessment of the typical NZEB, minimum energy performance requirements (min. EP) and beyond NZEB. The difference between min. EP and typical NZEB are better thermal envelope quality of the typical NZEB, heat supply (min. EP is connected to the district heating, while typical NZEB uses gas as heat supply) and in the usage of solar collector (typical NZEB has 190 m^2 of solar collectors). Between min. EP and the beyond NZEB there are more differences. First, the beyond NZEB uses heat pump for heating and DHW; second, the beyond NZEB has better thermal envelope, including triple glazed windows; third, the beyond NZEB has lower air infiltration and uses mechanical ventilation with heat recovery. Moreover, the beyond NZEB has 200 m^2 of PV, with 31 kWp installed.

Both typical NZEB building and beyond NZEB are a good solution from the environmental point of view but not from the economic point of view in comparison to a standard min. EP building. The environmental loads are in green colour, what means that they are much lower than those found for the min. EP building.

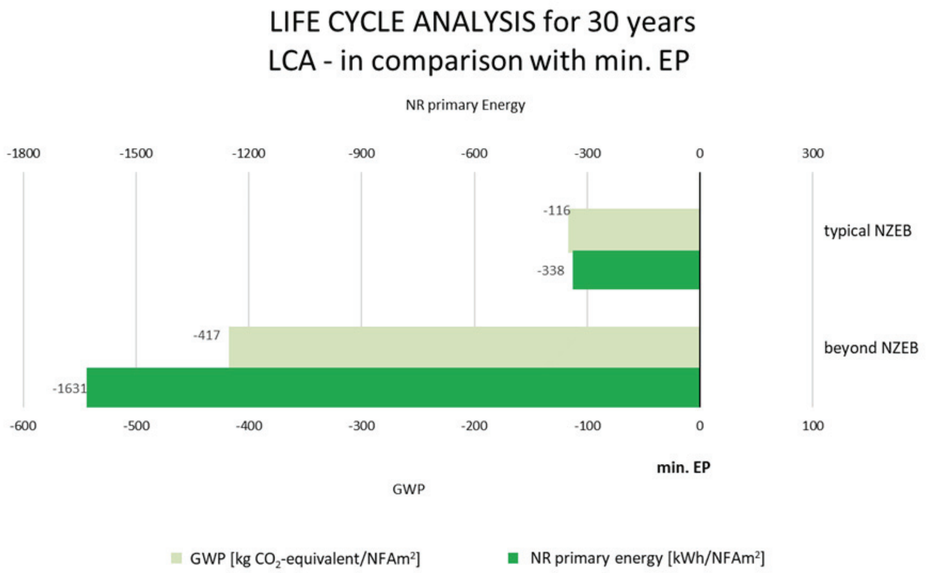

Figure 47: LCA analysis. Typical NZEB and beyond NZEB in comparison with min. EP in a 30 years period.

However, a decision for an either typical or beyond NZEB building is currently still more expensive over the 30-years lifetime than designing a standard building. This is due to the large investment cost despite of the energy-cost savings (over 30 years of the building economic life-time) found in these two energy performance levels. A beyond NZEB building in the observed case study is less costly than a typical NZEB in a study period of 30 years due to the large energy cost-reduction to nearly Zero Energy building.

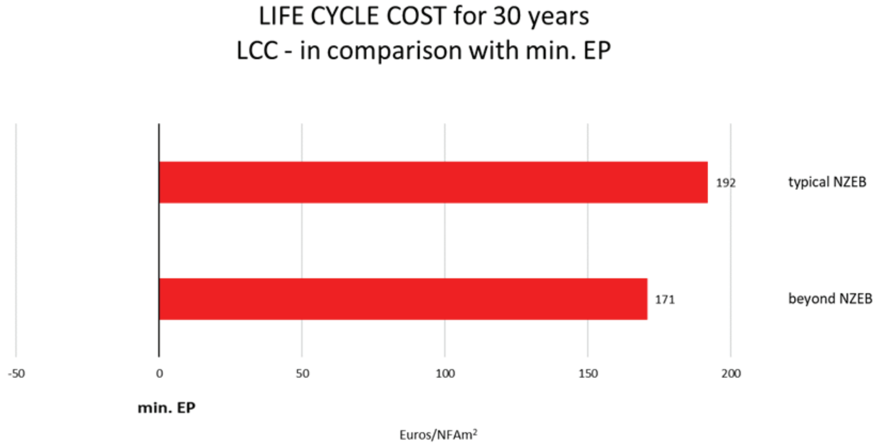

Figure 48: LCC analysis. Typical NZEB and beyond NZEB in comparison with min. EP in a 30 years period.

6.3. LCA and LCC for each NZEB solution set comparison with typical NZEB

In the following plots and paragraphs comparison of the typical NZEB with solution sets is shown. Four solutions sets (SS1 – SS4) have already been analysed and presented in the earlier CoNZEBs report [1].

6.3.1. Comparison of SS1 with typical NZEB

The first solution set is based on the district-heating source instead of gas condensing boiler, the installation of mechanical ventilation with heat recovery and the removing of solar heating system, which increases the primary energy use of the building. Furthermore, in SS1 a little better thermal envelope has been used.

The result of this solution set can be seen as an increment of the both GWP and Non-renewable energy source environmental load (Figure 49), mainly due to removal of solar collectors.

Summary of the LCA results for SS1:

1. By removing solar collectors as support for DHW, the GWP and NR-PE are higher for SS1 if compared to the typical NZEB.
2. Despite the use of mechanical ventilation system with heat recovery, energy use during the operation phase is also higher, due to removal of solar collectors and usage of district heating for heating and DHW, while in typical NZEB the major part of DHW is cover by solar collectors.

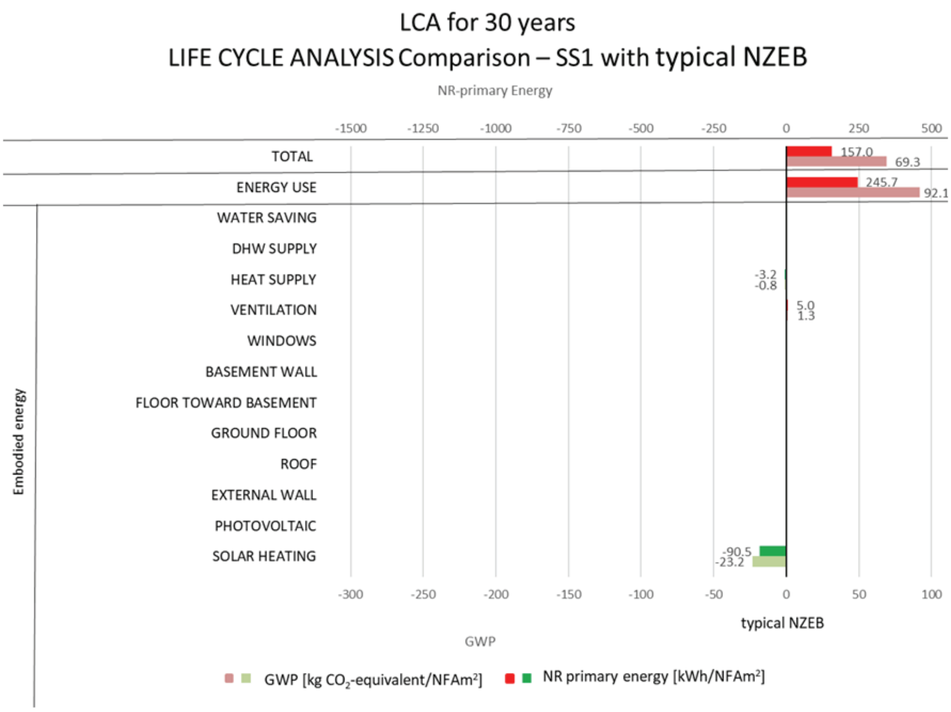

Figure 49: LCA comparison of SS1 with typical NZEB

In contrast, this solution is a good solution from economic point of view in spite of the energy cost-rise, since the LCC of the SS1 in comparison with the typical NZEB are lower (Figure 50).

The life cycle cost (LCC) of the solution set SS1 in comparison with the typical NZEB (shown in Figure 50) are lower, mainly due to:

1. Investment costs are significantly higher in typical NZEB, because of the solar collectors implementation, which results in much higher net present value of the typical NZEB.
2. Energy costs are quite higher in SS1. Since the SS1 does not have any of RES implemented, it covers all the energy demand with fossil fuels, resulting in 0,23 €/m^{2}yr higher energy costs in comparison to the typical NZEB. Consequently, the SS1 has 11,2 €/m^2 higher energy costs.
3. Replacement costs also have a minor influence on lower LCC. The SS1 uses mechanical ventilation with heat recovery, which increases the replacement costs. However in comparison to the typical NZEB it does not have solar collectors, which have the greatest impact on overall higher replacement costs.

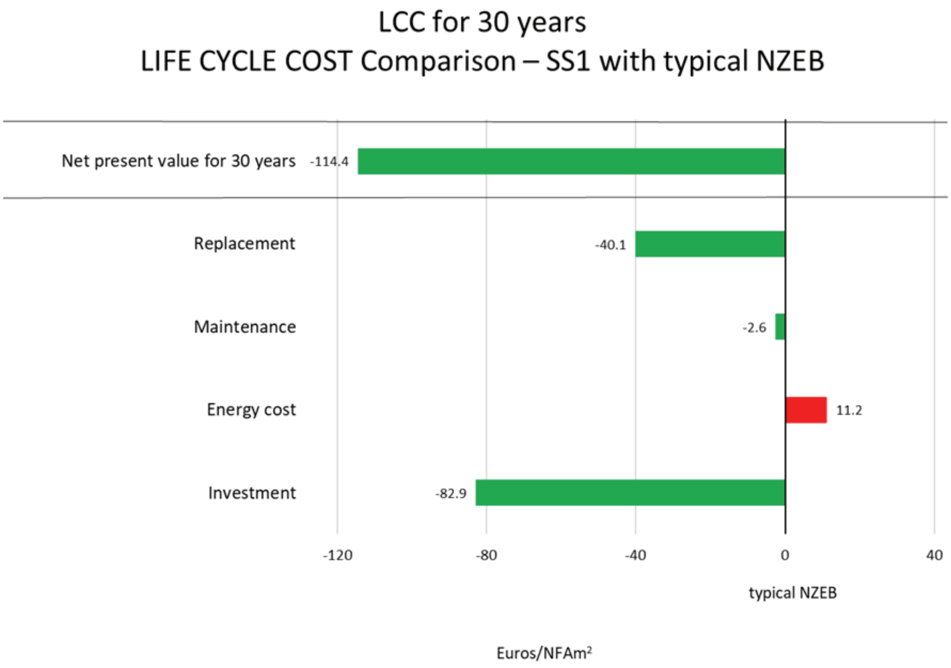

Figure 50: **LCC comparison of SS1 with typical NZEB**

6.3.2. Comparison of SS2 with typical NZEB

SS2 is primarily characterized by the implementation air-to water heat pump instead of gas condensing boiler. Besides, the SS2 uses mechanical ventilation with heat recovery and windows with triple glazing. The energy demand is reduced by half and it is supplied only by electricity source. This act results in a positive solution from both environmental and economic point of view, in spite of the higher price for electricity in comparison to gas energy.

The result of this solution set are lower GWP and higher ration of non-renewable energy source environmental load (Figure 51).

Summary of the LCA results for SS2:

1. By implementing the air-to water heat pump instead of gas condensing boiler for heating and DHW, the GWP and NR-PE are slightly lower, while the use of RES increases for 20%. Even though the typical NZEB has a large area of solar collectors, this is not enough to compensate the use of air-to water heat pumps in the SS2.
2. Energy use during the operation phase is reduced by half, due to the usage of heat pumps and windows with better thermal characteristics.

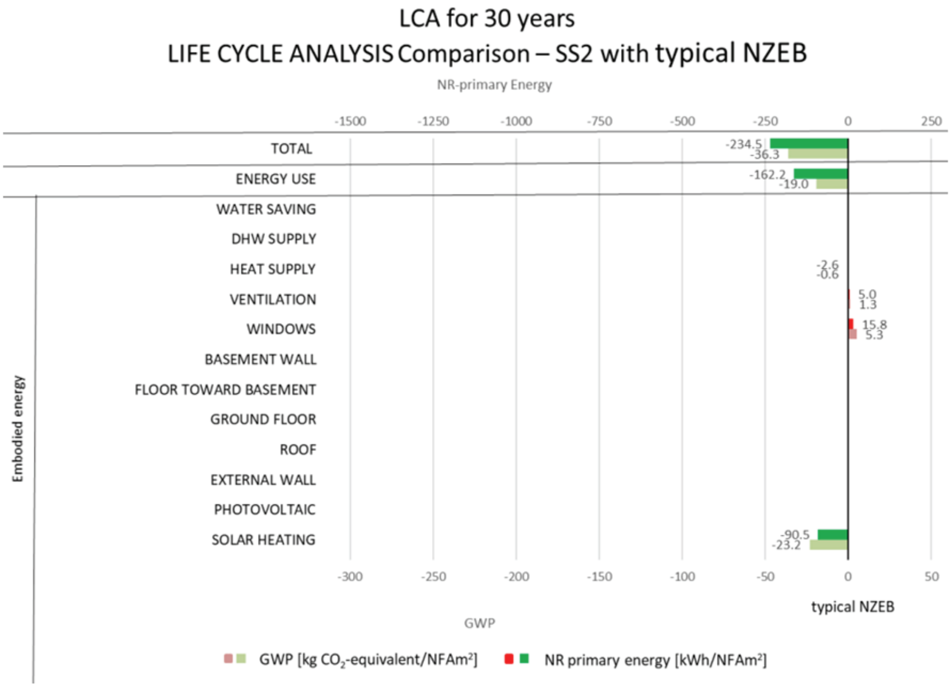

Figure 51: LCA comparison of SS2 with typical NZEB

Overall, the SS2 has lower net present value in comparison with the typical NZEB (shown in Figure 52), mainly due to:

1. Investment costs are lower in the SS2, despite the implementation of heat pumps. The reason for higher investment costs in the typical NZEB are solar collectors.
2. Energy costs are little higher in SS2, since all of the building services use electricity, which has the highest energy price and it is expected the rise of it throughout the years.

3. Replacement costs also have an impact on lower LCC, which are quite higher in the SS2, because of solar collectors, which also have a similar life time as heat pumps.
4. In this case also the maintenance costs have a significant impact on the net present value. Since the SS2 has more complex building systems it has also higher maintenance costs in comparison to the typical NZEB.

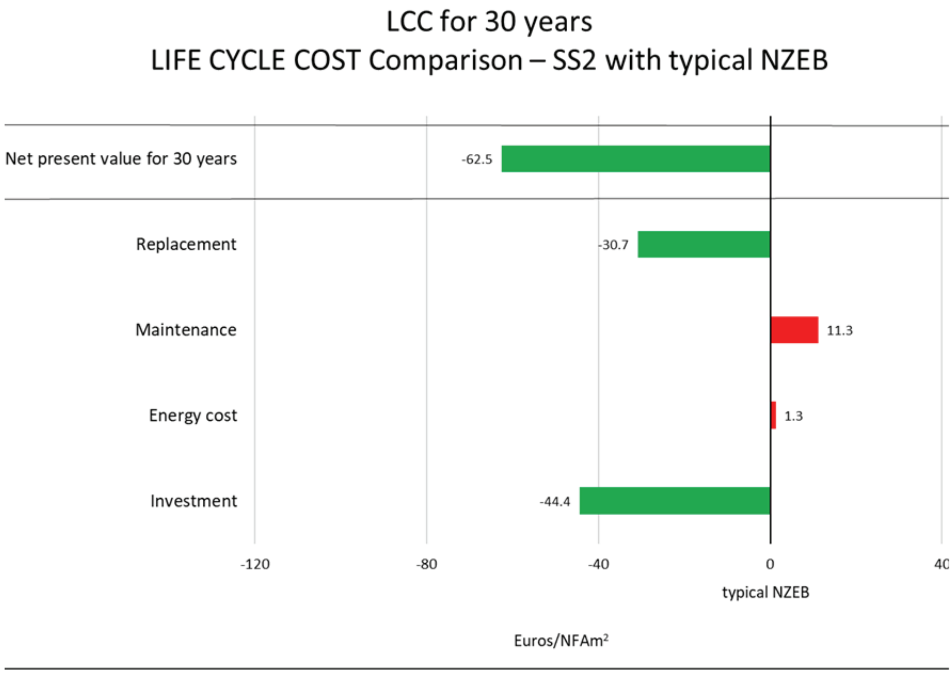

Figure 52: LCC comparison of SS2 with typical NZEB

6.3.3. Comparison of SS3 with typical NZEB

As in the previous case, this solution set is provided by air- water heat pump which supplies the DHW demand, while the gas condensing boiler still covers the space heating demand. Other than that, the SS3 differs from the typical NZEB by using mechanical ventilation with heat recovery and windows with triple glazing. The replacement of DHW supply with air-water heat pump is enough to give a good alternative solution instead of typical NZEB building design.

The LCA, presented in Figure 53, shows that GWP and NR-PE significantly decrease in the SS4.

Summary of the LCA results for SS3:

1. The installation of heat-pumps for DHW supply and removal of solar collectors help to reduce the GWP and NR-PE. Installation of mechanical ventilation with heat recovery and

use of windows with better thermal characteristics (windows with triple glazing) have a minor negative impact on the GWP and NR-PE.

2. The highest impact on the LCA has the energy use, since the DHW supply with condensing boiler was replaced by air-water heat pump, resulting in lower non-renewable primary energy factor and global warming potential than natural gas usage for boilers.

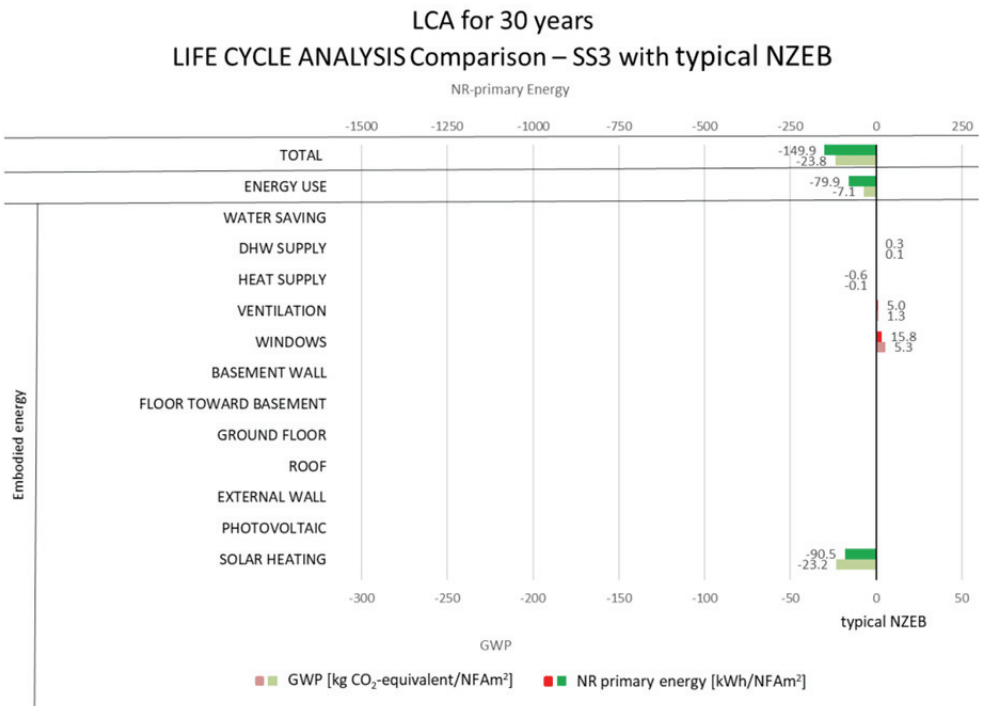

Figure 53: LCA comparison of SS3 with typical NZEB

Besides better result in LCA, the SS3 has as well lower LCC (Figure 54). The reasons are:

1. Investment costs are lower in the SS3, despite the implementation of heat pump for DHW supply. The reason for higher investment costs in the typical NZEB are solar collectors.
2. Energy costs are little higher in SS3, since heat pump and mechanical ventilation with heat recovery use electricity, which has the highest energy price and it is expected the rise of it throughout the years.
3. Replacement costs also have an impact on lower LCC, which are quite higher in the SS2, because of solar collectors.
4. In this case also the maintenance costs have a significant impact on the net present value. The SS3 has a more complex building systems it has also higher maintenance costs in comparison to the typical NZEB.

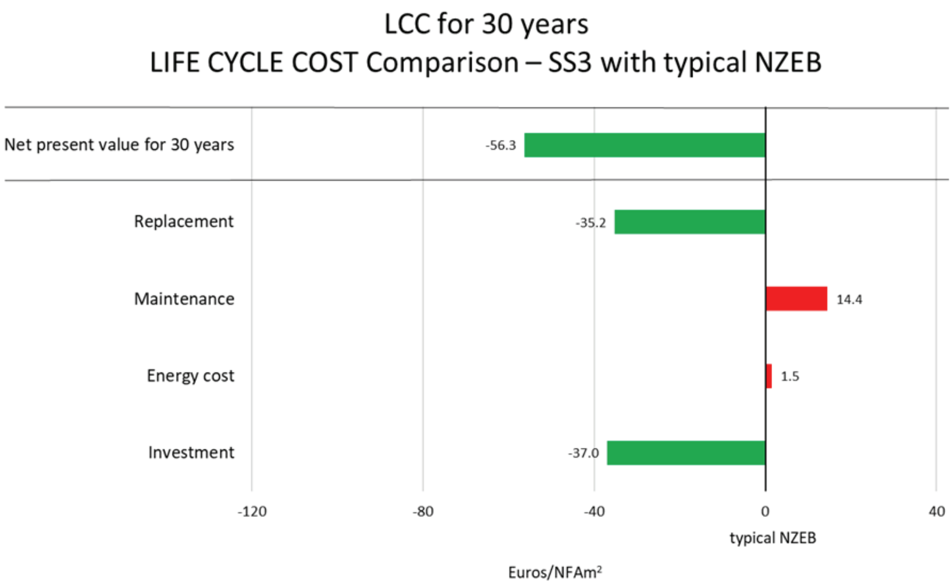

Figure 54: LCC comparison of SS3 with typical NZEB

6.3.4. Comparison of SS4 with typical NZEB

SS4 stands out by the implementation of photovoltaic panels reducing considerably the total electricity demand of the building. PV implementation, together with air-water heat pumps implementation, gives a large positive impact resulting in the best of evaluated alternative solutions to the typical NZEB building design.

The LCA, presented in Figure 55, shows that GWP and NR-PE decreases in the SS3.

Summary of the LCA results for SS3:

1. The GWP and the NR-PE are much lower for SS4 if compared to the typical NZEB, largely due to the PV installation and air-water heat pumps for heating and DHW supply.
2. The GWP and NR-PE due to the energy use are significantly lower thanks to the PV system and air-water heat pumps.

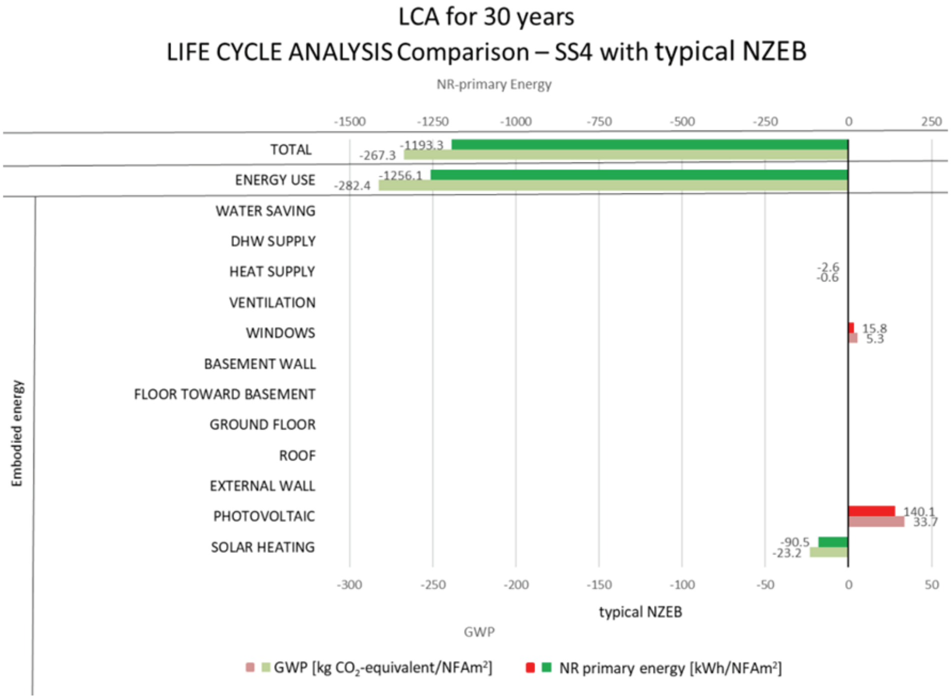

Figure 55: LCA comparison of SS4 with typical NZEB

The SS4 turns out to be also cost efficient over the life-time, as it can be seen in the LCC in Figure 56 the net present value for 30 years is much lower.

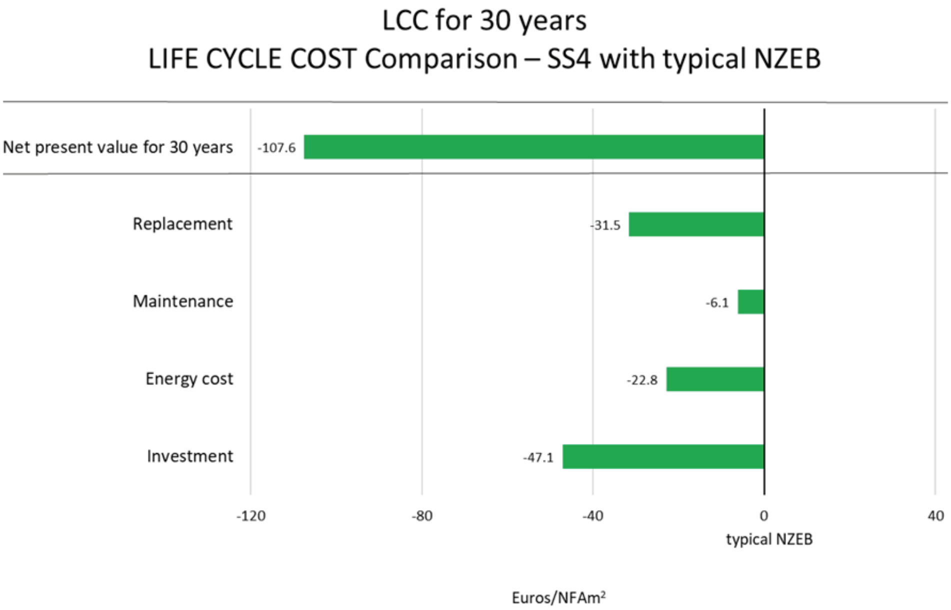

Figure 56: LCC comparison of SS4 with typical NZEB

6.3.5. Summary of investment costs and net present value in comparison with the typical NZEB

The main goal of this report was to design alternative solution sets to reduce investment cost of a typical NZEB design. As it can be seen from Figure 57 and Figure 58, the aim of this research was achieved.

The investment costs of all solution sets are lower than for typical NZEB, what confirmed the proper decision about design alternatives. Furthermore, the analysis of the replacement and maintenance cost impact by the installation of these alternative technologies result as well in a positive Net present value of the solution set as a whole. In summary, also in a long term consideration all solution sets designs are more profitable than the typical NZEB.

It has to be noted that the above results are relevant for a selected building, of frequently used architectural concept and compared with typically considered NZEB solution. The future development of NZEB technologies market will also influence the reduction of investment costs for NZEB solutions.

However, the economic evaluation of alternatives is subject to future development of the energy price that depends on the local and global climate and energy policy.

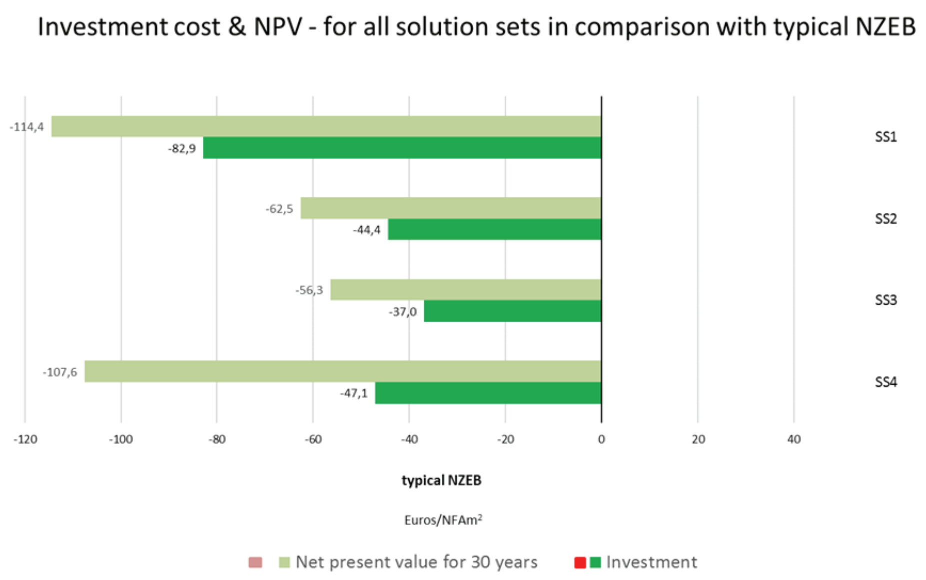

Figure 57: Summary of investment costs and NPV for all solution sets in comparison to the typical NZEB

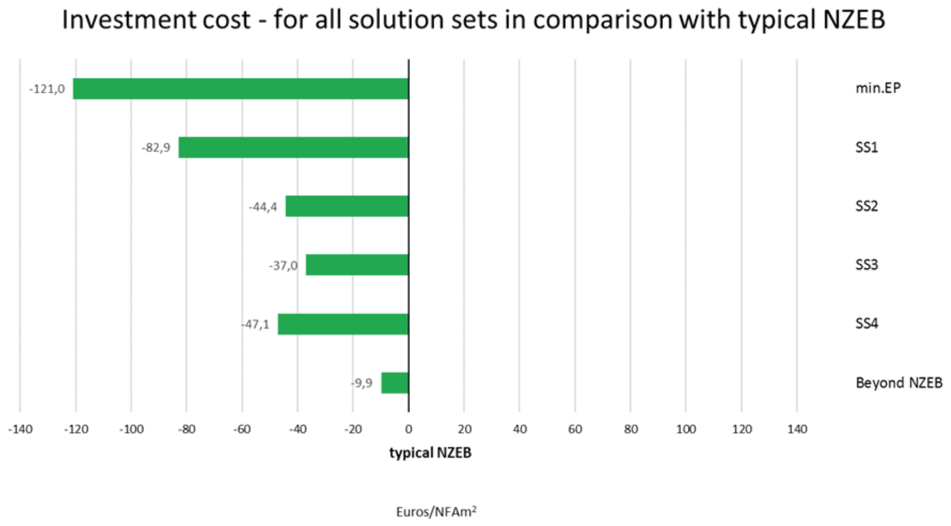

Figure 58: **Summary of investment costs of all solution sets in comparison to the typical NZEB level**

6.4. LCA and LCC analyses for the typical NZEB and the alternative NZEB solution sets in comparison with the min. EP level

It can be seen from Figure 59, that both the typical NZEB and all solution sets as alternatives to the typical NZEB are more environmental-friendly solutions compared to the min. EP building.

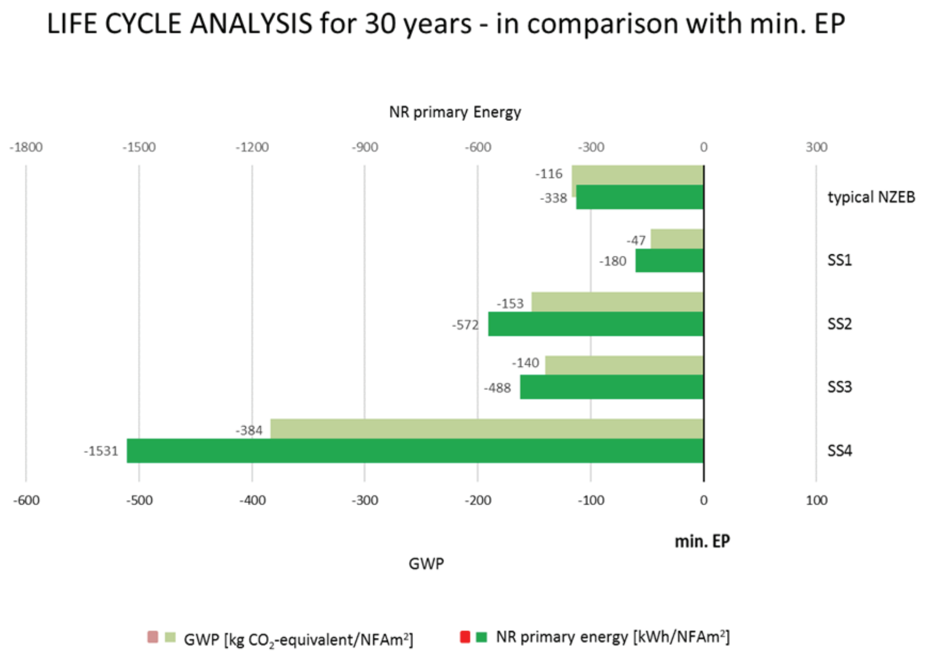

Figure 59: **LCA analyses. Comparison of the typical NZEB and the alternative NZEB solution sets in comparison with the min. EP level**

In contrast, all of them are more costly in comparison to the min. EP. All solution sets are cheaper solution in a period of 30 years in comparison to the typical NZEB, as the NPV is lower. However, they are not cheaper than min. EP, due to the fact that all investment cost by the technologies implementation in all alternative solution and energy performance levels are higher than the min. EP building design, as it can be seen from the following Figure 60.

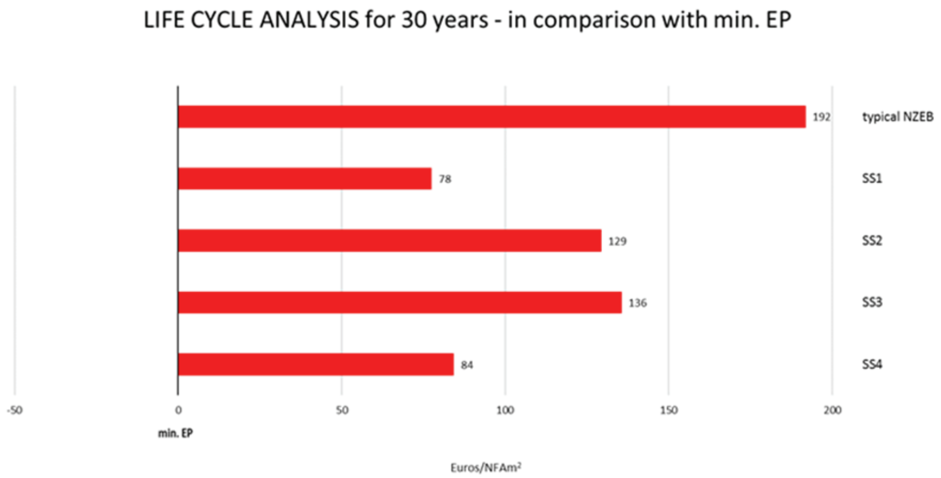

Figure 60: **LCC analyses. Comparison of the typical NZEB and the alternative NZEB solution sets in comparison with the min. EP level**

6.5. LCA and LCC analyses for the typical NZEB, the range of NZEB solution sets and the beyond NZEB in comparison with the min. EP level

Here the typical NZEB, the range of NZEB solution sets and beyond NZEB are compared to min. EP building, where the range of NZEB plots is interpreted as the interval between the best and the worst NZEB solution set result. The results are presented in Figure 61 to Figure 63.

The plots in Figure 61 to Figure 63 show that all the alternatives to the min. EP buildings are more environmental friendly, when comparing greenhouse gas emissions in the form of kg CO2-Equiv./m² and non-renewable primary energy than the min. EP building. However, from a purely economic perspective none is more cost-effective than the min. EP building, but on the other hand this is in line with the cost-optimality principle of the regulatory minimum requirements.

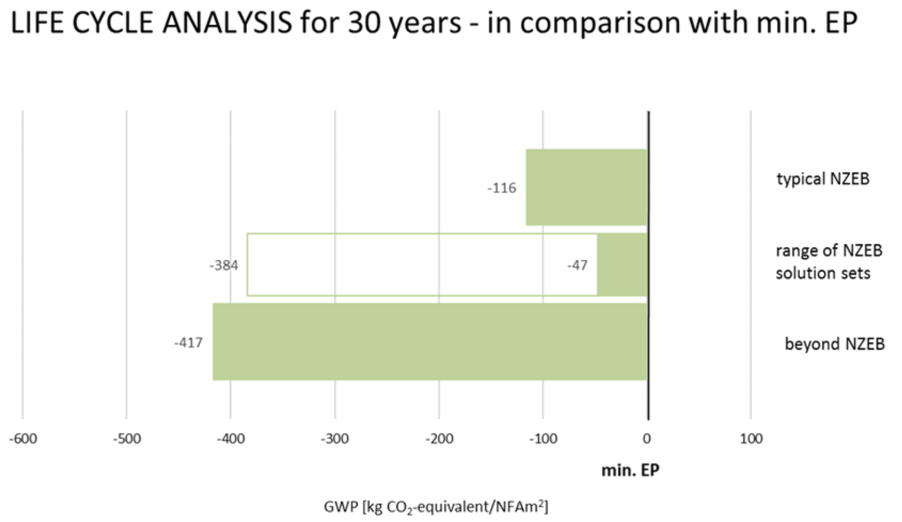

Figure 61: GWP for the typical NZEB, the range of NZEB solution sets and the beyond NZEB in comparison with the min. EP level

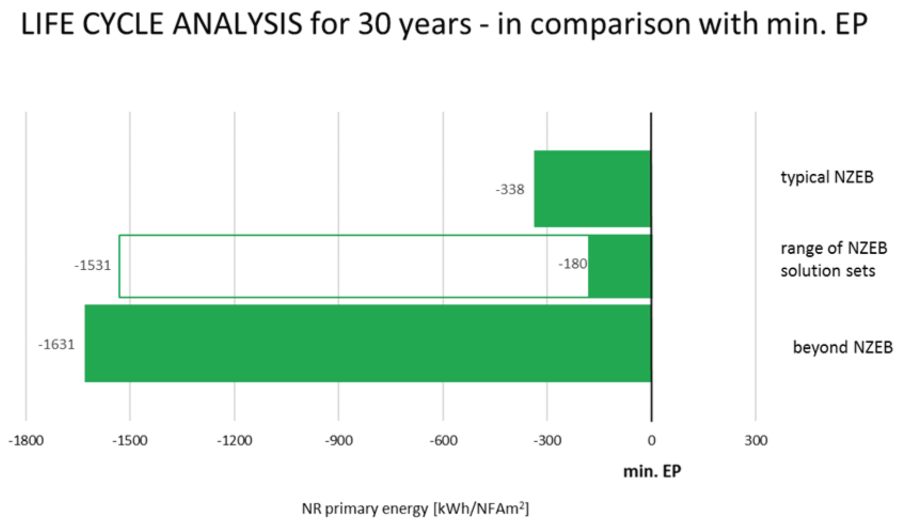

Figure 62: Non-renewable primary energy analysis for the typical NZEB, the range of NZEB solution sets and the beyond NZEB in comparison with the min. EP level

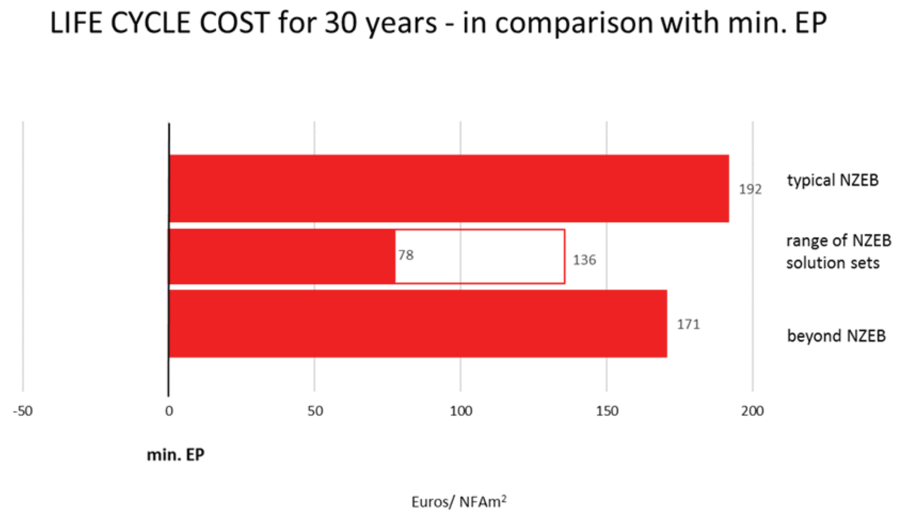

Figure 63: LCC analysis for the typical NZEB, the range of NZEB solution sets and the beyond NZEB in comparison with the min. EP level

6.6. Summary

From the analysis and calculations for Slovenian NZEB it can be seen that there are different options, described in the solution sets that enable lower investment costs in comparison with the typical NZEB, since all solution sets have lower investment costs. Namely, the typical NZEB has a large area of solar collector implemented, which improves the share of RES, but also significantly increases investment costs. This lead to the idea to use heat pumps, mechanical ventilation with heat recovery and photovoltaics in order to reduce the investment costs and at the same time greenhouse gas emissions in and non-renewable primary energy. Unfortunately, none of the solution sets was cheaper in the 30-years lifetime than the building fulfilling the minimum energy performance requirement level (min. EP), due to implementation of the technologies with higher energy performance, but also higher investment costs in all solution sets. Besides the investment costs, also the net present value for 30 years of all solution sets is lower in comparison with the typical NZEB.

Looking at the greenhouse gas emissions in the form of kg $CO2_{eq.}/m^2$ and non-renewable primary energy over the 30 year period of the LCA analyses, all solution sets, the typical NZEB and the beyond NZEB houses all show improved environmental results in comparison with the min. EP building. The results of calculations are promising, since the NZEB can be environmentally friendly and at the same time exhibit lower costs over the lifetime than the min. EP building. Taking in consideration the global warming potential and possible carbon taxes, additional investment costs should be neglected. However, when designing a building and its building services, it is important to consider building's location and to reach the NZEB level with the energy carriers nearby in appropriate combination of technologies for renewable energy sources.

In Slovenia alternative solution sets for NZEBs tending to achieve lower investment and life-cycle costs comparing to typical NZEB are related to district heating in combined space heating and DHW system and air-to-water heat pump for either both, space heating and DHW or for DHW only, in that case in combination with a condensing boiler for heating; combined also with roof PV panels. All solution sets are balanced by reduced or increased insulation levels at the building envelope and windows (2- or 3- glazing) and variations of ventilation systems with different heat recovery rates to meet NZEB / NZEB-like threshold.

LCC for alternative NZEB solution sets demonstrated lower costs in 30 years life-time with comparison to typical NZEB. LCA analysis showed lower GWP in comparison with min. EP and typical NZEB - for most of alternatives.

Beyond NZEB (with eco-insulation, HP and PV panels, and mechanical ventilation with heat recovery) has still got higher investment but lower LCC costs and lower GWP than all other NZEB solutions.

7. Buildings in Italy

The typical Italian multi-family house is a multi-family residential building of four floors (three residential and one public) with a total of 29 apartments, 4 staircases, and a civic centre at ground floor. The storey height is 2.7 m and the total building height is 13.3 m. The apartments range from 45 to 95 m^2, with an average net floor area (NFA) of 74 m^2 (NFA is about 85% of GFA). The GFA of each apartment is 87 m^2. The total apartments net floor area is 2127 m^2_{NFA}, while including also the civic centre it raises up to 2468.5 m^2_{NFA}. All energy values and cost values in the Italian buildings are related to the net floor area.

Both the minimum EP version and NZEB configurations of the buildings fulfills all the standard requirements defined in [IT1], [IT2] and the simulations have been performed in accordance to the national technical specification UNI/TS 1300 series [IT3].

It must be observed that NZEB requirements, as defined in the relevant Italian standard, are not based on the achievement of prescribed energy performances but on the compliance of several prescriptions, such as:

- Maximum values of transmittance for defined building envelope indicators;
- 50% of energy uses provided by renewable sources and contemporarily to cover the 50% of total energy demand (heating, cooling and DHW) with renewable sources.;
- Minimum efficiency of the energy systems (space heating and cooling, ventilation, domestic hot water);

This approach allows identifying many solutions complying with standard requirements without being obliged to observe mandatory levels of energy performances. It thus opens the doors to the design of different cost-effective solutions.

The typical NZEB building is a real case study located in the centre of Italy. According to this, investment cost data have been taken from the bill of quantities of the real building. The prices of proposed technologies (envelope and technical systems) in the low-cost solution sets, were either calculated as unitary variation (€/m^3) of the bill or quantities or asked to real construction companies.

In Italy beyond NZEB is defined as “0” energy building demand without including household electricity.

Italy has a wide variety of climatic conditions. The national building energy codes identify six classes, based on the heating degree days, calculated in base 20 °C. The classes range from A (below 600 degree days) to F (above 3000 degree days). In this project, two macro-classes were identified and represented by two large cities: Rome and Turin. Energy, economic and life cycle analysis were performed in both cities and results are shown in the following sub-sections.

7.1. Rome

Rome, 1440 degree days, is representative of zones from A to D, with milder climatic conditions, typical of central and southern zones. The characteristics of the case study building are adjusted to the requirements of the reference climatic zone for both minimum EP level building and typical NZEB. The following tables gives an overview of the technologies implemented for each building level in Rome.

7.1.1. Building energy levels with parameters

Table 22: Technologies set overview for each building level

	Technologies	Min. EP	Typical NZEB	SS1	SS2	SS3	SS4	Beyond NZEB
Envelope	Autoclaved concrete brick with increased insulation, facade			x	x	x	x	x
	Increased insulation, roof		x	x	x	x	x	x
	Increased insulation, ground floor		x	x	x	x	x	x
	Traditional 2-layer windows	x	x					
	Monoblock 2-layer windows			x	x	x	x	x
Technical building systems	Air-water heat pump	x	x		x			x
	Gas condensing boiler, 94 kW	x	x	x	x		x	x
	Floor heating	x	x					
	Traditional radiator			x			x	
	Low-temperature radiator				x			x
	Electric heater					x		
Renewable energy systems	PV panels on roof	x	x	x	x	x	x	x
	Solar heating	x	x	x		x	x	

Table 23: Environmental load used for LCA calculation

Energy	PE non-renewable [kWh/kWh (or MJ/MJ)]	GWP, CO_2,eq. [kg/kWh]
Natural gas, IT	1.05	0.20
Electricity, IT	1.95	0.445

Table 24: Final energy demand used for LCA and LCC calculation

	Final electricity demand [kWh/yr]	Final energy demand: gas [kWh/yr]	Total final energy demand [kWh/yr]	Total final energy demand [kWh/(NFAm^2 yr)]
Min. EP	3,924	35,264	39,189	15.9
Typical NZEB	1,519	23,110	24,629	10.0
SS1	0	28,987	28,987	11.7
SS2	6,956	940	7,896	3.2
SS3	8,431	18,808	27,238	11.0
SS4	0	29,222	29,222	11.8
Beyond NZEB	0	588	0	0.2

Table 25: Non-renewable primary energy demand used for LCA

	Non-renewable primary energy demand: electricity [kWh/yr]	Non-renewable primary energy demand: gas [kWh/yr]	Total non-renewable primary energy demand [kWh/yr]	Total non-renewable primary energy demand [kWh/(NFAm^2 yr)]
Min. EP	7,652	37,028	44,680	18.1
Typical NZEB	2,962	24,265	27,228	11.0
SS1	0	30,437	30,437	12.3
SS2	13,564	987	14,552	5.9
SS3	16,440	19,748	36,188	14.7
SS4	0	30,683	30,683	12.4
Beyond NZEB	0	617	617	0.3

Table 26: Energy cost data used for LCC calculation

Energy cost	Euros / kWh
Gas	0.076
Electricity	0.200

Table 27: Financial figures to calculate the net present value in LCC analyses

Financial figures	Value
Discount rate	4.0%
Tax of interest income	0%
Inflation of energy • Gas • Electricity	 2.3%/year 3.4%/year
Inflation of maintenance	2.0%/year
Expected economic lifetime	30 years

7.1.2. LCA and LCC analyses comparison of the three building levels

In this section the life cycle assessment (LCA) and life cycle cost (LCC) analysis of the typical NZEB and beyond NZEB are compared to the minimum energy performance requirement building (min. EP). The main differences between min. EP and NZEB buildings regard the low performing envelope and the lower amount of PV panels and solar collectors in the min. EP solution. The share of renewable sources to be fulfilled in min. EP buildings is 35% of the energy uses, while in NZEB is 50%. Conversely, the differences between the beyond NZEB and the min. EP are consistent:

- Much performing thermal envelope
- Different technologies used for the windows and the external walls
- Low-temperature aluminum radiators instead of heating floor
- Absence of solar thermal collectors
- Increased number of PV panels

According to this, as shown in Figure 64, the environmental impact and non-renewable primary energy are both lower in the NZEB and Beyond NZEB solutions compared to the min. EP. It is mainly due to very high contribute of renewable sources feeding the air-water heat pump. This is particularly relevant for the beyond NZEB case, where the heat pump supplies both heating and DHW.

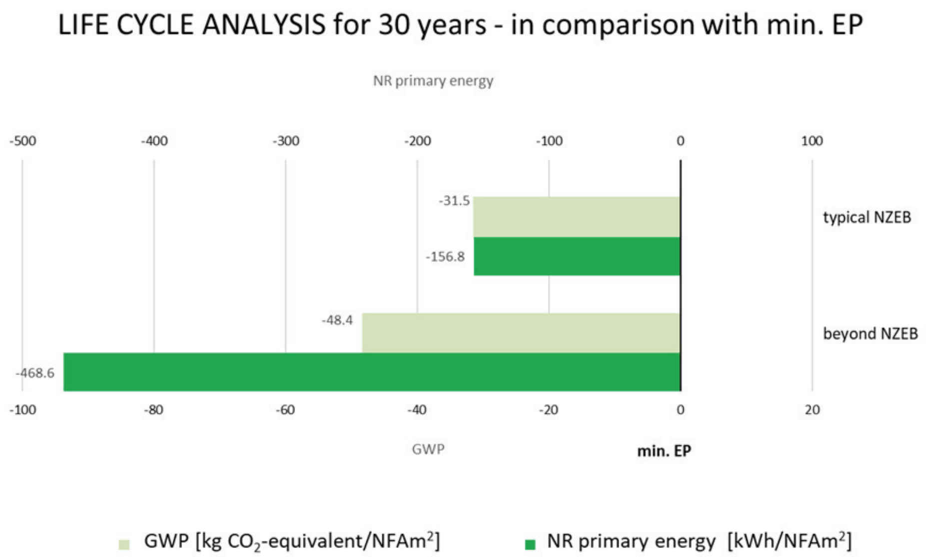

Figure 64: LCA analysis. Typical NZEB and beyond NZEB in comparison with min. EP in a 30 years period.

From the economic perspective (Figure 65), the LCC shows that the typical NZEB solution is overall little more expensive than the min. EP: savings in the operating phase of the building do not compensate for the higher initial investment costs. Conversely, the beyond NZEB is much more profitable than the min. EP due to the larger energy cost reduction in 30 years.

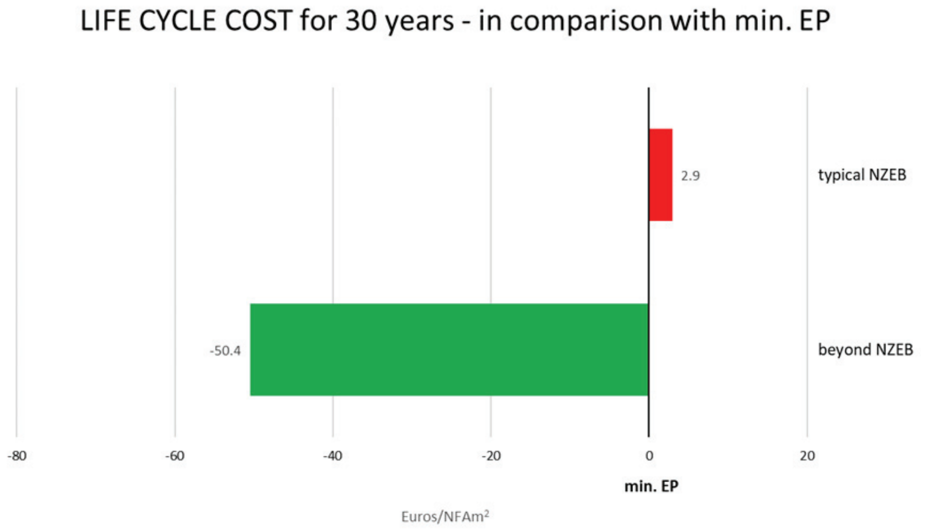

Figure 65: LCC analysis. Typical NZEB and beyond NZEB in comparison with min. EP in a 30 years period.

7.1.3. LCA and LCC analyses for each solution set in comparison with typical NZEB

The Italian CoNZEBs team has assessed four alternative NZEB solution sets in comparison with the typical NZEB for the climatic condition of Rome, which are described in detail in the report [1] and summarized in Table 22.

What is common to all the solution sets is: the use of dry laid systems for the envelope (autoclaved aerated concrete blocks) instead of brick walls with extra coating insulation; the installation of mono-block windows instead of traditional ones. The main differences among the solutions sets regard therefore the technical systems installed and the number of renewable sources.

7.1.3.1 Comparison of SS1 with typical NZEB

The use of autoclaved aerated concrete blocks instead of brick walls, despite they maintain the same values of thermal transmittance, has a considerable role in reducing the environmental impact: the GWP and non-renewable primary energy environmental load are about half time and 4 times less respectively comparing to the typical bricks in NZEB. Furthermore, the use of EPS in the external wall is avoided, whose production has a negative impact on environment. The heat supply is more performing in SS1, due to the removal of the heat pump (the condensing boiler in SS1 supplies both DHW and heating), the reduction of the heating distribution pipes and the replacement of floor heating with aluminium radiators. For all the solution sets, the insulation provided by the floor heating system was replaced with an additional layer of thermal insulation in XPS to respect the transmittance values required by the Standard. Environmental savings of the floor are therefore due to the addition of this type of insulation and the variation of the construction layer (in the typical NZEB it hosts a floor heating system while in the solution sets it does not). In contrast, the higher number of solar collectors causes a slight increase of emissions and NR primary energy. Regarding the energy use, both NR primary energy and the CO_2 emissions are slightly higher than a typical NZEB building due to the use of gas condensing boiler as heating system instead of electrical heat pump. Despite it, the total result is positive comparing to typical NZEB building, especially in terms of NR primary energy.

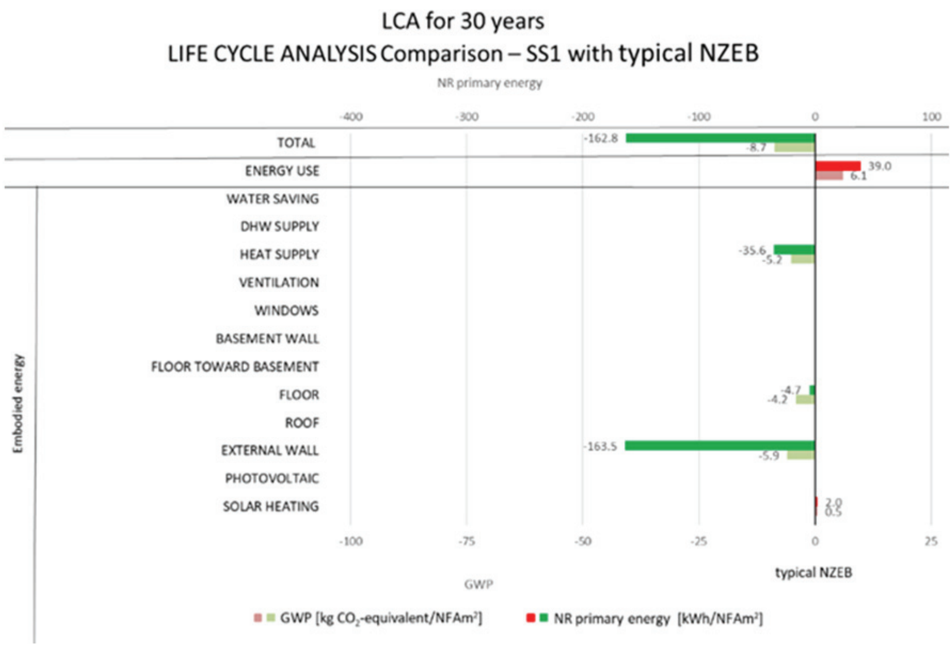

Figure 66: LCA comparison of SS1 with typical NZEB

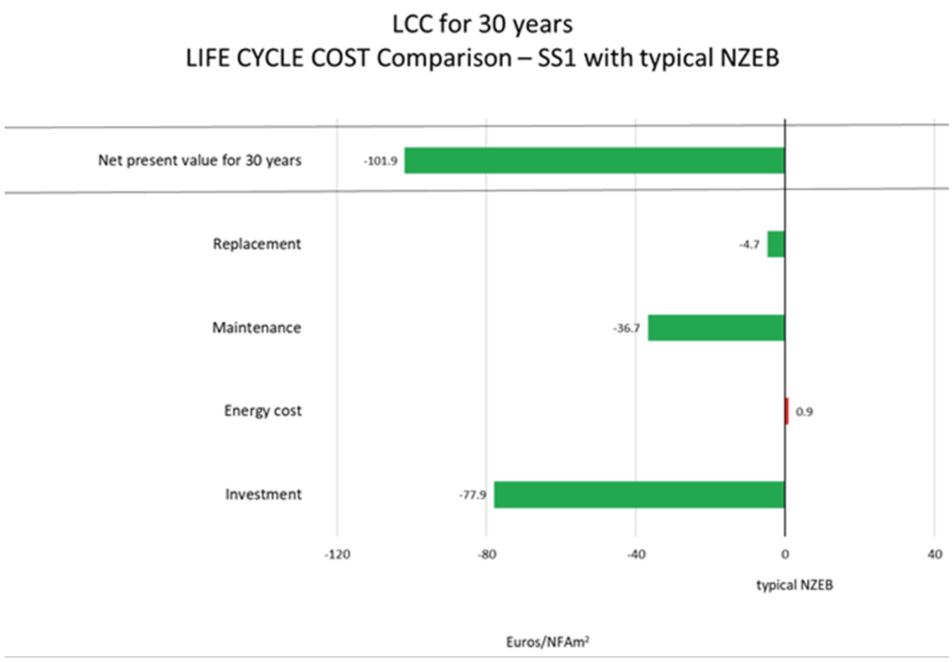

Figure 67: LCC comparison of SS1 with typical NZEB

From the economic point of view (Figure 67), the net present value of this solution is much better in comparison to the typical NZEB building, due to both investment and maintenance costs reduction. The highest savings are observed in the investment costs. The lower maintenance costs in SS1 regard the heating supply; they are expressed as percentage of investment costs: in SS1 the expenses for the condensing boiler are about half of the expenses for the heating pump in the typical NZEB; moreover the expenses for maintenance of aluminium radiators in SS1 are reduced up to -25% compared to the expenses for floor heating in the typical NZEB.

7.1.3.2 Comparison of SS2 with typical NZEB

As in the previous case, the use of autoclaved concrete block instead of traditional brick wall gives a positive environmental impact. This is an electricity driven solution: the air water heat pump is used both for heating and DHW production and the heating distribution is provided with low temperature aluminium radiators. According to this, the condensing boiler is used as a backup system for both services. For this reason, the energy use is much lower in comparison to typical NZEB. Moreover, the solar collectors are eliminated: it causes a decrease of about 8 kWh/m^2 of NR-primary energy and 2 kg CO_2-equivalent/m^2. Regarding the heat supply, it can be noticed that there is an opposite trend: NR primary energy is reduced, while emissions are slightly increased. This is due to the higher number of low-temperature aluminium radiators compared to SS1, whose production causes an increase of CO_2 emissions.

From the economic point of view, this solution is also more profitable in comparison to typical NZEB. The trends are similar as in SS1, but in this case also the energy costs in 30 years are lower than typical NZEB.

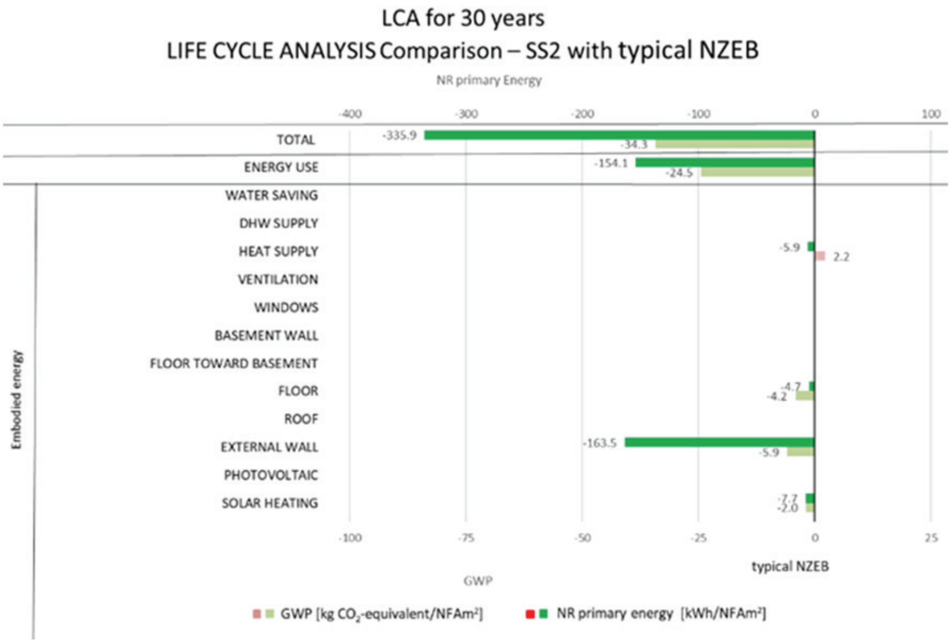

Figure 68: **LCA comparison of SS2 with typical NZEB**

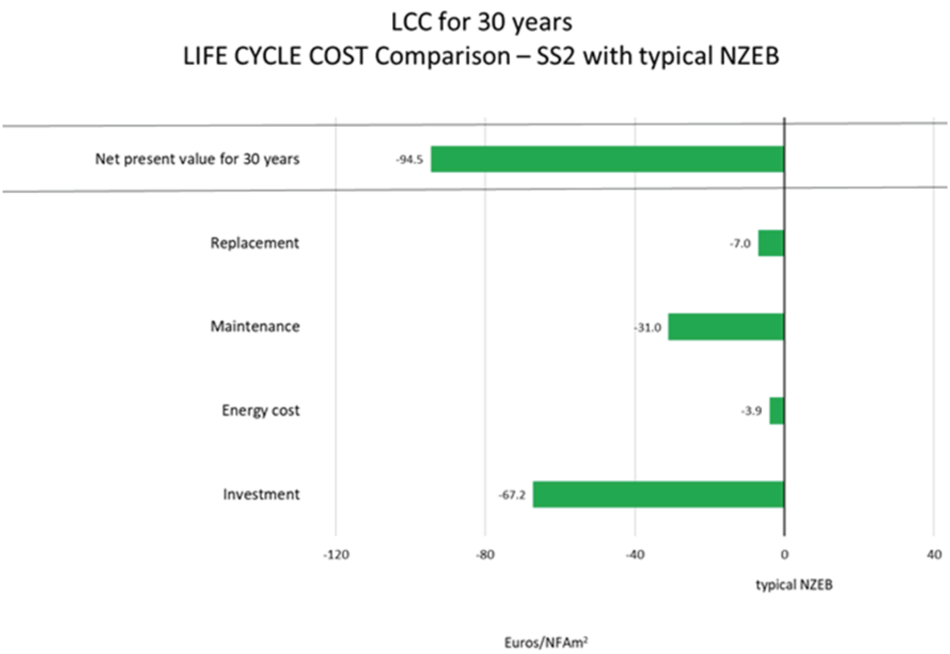

Figure 69: **LCC comparison of SS2 with typical NZEB**

7.1.3.3 Comparison of SS3 with typical NZEB

In this solution, heat supply is directly provided by electric radiators. It thus allows to eliminate the expense for the heat pump and the relative distribution pipes, causing an improvement in terms of environmental loads (reduction up to - 51 kWh/m^2 of NR-primary energy and -9 kg CO_2 -equivalent/ m^2). The increase of solar thermal collectors and PV panels up to 33 m^2 and 163 m^2 respectively has a negative impact on the environmental loads.

The energy use has also raised up, influencing in a negative way the amount of emissions and the NR energy consumption. This scenario has indeed the highest electricity costs compared to the others: when energy from PV panels is not enough, much more electricity is taken from the grid for heating supply using electric radiators compared to the other solutions. The increase of non-renewable primary energy in the operating phase of the building life-cycle is balanced by the positive impacts of the autoclaved concrete bricks. It allows to achieve a reduction of total NR-primary energy up to 99 kWh/m^2 in 30 years. However, the total GWP found in this solution set is negative, showing an increase up to 27 kg CO_2 -equivalent/ m^2.

From the economic perspective, the high savings in investment costs sticks out. Up to 90 €/m^2 can be saved thanks to the cheaper technology’s implementation for heat supply. This clearly translate into a positive effect also in maintenance and replacement costs. Accordingly, an overall very positive NPV is achieved, despite the energy cost increase.

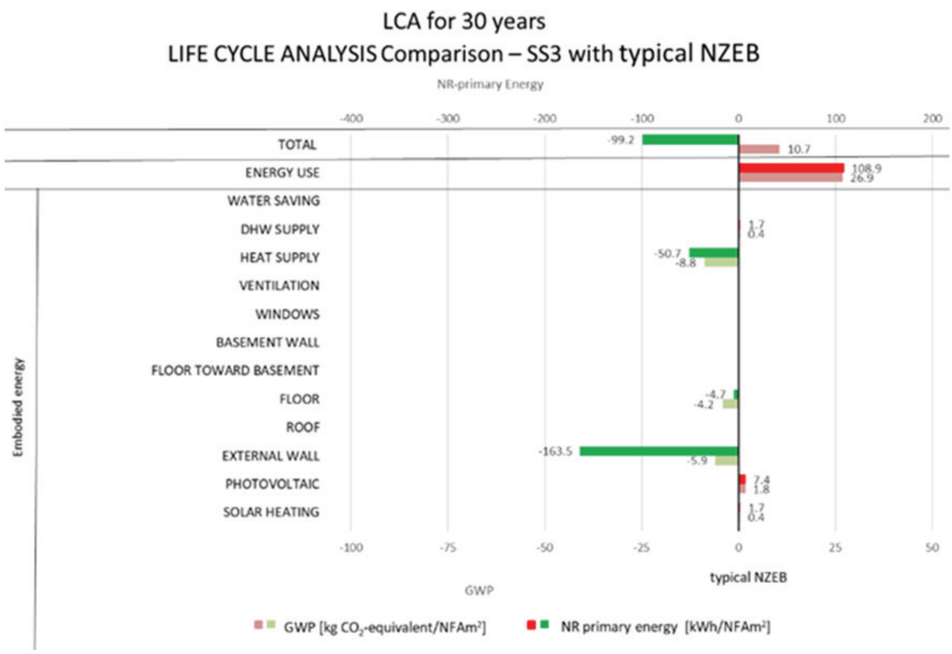

Figure 70: LCA comparison of SS3 with typical NZEB

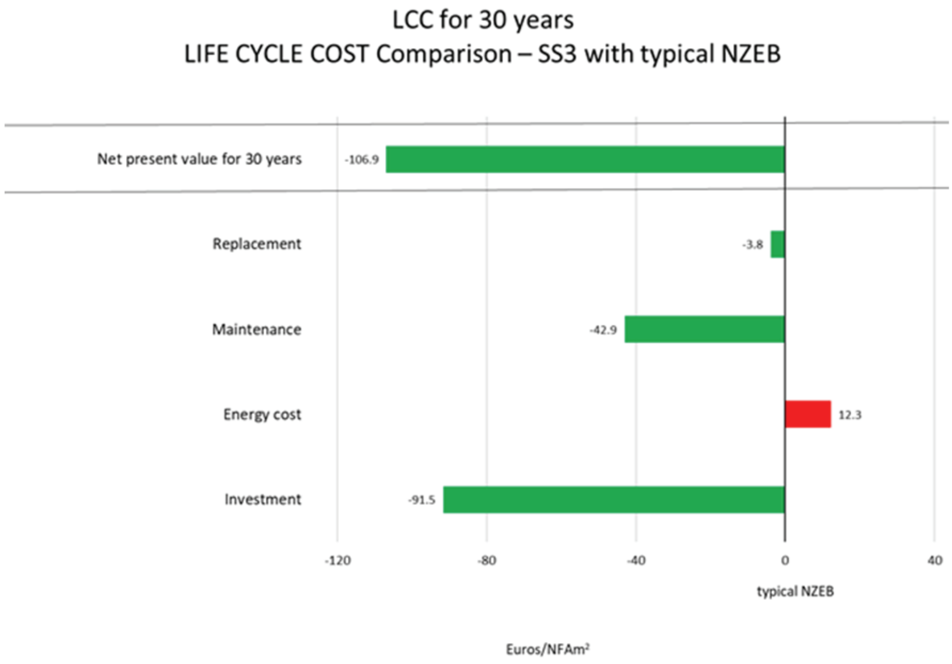

Figure 71: **LCC comparison of SS3 with typical NZE**

7.1.3.4 Comparison of SS4 with typical NZEB

This solution set is similar to SS1 (condensing boiler is used for both heating and DHW services and floor heating distribution system is replaced by aluminium radiators) with the difference that the amount of photovoltaic panels has been considerably reduced, based on the real energy needs of the building. Therefore, the environmental loads are worse during the operating phase of the building: as in SS1, the gas is the main energy source and its consumption is further slightly increased in this case due to the reduction of PV panels. Contrary, the PV area reduction influences positively the amount of CO_2 emissions and NR-primary energy during the production phase of the component, resulting in a positive total outcome both in terms of NR-primary energy and gas emissions.

The economic analysis shows that this solution guarantees the highest savings in the investment phase, combining the low expense of SS1 with a further cost reduction due to the much lower number of PV panels installed. Consequently, the NPV of this solution set is really good, making this SS the most profitable solution among all.

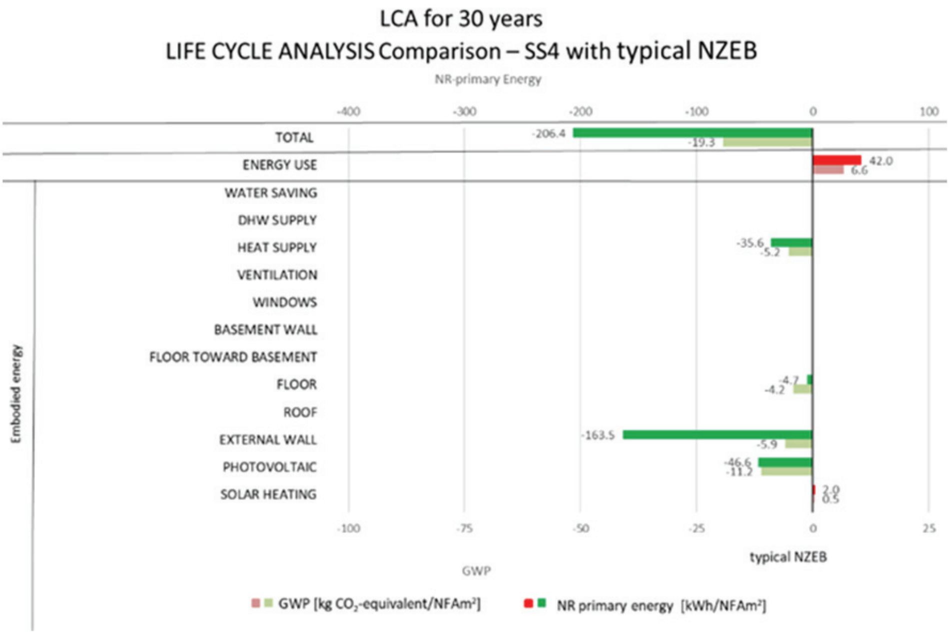

Figure 72: **LCA comparison of SS4 with typical NZEB**

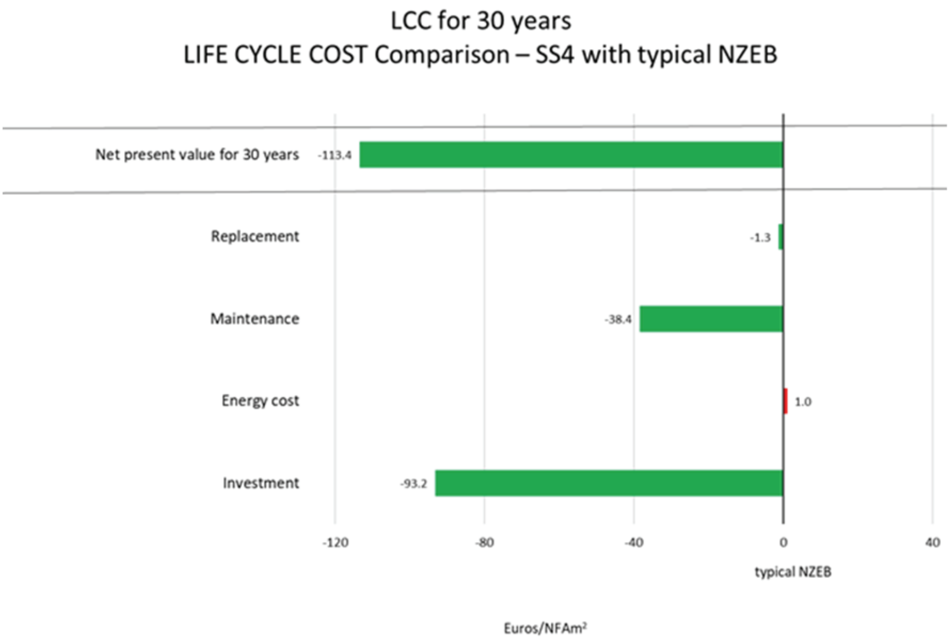

Figure 73: **LCC comparison of SS4 with typical NZEB**

7.1.3.5 Summary of investment costs and net present value in comparison with the typical NZEB

The main goal of this report was to design alternative solution sets to reduce investment cost of a typical NZEB design. As it can be seen from Figure 74, the purpose of this research was achieved. The investment cost and net present value (NPV) of all solution sets has been designed properly, being both cheaper in the first and in the long-term phase of the building life-cycle. What emerged from the results is that SS4, having both the lower investment cost and the lowest NPV in 30 years is the most profit-earning among the four solutions.

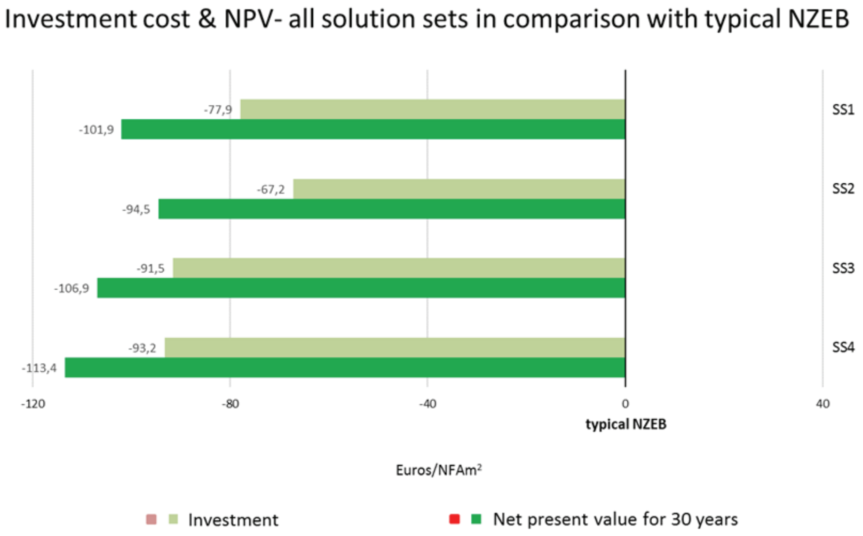

Figure 74: **Summary of investment costs and NPV of all solution set in comparison to the typical NZEB**

Comparing the investment costs of the typical NZEB with all the designed solutions (including min. EP and Beyond NZEB) interesting results emerge in Figure 75. The min. EP is reasonably cheaper during the construction phase of the buildings since less efficient energy requirements are needed according to the requirements compared to typical NZEB (-18 €/m^2) ; the solution sets, thus keeping the highest grade of energy performance as the typical NZEB, were designed in order to be profit-earning, and the target was definitely achieved not only in a long term phase but also in the construction stage; the Beyond NZEB, which is characterized by very low transmittance values and a “0” energy demand, was expected to be more expensive that the typical NZEB. Conversely, a little reduction in the investment cost was achieved also in this case compared to the typical NZEB (about -2 €/m^2). Beyond NZEB solution is indeed similar to SS2 with an increase of PV panels installed and more insulation the envelope. These two variations, compared to SS2, made the investment cost of the beyond NZEB arise, being however lower than the typical NZEB.

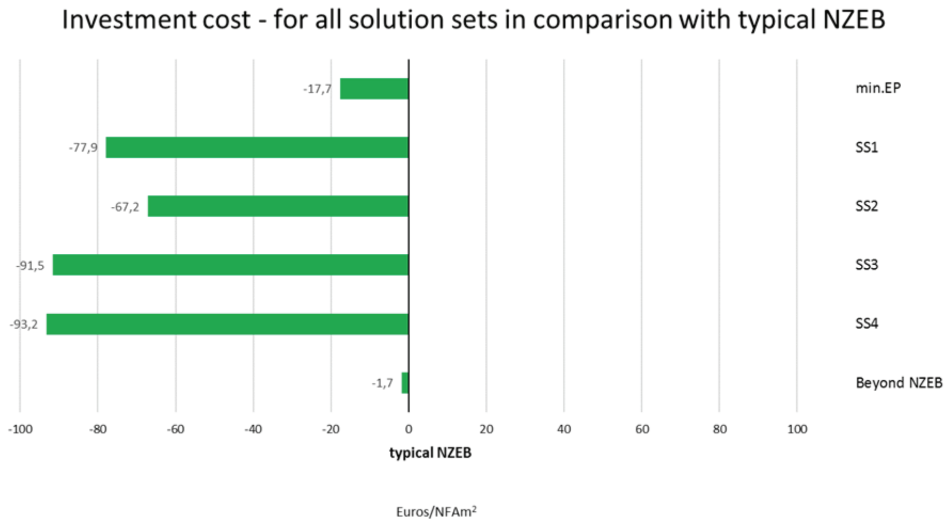

Figure 75: Investment cost overview in comparison with the NZEB level

7.1.4 LCA and LCC analyses for the typical NZEB and the alternative NZEB solution sets in comparison with the min. EP level

The LCA and LCC performance of the typical NZEB and the developed solution sets in comparison to the current minimum energy performance requirements (min. EP) are shown in Figure 76. It shows that all the alternatives are more performing than the min. EP level both in terms of NR-Primary Energy and CO_2 emissions. Among the five, SS2 got the highest scores, showing a reduction of about -490 kWh/m^2 of NR-PE and -66 kg CO_2-equivalent/m^2 compared to min. EP building.

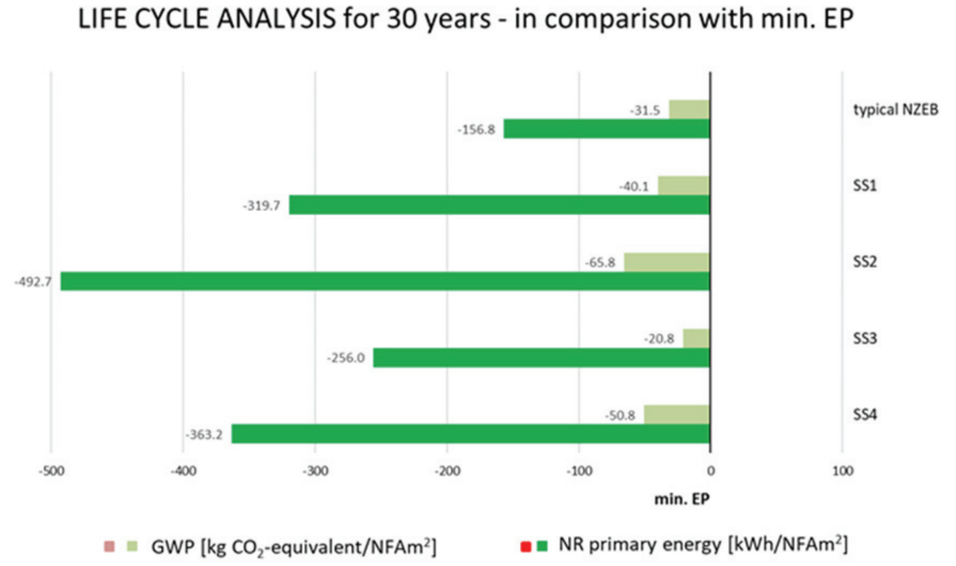

Figure 76: **LCA analyses. Comparison of the typical NZEB and the alternative NZEB solution sets in comparison with the min. EP level.**

Regarding the costs, it can be noticed in Figure 77 that all the alternatives are profit-earning compared to min. EP. Both the investment and energy costs of the solution sets are indeed lower than the typical NZEB as shown in Figure 74; being the economic difference between typical NZEB and min. EP also very low, it results that all the proposed alternatives are very economically efficient, also compared to min. EP. The typical NZEB is only about 3 €/m^2 more expensive than min. EP in a long term analysis of 30 years.

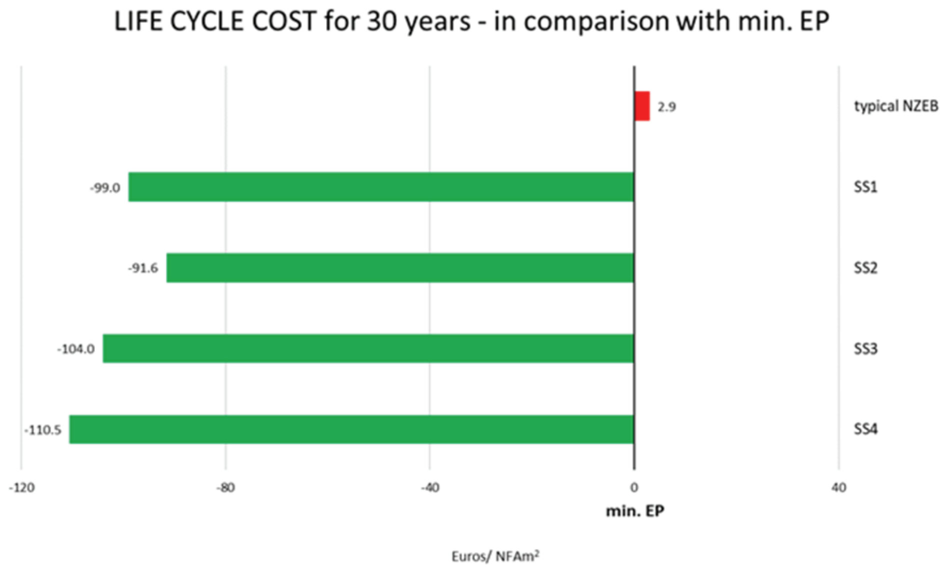

Figure 77: **LCA analyses. Comparison of the typical NZEB and the alternative NZEB solution sets in comparison with the min. EP level.**

7.1.5 LCA and LCC analyses for the typical NZEB, the range of NZEB solution sets and the beyond NZEB in comparison with the min. EP level

In this section the typical NZEB, the range of NZEB solution sets and the beyond NZEB are compared to the min. EP level. The range of NZEB plots solution sets is interpreted as the interval between the best and the worst NZEB solution set results. The results of this comparison are presented in Figure 78 to Figure 80.

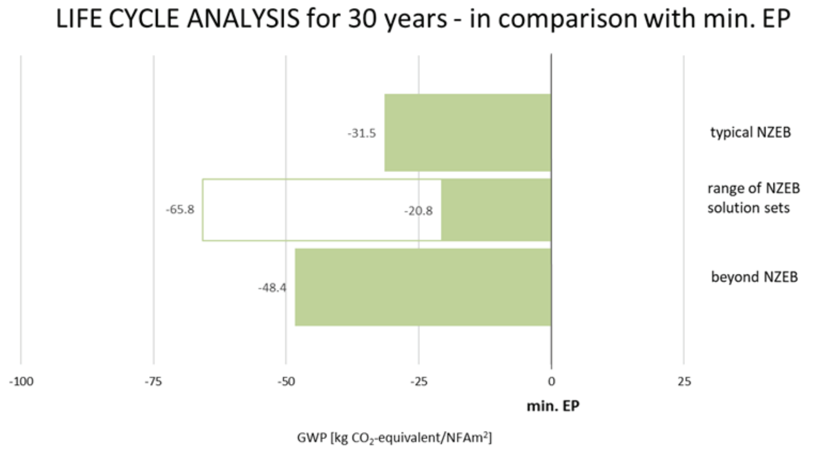

Figure 78: GWP analysis for the typical NZEB, the range of NZEB solution sets and the beyond NZEB in comparison with the min. EP level

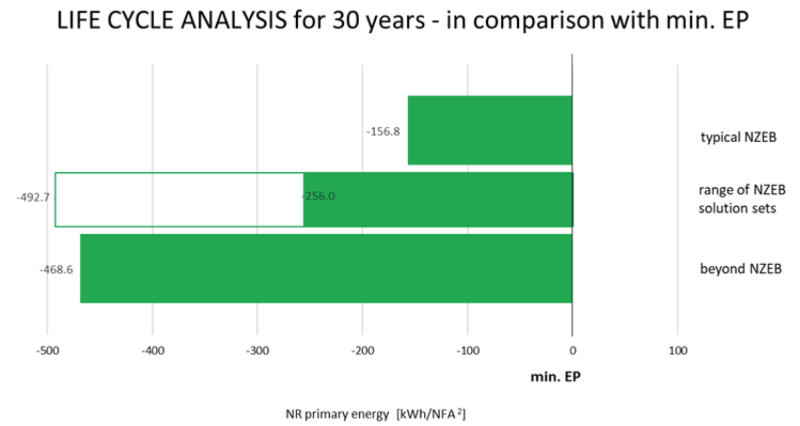

Figure 79: Non-renewable primary energy analysis for the typical NZEB, the range of NZEB solution sets and the beyond NZEB in comparison with the min. EP level

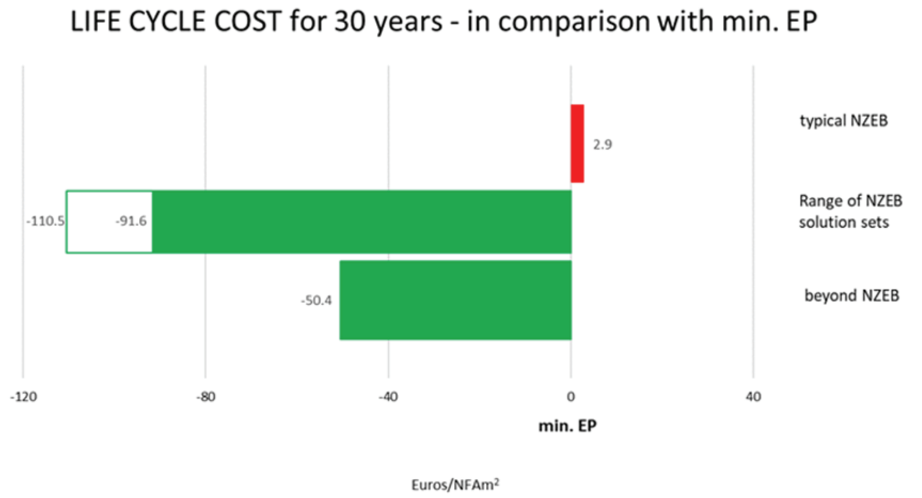

Figure 80: **LCC analysis for the typical NZEB, the range of NZEB solution sets and the beyond NZEB in comparison with the min. EP level**

The plots show that all the solution sets and the beyond NZEB are more environmental friendly than the min. EP building, when comparing greenhouse gas emissions in the form of kg CO_2-equivalent/NFA m² and non-renewable primary energy. Moreover, from a purely economic perspective all SS and beyond NZEB are more cost-effective than the min. EP building.

7.1.6 Summary

The Italian calculations in Rome have shown that all the proposed solutions are more environmental friendly and more profit-earning than the typical NZEB and the min. EP building. All the solutions are characterized by the same transmittance values than the typical NZEB, but different envelope technologies are chosen to lower the investment costs. From the technical point of view, some of them go in the direction of using electricity as main driver for heating and DHW supply, either via heat pumps or electric radiators; others, oppositely, use the gas for the condensing boiler, supplying both heating and DHW. Furthermore, savings are based on lower costs for heating distribution (radiators instead of floor heating).

More in detail, LCA results show that the most performing solution in a long term perspective of 30 years is SS2 with a reduction of non-renewable primary energy up to -335 kWh/m² and a reduction of gas emissions up to 2 kg CO_2 -equivalent/m² compared to typical NZEB. This is an electricity driven solution where the air water heat pump is used both for heating and DHW production.

LCC results show instead that the most profitable solution is SS4 both in terms of investment costs (up to 93 €/m² less than the typical NZEB) and net present value in 30 years (up to

113 €/m^2 less than the typical NZEB). In this scenario the condensing boiler is used for both heating and DHW services, coupled with aluminium radiators. These savings are even more considerable if compared to the min. EP building.

Additionally, it has to be noted that the beyond NZEB solution achieved the best environmental results compared to the min. EP level for non-renewable primary energy (468.6 kWh/m^2) within the 30 years period. These results were predictable, since the beyond NZEB solution is characterized by the highest energy performance, the lowest envelope transmittance values and the highest number of renewable sources installed. Last but not least, the beyond NZEB is also more profit-earning than the min. EP due to the large energy cost reduction in 30 years. Savings in operative costs do indeed compensate for the higher investment costs.

7.2 Turin

Turin, 2617 degree days, representative of climatic zone E (northern and mountain zones) and F (alpine zone). The characteristics of the case study building are adjusted to the requirements of the reference climatic zone for both Minimum EP level building and typical NZEB. The following tables gives an overview of the technologies implemented for each building level in Turin.

7.2.3 Building energy levels with parameters

Table 28: Technologies set overview for each building level

	Technologies	Min. EP	Typical NZEB	SS1	SS2	SS3	SS4	SS5	Beyond NZEB
Envelope	Autoclaved concrete brick with increased insulation, facade			x	x	x	x	x	x
	Increased insulation, wall apartment - staircases								x
	Increased insulation, roof		x	x	x	x	x	x	x
	Increased insulation, ground floor		x	x	x	x	x	x	x
	Traditional 2-layer windows	x	x						
	Monoblock 2-layer windows			x	x	x	x	x	x
Technical building systems	Natural ventilation	x							
	MVHR decentralized		x	x		x		x	x
	MEV exhaust				x		x		
	Air-water heat pump	x	x			x	x		x
	Gas condensing boiler, 94 KW	x	x	x	x	x	x		x
	Floor heating	x	x						
	Traditional radiator			x	x				
	Low-temperature radiator					x	x		x
	Electric radiator							x	
Renewable energy systems	PV panels on roof	x	x	x	x	x	x	x	x
	Solar heating	x	x	x	x			x	

Table 29: Environmental load used for LCA calculation

Energy	PE non-renewable [kWh/kWh (or MJ/MJ)]	GWP, CO_2,eq. [kg/kWh]
Natural gas, IT	1.05	0.20
Electricity, IT	1.95	0.445

Table 30: Final energy demand used for LCA and LCC calculation

	Final electricity demand [kWh/yr]	Final energy demand: gas [kWh/yr]	Total final energy demand [kWh/yr]	Total final energy demand [kWh/(NFAm^2 yr]]
min. EP	13,482	59,479	72,961	29.6
typical NZEB	8,254	34,606	42,860	17.4
SS1	76	41,142	41,218	16.7
SS2	0	40,860	40,860	16.6
SS3	17,672	12,013	29,685	12.0
SS4	16,039	12,201	28,240	11.4
SS5	16,621	18,620	35,241	14.3
beyond NZEB	418	6,254	6,671	2.7

Table 31: Non-renewable primary energy demand used for LCA

	Non-renewable primary electricity demand [kWh/yr]	Non-renewable primary energy demand: gas [kWh/yr]	Total non-renewable primary energy demand [kWh/yr]	Total non-renewable primary energy demand [kWh/(NFAm^2 yr)]
min. EP	26,290	62,453	88,743	36.0
typical NZEB	16,095	36,336	52,431	21.2
SS1	148	43,199	43,347	17.6
SS2	0	42,903	42,903	17.4
SS3	34,460	12,614	47,074	19.1
SS4	31,276	12,812	44,087	17.9
SS5	32,411	19,551	51,962	21.1
beyond NZEB	815	6,566	7,381	3.0

Table 32: Energy cost data used for LCC calculation

Energy cost	Euros/kWh
Gas	0.076
Electricity	0.200

Table 33: Financial figures to calculate the net present value in LCC analyses

Financial figures	Value
Discount rate	4.0%
Tax of interest income	0%
Inflation of energy • Gas • Electricity	 2.3%/year 3.4%/year
Inflation of maintenance	2.0%/year
Expected economic lifetime	30 years

7.2.4 LCA and LCC analyses comparison of the three building levels

In this section the life cycle assessment (LCA) and life cycle cost (LCC) analysis of the typical NZEB and beyond NZEB are compared to the minimum energy performance requirement building (min. EP). In Turin the main differences between min. EP and typical NZEB regards the low performing envelope, the lower amount of PV panels and solar collectors and the use of natural ventilation instead of the Mechanical Ventilation with Heat recovery in the min. EP solution. The amount of PV panels between the typical NZEB and the min. EP building decreases from 142 m^2 to 57 m^2, while the number of solar collectors from 22 to 7 modules.

Conversely, the differences between the beyond NZEB and the min. EP are the following:

- Much performing thermal envelope
- Different technologies used for the windows and the external walls
- Low-temperature aluminum radiators instead of floor heating
- Heat pump supplying both heating and DHW
- Absence of solar thermal collectors
- Increased number of PV panels
- MVHR instead of natural ventilation

According to this, as shown in Figure 81, the environmental impact and non-renewable primary energy are both lower in the NZEB and beyond NZEB compared to the min. EP. The differences in environmental savings between typical and beyond NZEB are mainly due to the increase of renewable sources, the use of a more performing envelope (with different technologies), the replacement of the floor heating with radiators.

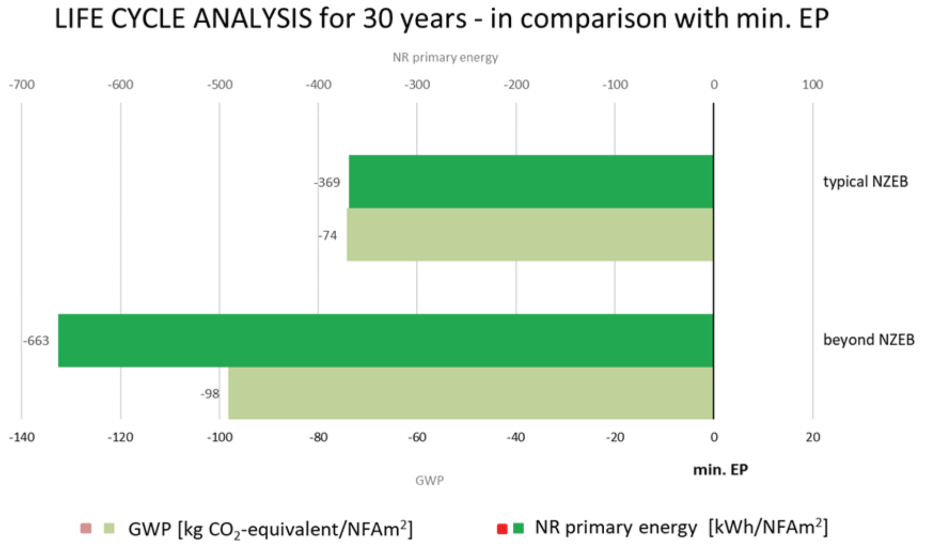

Figure 81: LCA analysis. Typical NZEB and beyond NZEB in comparison with min. EP in a 30 years period.

Conversely, from the economic point of view (Figure 82), the LCC shows that both the NZEB and beyond configurations are more expensive than the min. EP. Nevertheless, it can be noticed that the beyond NZEB solution is more profit-earning compared to the typical NZEB. The investment costs of the typical NZEB and beyond NZEB are both higher than the min.EP and the beyond NZEB is understandably the most expensive among the three. In particular, the difference in investment costs between min. EP and beyond NZEB is about 2 times higher than the difference in investment costs between min. EP and typical NZEB. Nevertheless, energy and maintenance costs in 30 years lifetime of the beyond NZEB are very low and can compensate for the higher initial investment costs. As a result, it can be said that also in Turin as in Rome the beyond NZEB is more profitable than the typical NZEB.

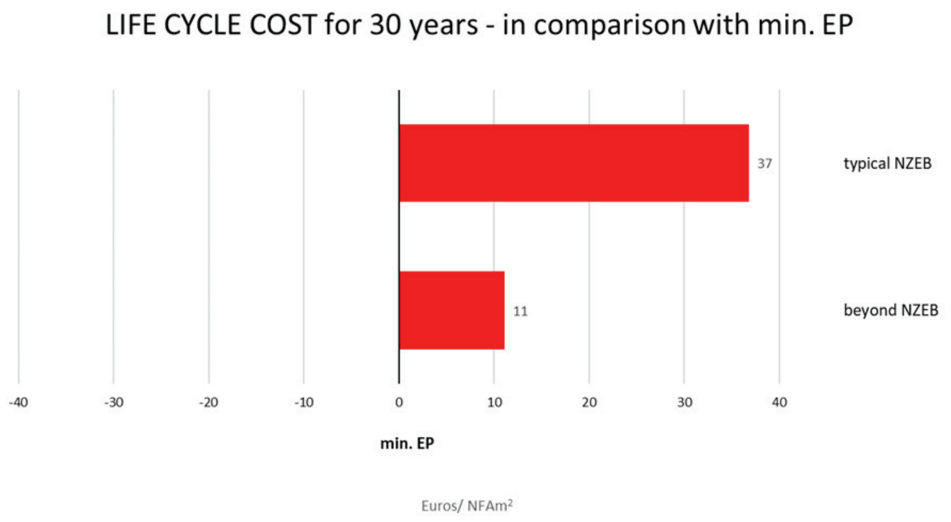

Figure 82: LCC analysis. Typical NZEB and beyond NZEB in comparison with min. EP in a 30 years period.

7.2.5 LCA and LCC analyses for each solution set in comparison with typical NZEB

The Italian CoNZEBs team has assessed five alternative NZEB solution sets in comparison with the typical NZEB for the climatic condition of Turin, which are described in detail in the report [1] and summarized in Table 28.

As in Rome, the envelope of the five solution sets was modified: autoclaved aerated concrete blocks are used instead of brick walls with extra coating insulation. Additionally, mono-block windows are installed instead of traditional ones. Two of the five scenarios have the same transmittance values of the building envelope as in the typical NZEB (scenarios 1 and 3), while the other three scenarios have a Super NZEB envelope. In Super NZEB scenarios, transmittances of the walls, roof and ground floor are lower than the values required in the NZEB Italian Standards: 45 cm low-energy blocks are used for the walls; the rooftop and the ground floor are insulated with additional insulating layers of XPS.

The main differences among the solutions sets regard therefore the technical systems installed and the number of renewable sources.

7.2.5.1 Comparison of SS1 with typical NZEB

As in Rome, the installation of autoclaved aerated concrete blocks largely influences the environmental impact. The elimination of the floor heating system allows to simplify and reduce the structural part of the floor and to eliminate the EPS insulation layer, which made the environmental load decrease up to -5 kWh/m^2 of NR-primary energy and about -5 kg CO_2-equivalent/ m^2.

Moreover, in the production process, the gas condensing boiler connected to radiators is also more environmental friendly than the use of the heat pump (+ gas condensing boiler as backup system) feeding the floor heating system. On the contrary, the higher number of solar collectors causes a slight increase of emissions and NR primary energy compared to the typical NZEB.

Energy demand during the study period of 30 years is lower than the energy demand of a typical NZEB: reductions in the energy use up to -110 kWh/m^2 of NR-primary energy and about -28 kg CO_2-equivalent/ m^2 are therefore achieved. Summing up all these results, SS1 is the best solution among the five in terms of environmental load.

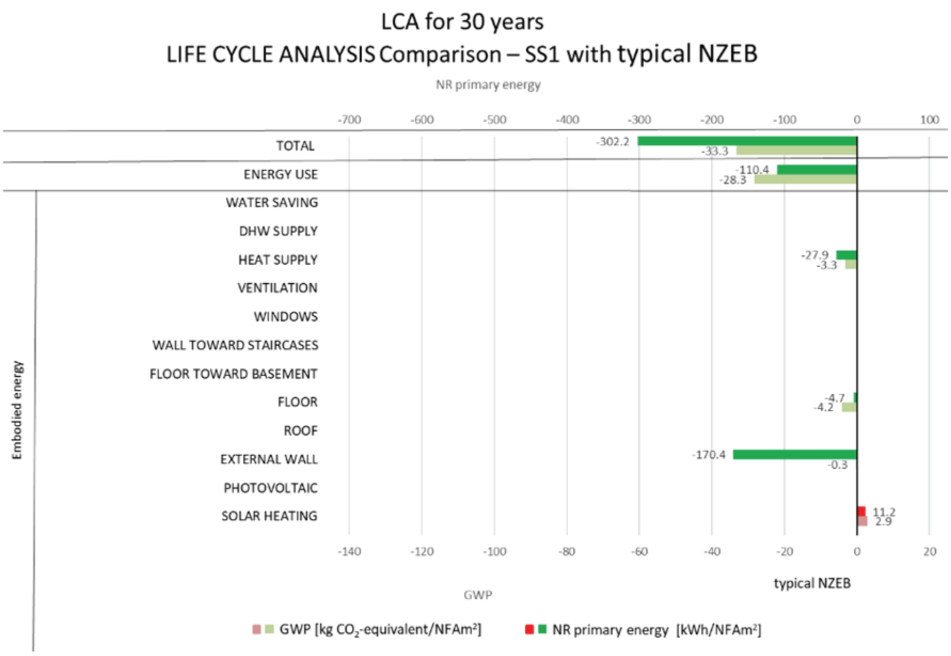

Figure 83: LCA comparison of SS1 with typical NZEB

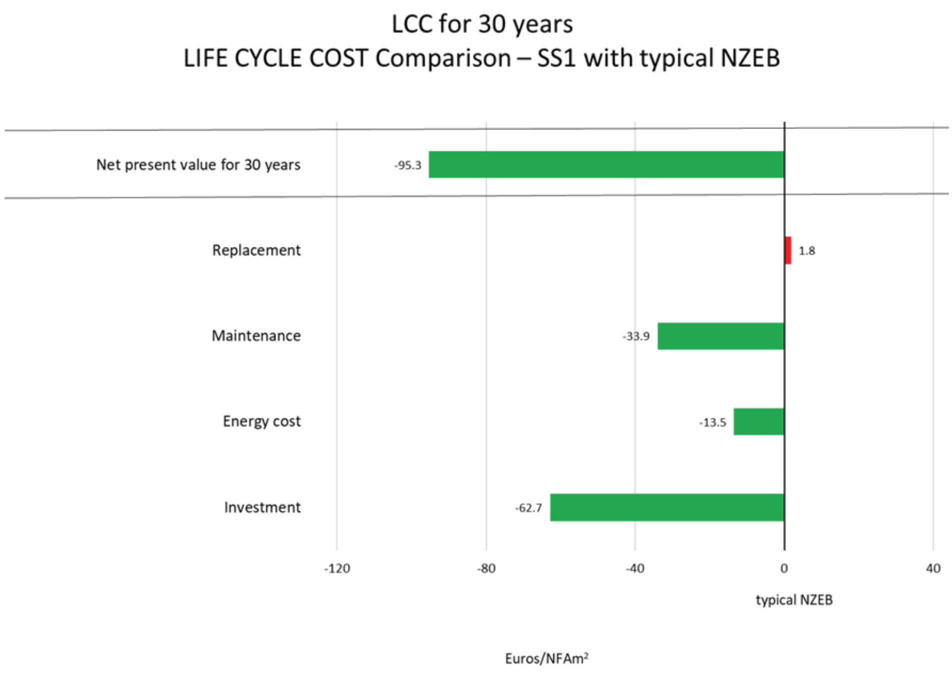

Figure 84: LCC comparison of SS1 with typical NZEB

From the economic point of view (Figure 84) the net present value of this solution is much better in comparison to the typical NZEB building, due to both investment and maintenance costs reduction. High savings are observed in the investment costs where up to 63 €/m^2 are saved; the main cause is the elimination of the floor heating and the distribution pipes. The lower maintenance costs in SS1 also regard the installation of a simpler heating supply system. Conversely, the replacement cost is slightly higher compared to the typical NZEB. Regarding the energy costs, the use of the condensing boiler for both heating and DHW supply allows to minimize the use of electricity (which is also mainly provided by the PV panels). Additionally, also gas consumption is minimized due to the increase of solar collectors compared to the typical NZEB. The combination of these two aspects allows to achieve considerable economic savings in the energy costs in 30 years.

7.2.5.2 Comparison of SS2 with typical NZEB

In this scenario, the envelope has lower transmittance values than the typical NZEB (Super NZEB scenario). The technical systems and the surface areas of renewable sources are the same as in SS1; a mechanical extraction ventilation system without heat recovery is installed.

In Figure 85, it can be noticed that the external wall has a very good performance in terms of NR primary energy but the amount of emissions is higher than the typical NZEB. In this solution a bigger autoclaved block (45 cm) was used compared to SS1 to get lower transmittance values. The index of non-renewable primary energy/ m^2 for producing autoclaved concrete blocks is 4 times lower than traditional bricks, while the global warming potential/m^2 is only half time lower. Since the amount of material used for producing the largest autoclaved block is sizeable, the good environmental performance of this block cannot compensate for the total amount of generated CO_2 emissions.

Similarly, more XPS insulation is placed in the floor and the roof of this solution for lowering thermal transmittance of the envelope, causing an increase of non-renewable primary energy and CO_2 emissions compared to typical NZEB. Regarding solar collectors and heat supply, the same results are achieved as in SS1. The installation of mechanical ventilation without heat recovery allows to reduce the environmental load but the result is negligible.

Summing up, despite some negative impacts, the total environmental load of this solution is lower than typical NZEB.

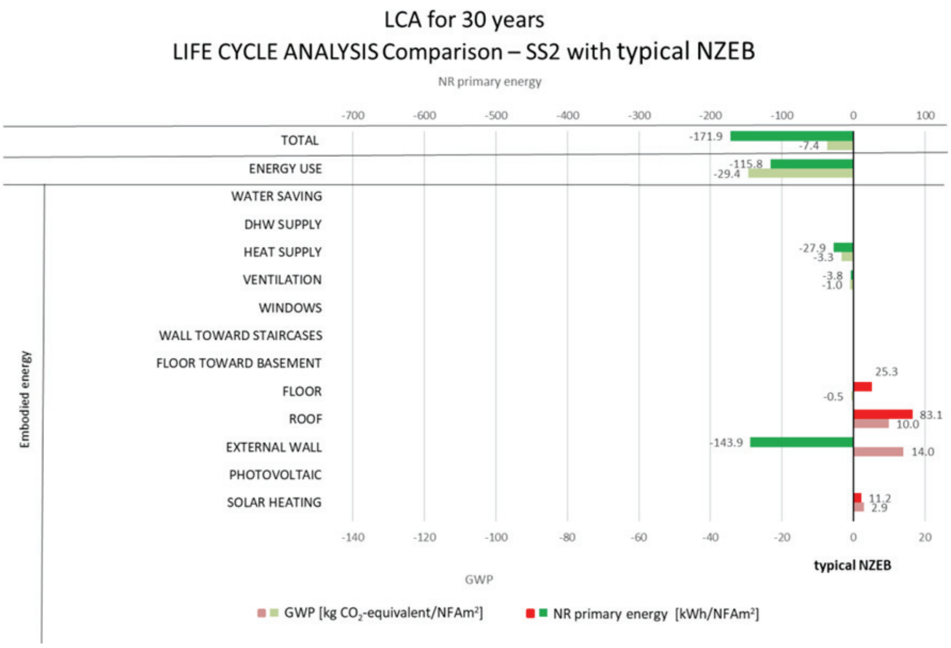

Figure 85: **LCA comparison of SS2 with typical NZEB**

From the economic perspective, results are similar as in SS1. Regarding the investment costs, the higher expense for the envelope is balanced by the lower cost of mechanical extract ventilation compared to MVHR. The simpler ventilation system allows to obtain higher savings in maintenance costs, also compared to SS1. Consequently, the NPV of this solution is very low compared to the typical NZEB, making this SS the most profitable solution among all.

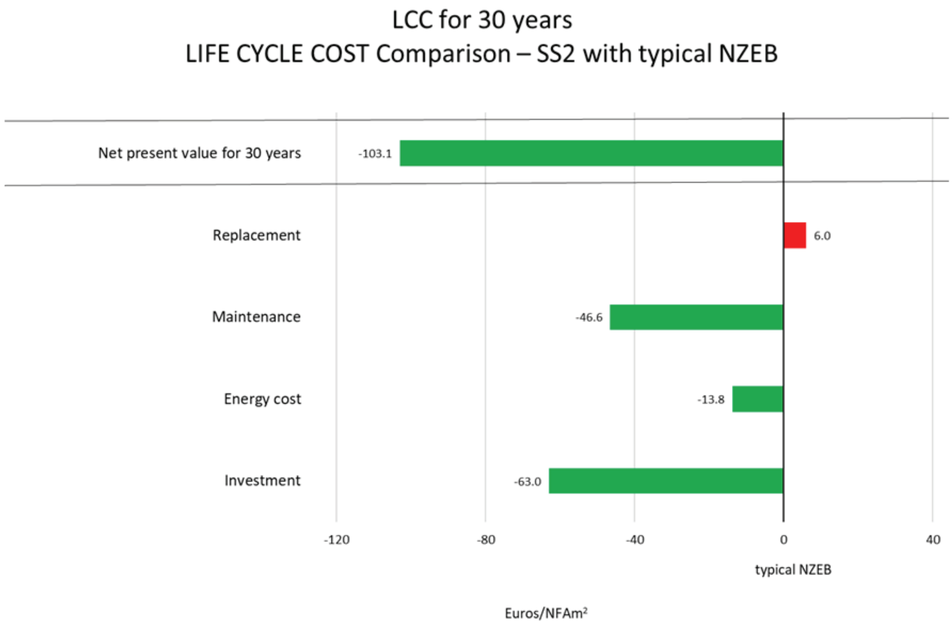

Figure 86: LCC comparison of SS2 with typical NZEB

7.2.5.3 Comparison of SS3 with typical NZEB

In this scenario, the environmental impact of external wall, floor and solar collectors is positive compared to typical NZEB. External wall is made up of autoclaved blocks as in SS1 complying with the minimum NZEB requirements, which makes both the environmental indices decrease; in the floor, the elimination of the EPS layer and the floor heating system allows to reduce both the non-renewable primary energy and the GWP; solar collectors are not installed. Heat supply only presents slightly negative values: the heating system is the same (heat pump is used both for heating and DHW production) as in the typical NZEB but floor heating system is replaced with low-temperature aluminium radiators. In this case the number of radiators is higher than SS1, causing a little increase of non-renewable energy index and GWP. Nevertheless, the overall results achieved are very positive.

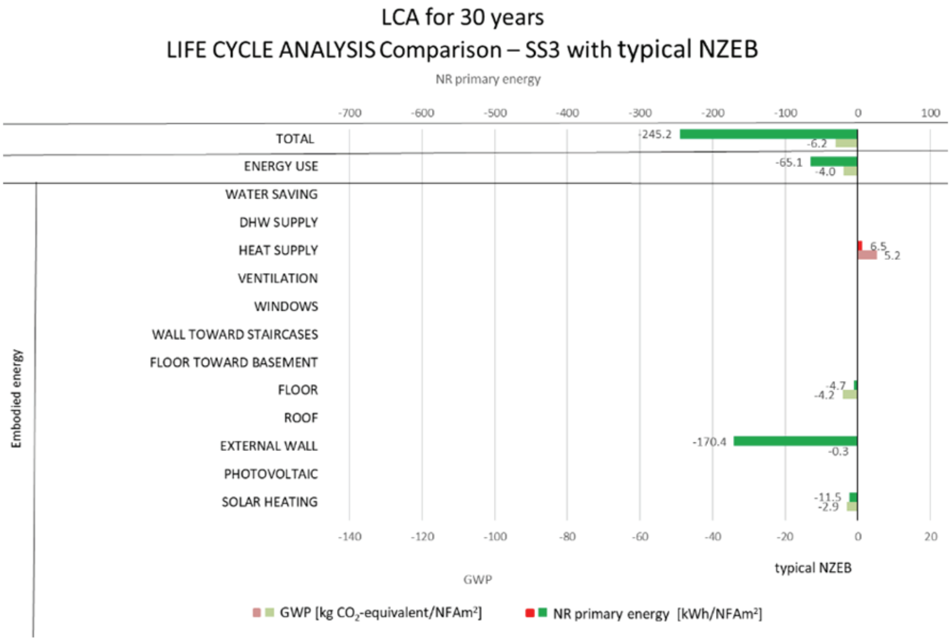

Figure 87: LCA comparison of SS3 with typical NZEB

The LCC analysis shown in Figure 88, demonstrates that the NET present value in 30 years is positive. Energy costs are higher than the base case since solar collectors are not installed: in this climate zone the heat pump which supplies both DHW and heating, needs the support of condensing boiler quite frequently, due to the low outdoor temperature in winter. According to this, the need of gas from the grid in this solution is higher, especially due to the absence of solar collectors, which causes an increase in the energy costs. Maintenance costs in this case are lower both for the absence of solar collectors and the installation of a simpler heating distribution system (low temperature radiators).

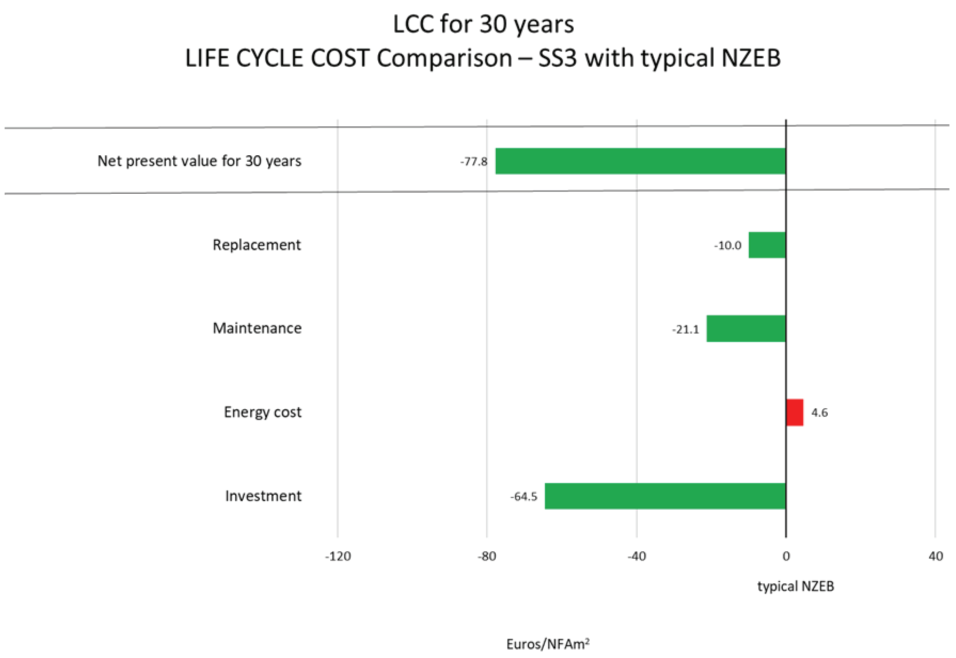

Figure 88: LCC comparison of SS3 with typical NZEB

7.2.5.4 Comparison of SS4 with typical NZEB

This solution set is a SuperNZEB scenario, where the technical systems and the surface areas of renewable sources are the same as in scenario 3 (heat pump used both for heating and DHW production + low temperature radiators, solar collectors not installed) apart from the ventilation service which is provided by a mechanical ventilation system without heat recovery.

As in SS2, GWP emitted during the production of autoclaved blocks is higher than the production of brick wall + insulation placed in external walls of typical NZEB. Moreover, the addition of insulation in floor and roof also causes an increase of the environmental loads. Furthermore, regarding the heat supply, as in SS3 the higher amount of radiators causes a little increase of non-renewable energy index and GWP. The installation of mechanical ventilation without heat recovery allows to reduce the environmental load but the result is negligible.

This scenario sums up indeed both the negative aspects of SS2 and SS3. Therefore, all these actions result in a positive NR primary energy impact but in a negative overall GWP.

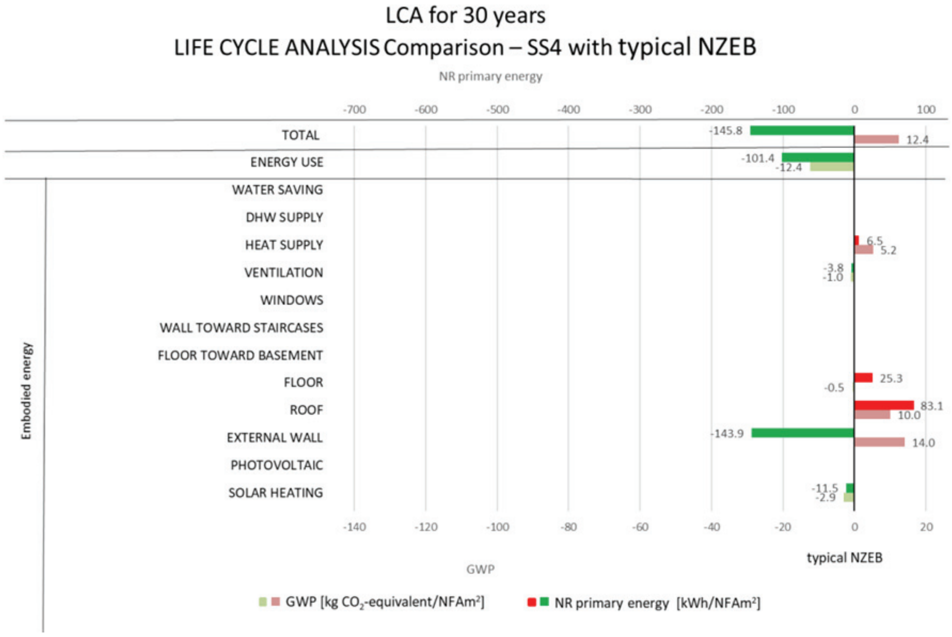

Figure 89: LCA comparison of SS4 with typical NZEB

The NPV of this scenario is positive, despite the replacement and energy costs are negative. The higher impact on the energy costs is due to the replacement of MVHR with the mechanical extract ventilation. Nevertheless, the difference is very low (only 1.1 €/m^2) since the SuperNZEB envelope allows to decrease the energy demand of the building. Regarding the investment costs, as in SS2 the higher expense for the envelope are balanced by lower cost of mechanical extract ventilation compared to MVHR. Maintenance costs are lower due to the absence of solar collectors, the use of radiators instead of floor heating, the installation of a simpler ventilation system.

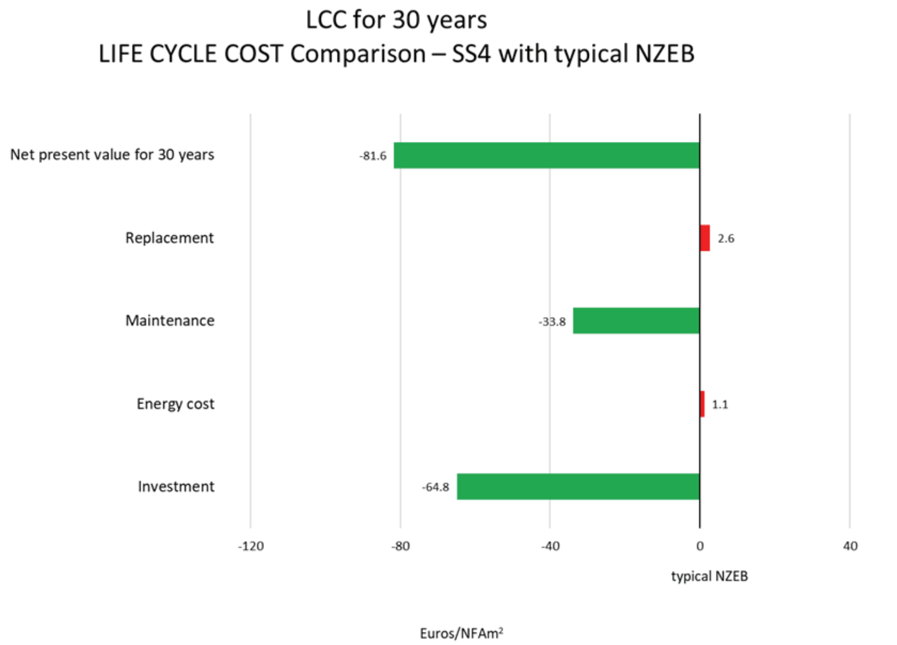

Figure 90: **LCC comparison of SS4 with typical NZEB**

7.2.5.5 Comparison of SS5 with typical NZEB

This is a SuperNZEB scenario where the central heating supply is eliminated and electric radiators in rooms provide the heating service. Furthermore, solar thermal collectors and PV panels are increased up to 54 m^2 and 163 m^2 respectively, in order to achieve the minimum levels of energy production from renewable sources required by Legislative Decree 28/2011.

Basically, impacts of external wall, roof and floor are the same as in SS2 and SS4; the increase of solar collectors and PV panels makes the NR primary energy increase up to 11.4 kWh/m^2 and the emissions of CO_2 up to 2.8 kg CO_2-equivalent/m^2.

Environmental loads for heat supply are considerably reduced since only electric radiators are installed, while central unit and pipes distribution are eliminated.

Regarding the energy use, only the GPW is higher than typical NZEB while the NR-primary energy is lower. Analyzing the amount of kWh of electricity and gas taken from the grid in SS5 compared to typical NZEB, it can be noticed that the total NR-primary energy is quite similar. The variation in the energy use between the two solutions is indeed very low in 30 years (-5.7 kWh/m^2 of NR primary energy). Nevertheless, the repartition of energy use is different: consumption of gas in typical NZEB is almost two times higher than SS5, while consumption of electricity is almost two times lower. Considering that the $CO_{2,eq.}$ emission factor for gas is 0.2 kg/kWh_H while for electricity is 0.445 kg/kWh_H, the double amount of electricity consumed in SS5 has a considerable impact on environment, leading the GWP increase up to 6.4 kg CO_2-equivalent/m^2.

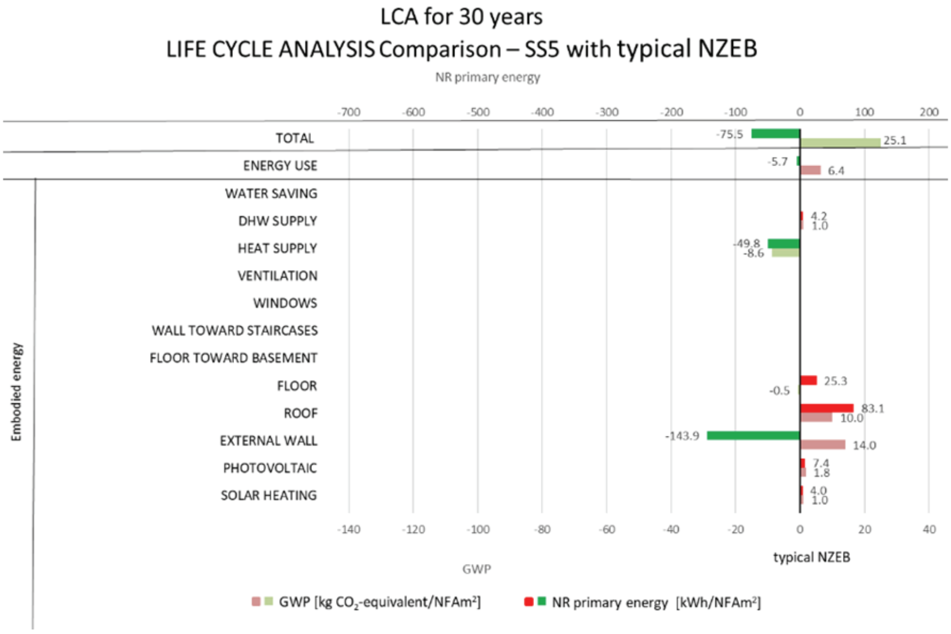

Figure 91: LCA comparison of SS5 with typical NZEB

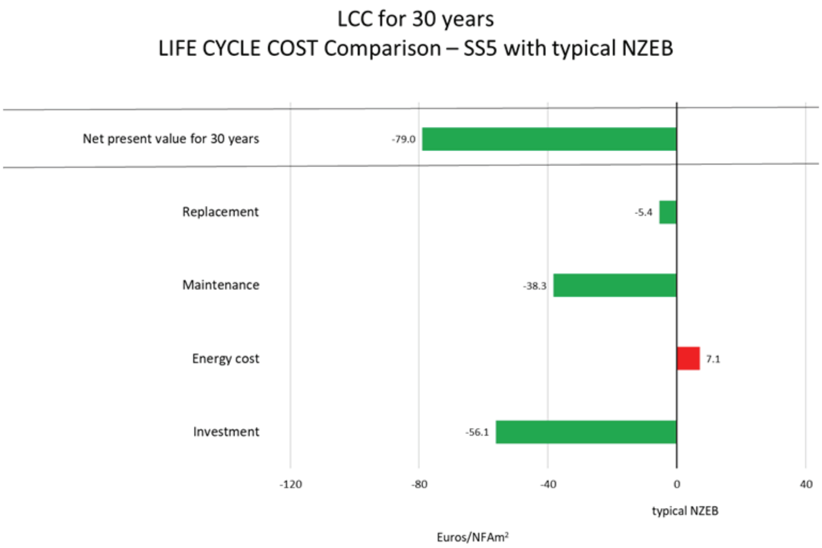

Figure 92: LCC comparison of SS5 with typical NZEB

From the other side, the overall economic result is positive due to the cheaper investment in technologies for heat supply, despite the energy cost increase. Energy costs for electricity are higher than the base case: for the electric radiators much more electricity is taken from the grid for heating supply compared to amount of electricity needed for the heat pump compressor.

7.2.5.6 Summary of investment costs and net present value – in comparison with the typical NZEB

The main goal of this report was to design alternative solution sets to reduce investment cost of a typical NZEB design. As it can be seen from

Figure **93**, the purpose of this research was achieved. The investment cost and net present value (NPV) of all solution sets has been designed properly, being both cheaper in the first and in the long-term phase of the building life-cycle. In particular, it can be noticed that SS2 has the best NPV in 30 years (103 €/m^2), while in terms of investment costs the cheapest is SS4 which allows to save up to 64.8 €/m^2. Regarding the investment cost, Figure 94 shows that all the solution sets have a lower investment costs compared to the typical NZEB, achieving similar savings as the min.EP. The min. EP building requires lower investment costs since the transmittance values of the envelope are less performing (the thickness of the insulation layer is lower) and the natural ventilation is provided instead of MVHR. All the solutions sets guarantee high performance and high technological levels, thus keeping the investment costs on the safe side and guaranteeing considerable savings.

On the contrary, the beyond NZEB solution is more expensive than the typical NZEB. Differently from Rome, in this case the climate conditions required very high expenses to adapt the envelope and the amount of renewable sources to a “0” energy demand building.

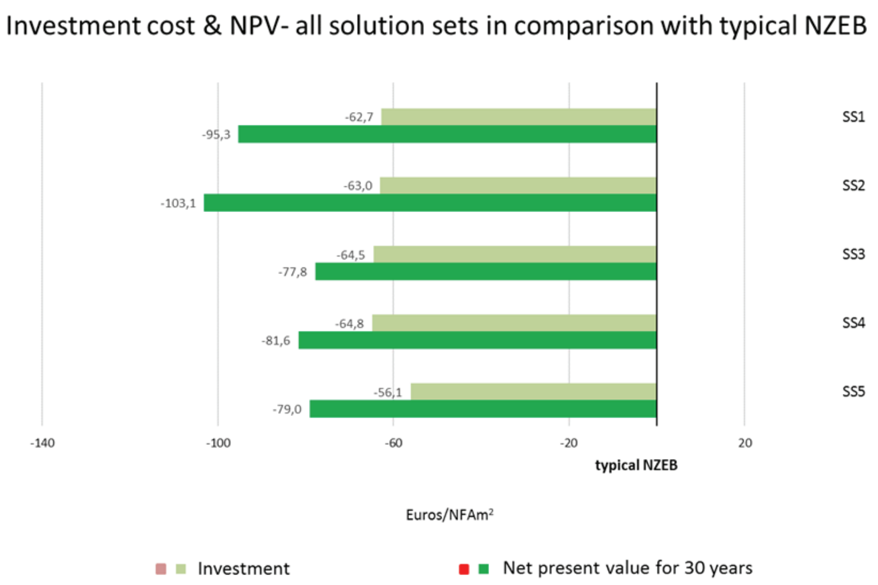

Figure 93: Summary of investment cost and net present value of all solution sets in comparison to typical NZEB

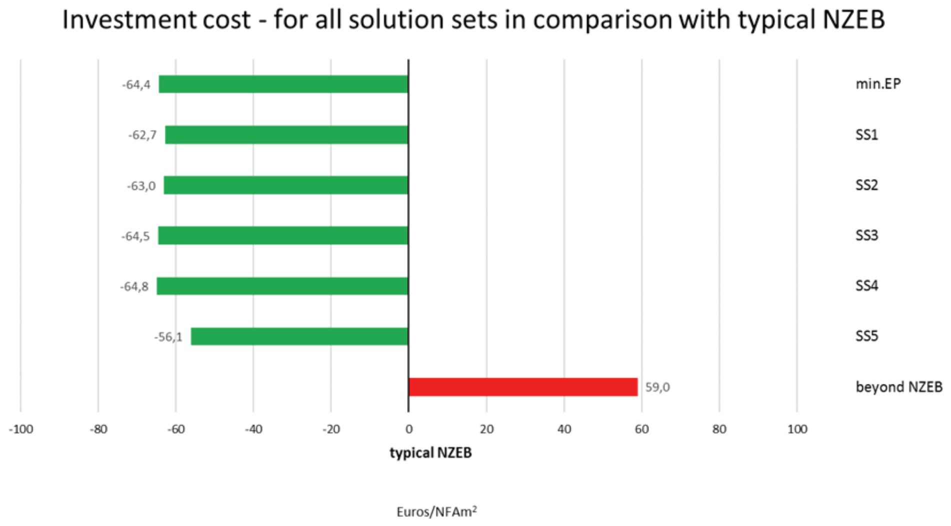

Figure 94: **Overview of investment cost of all energy performance levels in comparison to typical NZEB**

7.2.6 LCA and LCC analyses for the typical NZEB and the alternative NZEB solution sets in comparison with the min. EP level

The LCA and LCC performance of the typical NZEB and the alternative solution sets in comparison to the current minimum energy performance requirements (min. EP) are shown in Figure 95. It shows that all the scenarios are more performing than the min. EP level both in terms of NR- Primary Energy and CO_2 emissions. Among the five, SS1 got the highest scores, showing a reduction of about -671 kWh/m^2 of NR-PE and -108 kg CO_2 -equivalent/m^2 compared to min. EP building.

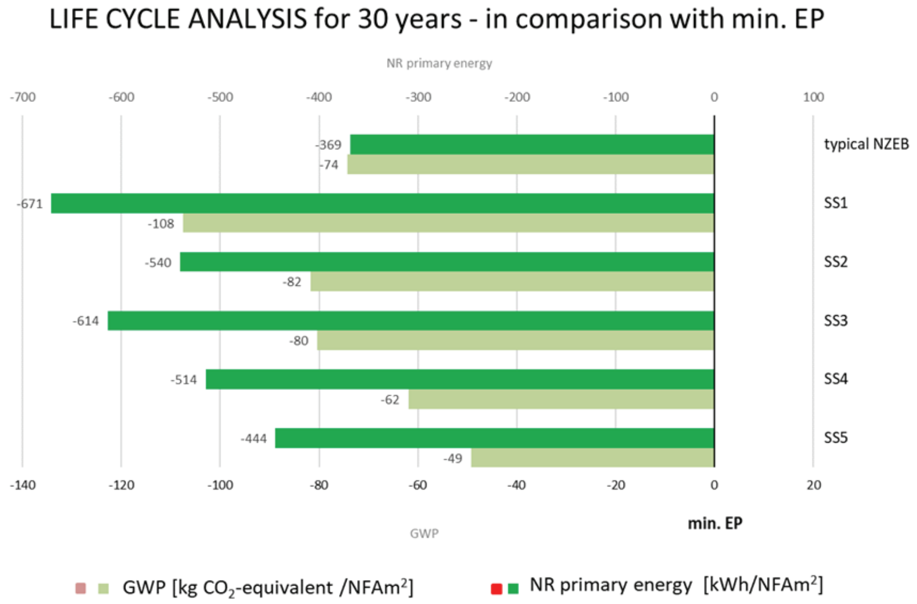

Figure 95: LCA analyses. Comparison of the typical NZEB and the alternative NZEB solution sets in comparison with the min. EP level.

Regarding the costs, it can be noticed in Figure 96 that all the solutions are much better than the min. EP especially if compared to the typical NZEB. It is indeed about 37 €/m^2 more expensive than min. EP in 30 years. These results are very promising for the development of NZEBs in Italy: even in a colder climate condition like Turin, as long as certain simple expedients are met, it is possible to design high energy performance buildings, with a good technological level, which result to be more profit earning than a typical NZEB and even than a min. EP.

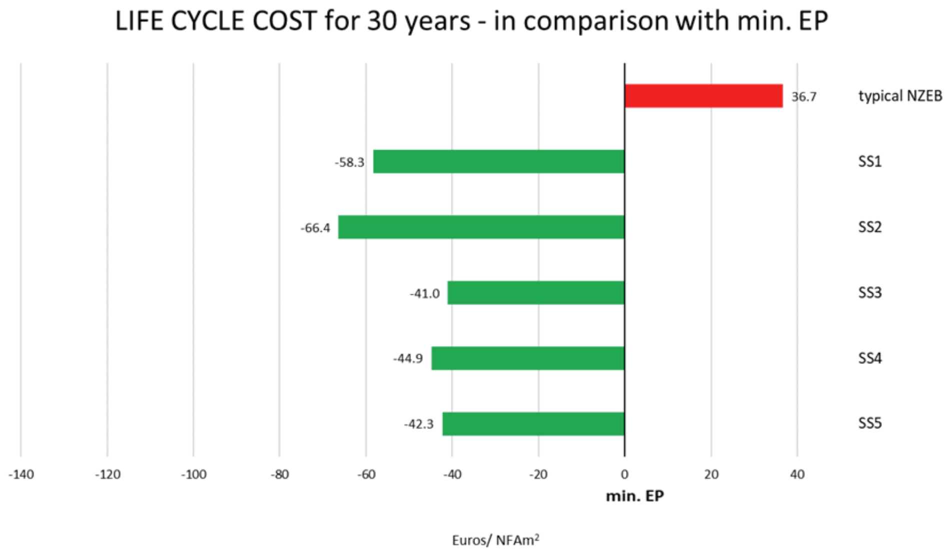

Figure 96: **LCA analyses. Comparison of the typical NZEB and the alternative NZEB solution sets in comparison with the min. EP level.**

7.2.7 LCA and LCC analyses for the typical NZEB, the range of NZEB solution sets and the beyond NZEB in comparison with the min. EP level

Here the typical NZEB, the range of NZEB solution sets and the beyond NZEB are compared to min. EP building. The range of NZEB plots solution sets is interpreted as the interval between the best and the worst NZEB solution set results. The results are presented in Figure 97 to Figure 99.

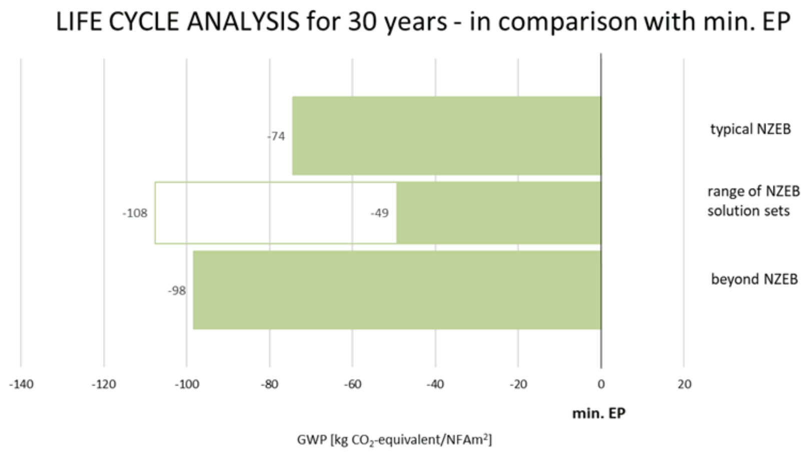

Figure 97: **GWP analysis for the typical NZEB, the range of NZEB solution sets and the beyond NZEB in comparison with the min. EP level**

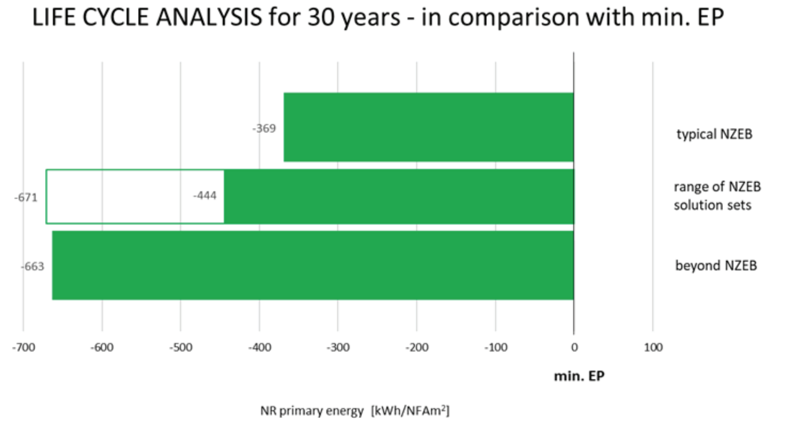

Figure 98: **Non-renewable primary energy analysis for the typical NZEB, the range of NZEB solution sets and the beyond NZEB in comparison with the min. EP level**

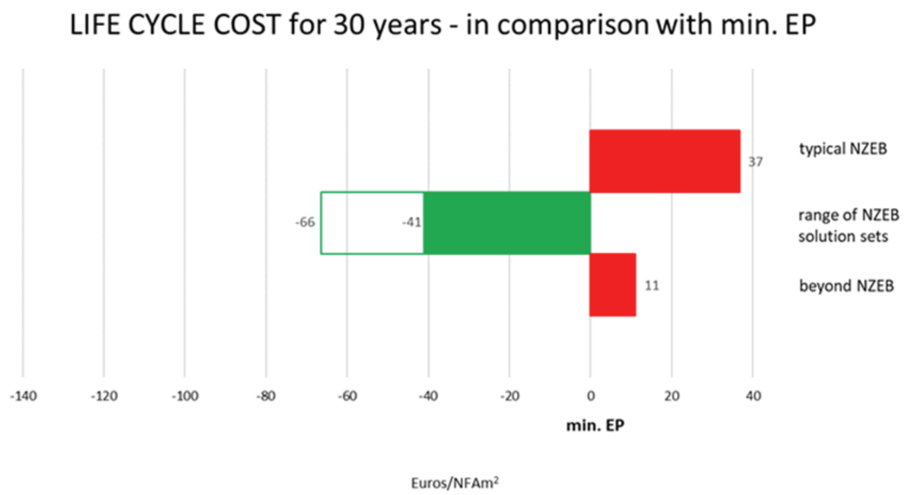

Figure 99: **LCC analysis for the typical NZEB, the range of NZEB solution sets and the beyond NZEB in comparison with the min. EP level**

The plots show that both the alternatives solutions and the beyond NZEB have a lower environmental impact than the min. EP. Moreover, regarding the costs, all the SS are more cost-effective than the min. EP building, while, as also shown in Figure 96, both the typical NZEB and beyond NZEB are more expensive.

7.2.8 Summary

The Italian calculations in Turin have shown that all the solutions designed as alternative to the typical NZEB building are more environmental friendly and more profit-earning than the typical NZEB and the min. EP building. Some solutions have the same transmittance values as the typical NZEB but are characterized by different envelope technologies. Some other have a Super NZEB envelope where transmittances of the walls, roof and ground floor are lower than the values required in the NZEB Italian Standards. As in Rome, from the technical point of view, some of them go in the direction of using electricity as main driver for heating and DHW supply, either via heat pumps or electric radiators; others, oppositely, use the gas for the condensing boiler, supplying both heating and DHW. Additionally, the MVHR and the mechanical ventilation without heat recovery were alternatively used: the first one is more expensive in the construction phase but allows high savings in the heating costs during the operation phase of the building; the second one behaves oppositely. Furthermore, radiators are installed instead of floor heating in all the solution sets.

More in detail, LCA results show that the most performing solution in a long-term perspective of 30 years is SS1 with a reduction of non-renewable primary energy up to -302 kWh/m^2 and a reduction of gas emissions up to 33.3 kg CO_2-equivalent/m^2 compared to typical NZEB. In SS1 the condensing boiler is used as main source, supported by solar thermal collectors, providing both heating and DHW. Differently from Rome, where the electricity driven solution got the best results, in Turin a thermal driven solution achieved the highest score.

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. This is similar to SS1 apart from the envelope which is SuperNZEB (very low transmittance) and the use of mechanical extract ventilation instead of MVHR. Regarding the investment costs, all the solutions are comparable among each other (maximum percentage difference between SS5 and SS4 is 15%) and the cheapest is SS4.

As in Rome, the beyond NZEB configuration got very good environmental results compared to the min. EP (-98 kg CO_2-equivalent/ m^2 and -663 kWh/m^2 of non-renewable primary energy). Regarding the costs, in Turin both the typical NZEB and the beyond NZEB are more expensive than the min. EP. Nevertheless, thanks to the savings in the energy costs during the operating phase of the building, the beyond NZEB results to be more profit-earning than the typical NZEB.

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

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9 Appendices.

9.1 The input used for LCA & LCC analyses for each country

Denmark

			min. EP	NZEB reference building	SS1	SS2	SS3	SS4	SS5	beyond NZEB	
Technology		Units	Quantity for whole building								Description of system
SOLAR HEATING											
	flat-plate solar thermal collector	m^2				9,6					
PHOTOVOLTAIC											
	monocrystalline	m^2							16,8	160	
EXTERNAL WALL											EP: Brickwork with external thermal insulation system-Mineral wool (ETICS)-0.15 W/m^2K
	Insulation	m^3	183,7	183,7	102,1	139,3	183,7	139,3	139,3	139,3	NZEB: Brickwork with external thermal insulation system-Mineral wool (ETICS)-0.15 W/m^2K
											SS1: Brickwork with external thermal insulation system-Kingspan (ETICS)-0.15 W/m^2K
											SS2: Brickwork with external thermal insulation system-Mineral wool (ETICS)-0.22 W/m^2K
											SS3: Brickwork with external thermal insulation system-Mineral wool (ETICS)-0.15 W/m^2K
											SS4: Brickwork with external thermal insulation system-Mineral wool (ETICS) -0.22 W/m^2K
											SS5: Brickwork with external thermal insulation system-Mineral wool (ETICS)-0.22 W/m^2K
											Beyond NZEB: Brickwork with external thermal insulation system-Mineral wool (ETICS)-0.22 W/m^2K
ROOF											EP: Flat, build-up roof with roofing felt-0.1 W/m^2K
	Insulation	m^3	172,8	172,8	172,8	124,8	172,8	124,8	124,8	124,8	NZEB: Flat, build-up roof with roofing felt-0.1 W/m^2K
											SS1: Flat, build-up roof with roofing felt-0.1 W/m^2K
											SS2: Flat, build-up roof with roofing felt-0.14 W/m^2K
											SS3: Flat, build-up roof with roofing felt-0.1 W/m^2K
											SS4: Flat, build-up roof with roofing felt-0.14 W/m^2K
											SS5: Flat, build-up roof with roofing felt-0.14 W/m^2K
											Beyond NZEB: Flat, build-up roof with roofing felt-0.14 W/m^2K
FLOOR											EP: Slab on ground-0.1W/m^2K
	Insulation	m^3	156,7	156,7	156,7	113,1	156,7	113,1	113,1	113,1	NZEB: Slab on ground-0.1W/m^2K
											SS1: Slab on ground-0.1W/m^2K
											SS2: Slab on ground-0.14 W/m^2K
											SS3: Slab on ground-0.1 W/m^2K
											SS4: Slab on ground-0.14 W/m^2K
											SS5: Slab on ground-0.14 W/m^2K
											Beyond NZEB: Slab on ground-0.14 W/m^2K
WINDOWS											EP: Doubled-glazed windows-1.15 W/m^2K
	Glass	m^2	422,4	422,4	422,4	422,4	422,4	422,4	422,4	422,4	NZEB: Triple-glazed windows-0.85 W/m^2K
	Frame	m	718,1	718,1	718,1	718,1	718,1	718,1	718,1	718,1	SS1: Triple-glazed windows-0.85 W/m^2K
											SS2: Triple-glazed windows-0.85 W/m^2K
											SS3: 4- layer glazed windows-0,6 W/m^2K
											SS4: Triple-glazed windows-0.85 W/m^2K
											SS5: Triple-glazed windows-0.85 W/m^2K
											Beyond NZEB: Triple-glazed windows-0.85 W/m^2K
VENTILATION											EP: Balanced mechanical ventilation (0.34 l/m^2s) with heat recovery (80% dry efficiency and SPF 1.5)
	Unit	m^3/h	1 unit 2350 m^3/h	1 unit 2350 m^3/h	1 unit 2350 m^3/h	1 unit 2350 m^3/h		24 units 98 m^3/h	24 units 98 m^3/h	24 units 98 m^3/h	NZEB: Balanced mechanical ventilation (0.34 l/m^2s) with heat recovery (90% dry efficiency and SPF 1.2). Ventilation galvanized sheet ducts and PE-X tube.
	Ducts	kg	453,9	453,9	453,9	453,9		0	0	0	SS1: Balanced mechanical ventilation (0.34 l/m^2s) with heat recovery (90% dry efficiency and SPF 1.2).Ventilation galvanized sheet ducts and PE-X tube.
	Ducts	kg	233,9	233,9	233,9	233,9		0	0	0	SS2: Balanced mechanical ventilation (0.34 l/m^2s) with heat recovery (90% dry efficiency and SPF 1.2).Ventilation galvanized sheet ducts and PE-X tube.
											SS3: Natural Ventilation
											SS4: Decentral mechanical ventilation (0.34 l/m^2s) with heat recovery (85% dry efficiency and SPF1.0)
											SS5: Decentral mechanical ventilation (0.34 l/m^2s) with heat recovery (85% dry efficiency and SPF1.0)
											SPF1.0)

HEAT SUPPLY											EP: Connection to the district heating network (90/70°C). Eff:100%_Insulated distribution pipes and heat exchanger to national standard_Radiators in general but floor heating in bathrooms.
	Unit Central/ descentral	KW per unit									NZEB: Id.
	Supplement Heat supply	KW per unit									SS1: Id.
	Storage	Kg									SS2: Id.
	Pipes distribution	kg									SS3: Id.
	Heating system(radiator, floor heating…)	kg									SS4: Id.
											SS5:Id.
											Beyond NZEB: Id.
DHW SUPPLY											EP: Heating through district heating heat exchanger. Eff:100%_Insulated pipes and circulation using a 24/7 low- energy pump
	Unit Central/ descentral	unit									NZEB: Id.
	Pipes distribution	kg									SS1: Id.
											SS2: Id.
											SS3: Id.
											SS4: Id.
											SS5: Id.
											Beyond NZEB: Id.
WATER SAVING System											EP: Standard fixtures and shower
	Unit	units					1	72		72	NZEB: Standard fixtures and shower
	Pipes distribution	kg					39				SS1: Standard fixtures and shower
											SS2: Standard fixtures and shower
											SS3: Heat recovery waste water system with heat water reduction of 50%. PE-X pipes
											SS4: Efficient energy water taps with a reduction of 25%.
											SS5: Standard fixtures and shower
											Beyond NZEB: Efficient energy water taps with a reduction of 25%.

LCC analyses

Technology	Total cost per building, Euros								Life time	Maintan. %/yr	Replace %
	EP	NZEB	SS1	SS2	SS3	SS4	SS5	beyond nZEB			
SOLAR HEATING		Reference building									
flat-plate solar thermal collector. + 9,6 m^2				7.258					20	2%	120%
PHOTOVOLTAIC											
monocristaline. + 16.8 m^2							5.134,0		25	1%	120%
monocristaline. + 160 m^2								44.299	25	1%	120%
EXTERNAL WALL											
Brickwork with external thermal insulation system (ETICS). -50 mm mineral wool				-3.429		-3.429	-3.429	-3.429	80	0%	120%
Brickwork with external thermal insulation system-kingspan (ETICS)			-3.984						80	0%	120%
ROOF											
Flat, build-up roof with roofing felt. -100 mm mineral wool				-8.170		-8.170	-8.170	-8.170	80	0%	120%
FLOOR											
Slab on ground. -100 mm mineral wool				-6.306		-6.306	-6.306	-6.306	80	0%	120%
WINDOWS											
Double-glazed windows									25	2%	120%
Triple-glazed windows	-17.664								25	2%	120%
Four-glazed windows					78.072				25	2%	120%
VENTILATION											
Natural Ventilation					-128.832				40	0%	120%
Central Mechanical ventilation with heat recovery (80% dry efficiency and SPF 1.5)									25	4%	120%
Central Mechanical ventilation with heat recovery (90% dry efficiency and SPF 1.2)	-16.008								25	4%	120%
Decentral Mechanical ventilation with heat recovery (85% dry efficiency and SPF 1.0)						-10.899	-10.899	-10.899	25	5%	120%
HEAT SUPPLY											
District Heating									30	1%	120%
DHW SUPPLY											
District Heating									30	1%	120%
WATER SAVING System											
Grey water heat recovery system					16.008				30	2%	120%
Fresh water stations						0		0	40	0%	120%
Total	-33.672		-3.984	-10.647	-34.752	-28.804	-23.670	15.495			

Germany

LCA analyses			min. EP	NZEB reference building	SS2	SS3	SS7	SS8	beyond nZEB	
Technology		Units	quantity per whole building							Description of system
SOLAR HEATING										EP: flat-plate solar thermal collector
	flat-plate solar thermal collector	m^2	47,00	47	0	0	0	0		NZEB: flat-plate solar thermal collector
										SS2: None
										SS3: None
										SS7: None
										SS8: None
PHOTOVOLTAIC										EP: None
	monocrystalline	m^2	0,00	0	130	0	0	10	300	NZEB: None
										SS2: monocrystalline cells of 1000 kW/m^2 year
										SS3: None
										SS7: None
										SS2: monocrystalline cells of 1000 kW/m^2 year
EXTERNAL WALL										EP: 240 mm limestone with 110 mm EPS-20 external thermal insulation system (ETICS)
	Insulation	m^3	98,26	252	151	151	151	151	151	NZEB: 240 mm limestone with 300 mm EPS-20 external thermal insulation system (ETICS)
	Construktion	m^3		-	-	-	-	-		SS2: 240 mm limestone with 180 mm EPS-20 external thermal insulation system (ETICS)
	Cover	m^3		-	-	-	-	-		SS3: 240 mm limestone with 180 mm EPS-20 external thermal insulation system (ETICS)
										SS7: 240 mm limestone with 180 mm EPS-20 external thermal insulation system (ETICS)
										SS8: 240 mm limestone with 180 mm EPS-20 external thermal insulation system (ETICS)
ROOF										EP: Saddle roof with 260 mm mineral wood between rafters
	Insulation	m^3	69	131	91	91	91	91	91	NZEB: Saddle roof with 300 mm mineral wood between and 190mm above the rafters
	Construktion	m^3		-	-	-	-	-		SS2: Saddle roof with 300 mm mineral wood between and 40mm above the rafters
	Cover	m^3		-	-	-	-	-		SS3: Saddle roof with 300 mm mineral wood between and 40mm above the rafters
										SS7: Saddle roof with 300 mm mineral wood between and 40mm above the rafters
										SS8: Saddle roof with 300 mm mineral wood between and 40mm above the rafters
FLOOR										EP: Insulated cellar ceiling with 96 mm EPS-20
	Insulation	m^3	25	31	25	25	25	25	25	NZEB: Insulated cellar ceiling with 120mm EPS-20
	Construktion	m^3		-	-	-	-	-		SS2: Insulated cellar ceiling with 96 mm EPS-20
	Cover	m^3		-	-	-	-	-		SS3: Insulated cellar ceiling with 96 mm EPS-20
										SS7: Insulated cellar ceiling with 96 mm EPS-20
										SS8: Insulated cellar ceiling with 96 mm EPS-20
WINDOWS										EP: Glass double pane
	Glass	m^2	180	180	180	180	180	180	180 (glass triple pane)	NZEB: Glass triple pane
	Frame	m		-	-	-	-	-		SS2: Glass Double pane
										SS3: Glass Double pane
										SS7: Glass Double pane
										SS8: Glass Double pane
VENTILATION										EP: 1100 m3/h Exhaust ventilation system. 30m of Ø:180mm and 45m of Ø:100mm galvanized steel. ducts and 30m of 50mm HDPE connection ducts. Volume flow controllers (15 pieces). Fresh air openings in the window frame (60 pieces).
	Unit	m^3/h	1100	1100	31 but 65 times	1100	1100	1100	31 but 65 times (like SS2)	NZEB: 1100 m^3/h Exhaust ventilation system. 30m of Ø:180mm and 45m of Ø:100mm galvanized steel ducts and 30m of 50mm HDPE connection ducts. Volume flow controllers (15 pieces). Fresh air openings in the window frame (60 pieces).
	Ducts	kg	119	119	0	238	119	119	0	SS2: Decentral reversing air flow ventilation with heat recovery 65 pieces - 31 m^3/h each
	Ducts	kg	15	15	0	120	15	15	0	SS3: MVHR 1100 m^3/h, moisture controlled. 60m of Ø:180mm and 90m of Ø:100mm galvanized steel ducts and 240m of 50mm HDPE connection ducts. Volume flow controllers - 15 pieces. Heating register 30 kW - 1 piece.
										SS7: 1100 m^3/h Exhaust ventilation system. 30m of Ø:180mm and 45m of Ø:100mm galvanized steel ducts and 30m of 50mm HDPE connection ducts. Volume flow controllers (15 pieces). Fresh air openings in the window frame (60 pieces).
										SS8: 1100 m^3/h Exhaust ventilation system. 30m of Ø:180mm and 45m of Ø:100mm galvanized steel ducts and 30m of 50mm HDPE connection ducts. Volume flow controllers (15 pieces). Fresh air openings in the window frame (60 pieces).

									EP: 63 kW Gas condensing boiler. 3,7 m3 thermal tank of steel S235JR+ 0,12 m polyester fleece insulation. 59 m of Ø:54mm and 93 m of Ø:28mm copper distribution pipes. 90 steel radiators of 0,35 KW each.
Unit Central/ descentral	kW per unit	1 unit of 63 kW	1 unit of 63 kW	0	1 unit of 33,6 kW	1 unit of 63 kW	1 unit of 37 kW	1 unit of 63 kW	NZEB: 63 kW Gas condensing boiler. 3,7 m^3 thermal tank of steel S235JR+ 0,12 m polyester fleece insulation. 59 m of Ø:54mm and 93 m of Ø:28mm copper distribution pipes . 90 steel radiators of 0,35 KW each.
Supplement Heat supply	kW per unit				1 unit of 15 kW		1 unit of 5,4 kW		SS2: 105 Elektric heating plates of 0,3 kW each.
Storage	Kg	89	89	0	0	89		89	SS3: Central Exhaust air to air heat pump of 33,6 KW. Electric air reheater of 15 kW as supplementary heat supply
Pipes distribution	kg	242	242	0	0	242	242	242	SS7: District heating exchanger of 63 kW. 3,7 m^3 thermal tank of steel S235JR+ 0,12 m polyester fleece insulation. 59 m of Ø:54mm and 93 m of Ø:28mm copper distribution pipes. 90 steel radiators of 0,35 KW each.
Heating system(radiator, floor heating…)	kg	553	553	105 stk	0	553	553	984 m² of floor heating	SS8: 58 kW Gas condensing boiler. Exhaust air heat pump of 5,4 KW as supplementary heat suply. 0,8 m3 thermal tank of steel S235JR+ 0,12 m polyester fleece insulation. 59 m of Ø:54mm and 93 m of Ø:28mm copper distribution pipes. 90 steel radiators of 0,35 KW each.
									beyond nZEB: 63 kW central air-water heat pump (heating and DHW)
									EP: 51m of Ø:5mm, 93m of Ø:4 mm and 62 m of Ø:32 mm PE-Xc pipes + 692m of Ø:15mm PE-Xc pipes from heating supply
Unit Central/ descentral	kW per unit	0	0	15 unit of 35 kW	15 unit of 35 kW	0	15 unit of 35 kW	0	NZEB: 51m of Ø:5mm, 93m of Ø:4 mm and 62 m of Ø:32 mm PE-Xc pipes + 692m of Ø:15mm PE-Xc pipes from heating supply
Pipes distribution	kg	91	91	0	0	91	91	20	SS2: Decentral electric DHW heaters of 35 kW each.
									SS3: Decentral electric DHW heaters of 35 kW each.
									SS7: 51m of Ø:5mm, 93m of Ø:4 mm and 62 m of Ø:32 mm PE-Xc pipes + 692m of Ø:15mm PE-Xc pipes from heating supply
									SS8: Decentral DHW heat exchanger units (15 pieces with 35 kW each). 62 m of Ø:32 mm PE-Xc pipes + 692m of Ø:15mm PE-Xc pipes from heating supply
									Beyond nZEB: Piping lengh [m] 62 m with an Exterior Pipe diameter [m] of 0.032 with an Insulation material of synthetic and closed-cell caoutchouc with an Insulation thickness B [m] of 0.032
									None
Unit Central/ descentral	units	0	0	1	1	0	0	0	NZEB: None
Pipes distribution	kg	0	0	40	40	0	0	0	SS2: Grey water heat exchanger, ~~30m of Ø:60mm, 62m of Ø:32 PE-Xc pipes~~ See manufacturer information i send you
									SS3: Grey water heat exchanger, ~~30m of Ø:60mm, 62m of Ø:32 PE-Xc pipes~~ See manufacturer information i send you
									SS7: None
									SS8: None

Technology	Total cost per building, Euros							Life time	Maintan. %/yr	Replace %
	EP	NZEB	SS2	SS3	SS7	SS8	beyond nZEB			
SOLAR HEATING										
47 m² flat-plate solar thermal collector	27.580	27.580						20	1,5	0
PHOTOVOLTAIC										
17,6 kWp			26.500					20	1,5	0
1,35 kWp						2.500		20	1,5	0
50,16 kWp							60.500	20	1,5	0
EXTERNAL WALL										
Opaque wall-limestone 0,3 m EPS insulation		181.095						40		0
Opaque wall-limestone 0,18 m EPS insulation			173.686	173.686	173.686	173.686	173.686	40		
Opaque wall-limestone 0,11 m EPS insulation	161.338							40		0
ROOF										
0,3 m betwwen rafters and 0,19 m mineral wool		52.084						50		0
0,3 m betwwen rafters and 0,04 m mineral wool			49.760	49.760	49.760	49.760	49.760	50		
0,xx m betwwen rafters	45.578							50		0
FLOOR										
Cellar ceiling 0,12 m EPS insulation		46.689						50		0
Cellar ceiling 0,085 m EPS insulation			44.920	44.920	44.920	44.920	44.920	50		
Cellar ceiling 0,0xx m EPS insulation	44.920							50		0
WINDOWS										
Triple-glazed windows		125.823					125.823	40		0
Double-glazed windows	91.993		91.993	91.993	91.993	91.993		40		0
VENTILATION										
Mechanical exhaust,demand-compensated	29.544	29.544			29.544			18	2,0	0
Mechanical exhaust						24.620		18	2,0	0
Reversing air-flow with heat recovery			39.000				39.000	18	2,0	0
Centrall ventilation with heat recovery 75%				76.814				18	2,0	0
Exhaust air heat pump				26.240				18	2,5	0
HEAT SUPPLY										
Gas condensing boiler, 63 kW	9.676	9.676						18	3,0	0
Gas condensing boiler, 58 kW						9.154		18	3,0	0
Thermal storage, 3,7 m^3	6.744	6.744			6.744			20	2,0	0
Thermal storage, 0,8 m^3						1.296	1.296	20	2,0	0
Heating distribution,emission and chimeny	67.512	67.512			54.164	67.512	79.276	35	1,0	0
Electric heating system			15.129					22	1,0	0
Electric reheaters				3.355				22	2,0	0
District Heating					6.314			20	3,0	0
Grid Connection cost & construction cost subsidy					8.087			30		0
Exhaust-air-water heatpump						12.255		18	2,5	0
Air-water heat pump							55.526	18	2,5	0
Single room controls for heating							5.374	10	1,5	0
DHW SUPPLY										
Hot water distribution with circulation	11.818	11.818			11.818			40	1,0	0
Hot water distribution with circulation						1.970	1.970	40	1,0	0
Electric DHW heaters			22.970	22.970				15	2,0	0
WATER SAVING System										
Grey water heat recovery system			12.000	12.000				30	2,0	0
Fresh water stations						35.700	35.700	30	3,0	0
Total	496.703	558.565	475.958	501.738	477.030	515.366	672.831			

Slovenia

		NZEB EP min	NZEB reference building	SS1	SS2	SS3	SS4	Beyond NZEB	
Technology	Units		Cuantity per apartment or whole building						Description of system
SOLAR HEATING									SS1: vacuum sollar collectors with flat plates
System	m2	0	190	0	0	0	0	0	SS2: /
									SS3: /
									SS4: /
PHOTOVOLTAIC									SS1: /
System	m2 (n..a in KWp)	0	0	0	0	0	200	200	SS2: polychrystalline silicium PV cells
									SS3: /
									SS4: /
EXTERNAL WALL	792 m2								SS1: Reinforced concrete - 25 cm; Rock wool - 25 cm; Plaster - 0,2 cm
Insulation	m3	174	198	198	198	198	198	198	SS2: Reinforced concrete - 25 cm; Rock wool - 25 cm; Plaster - 0,2 cm
Construktion	m3	198	198	198	198	198	198	198	SS3: Reinforced concrete - 25 cm; Rock wool - 25 cm; Plaster - 0,2 cm
Cover	m3	2	2	2	2	2	2	2	SS4: Reinforced concrete - 25 cm; Rock wool - 25 cm; Plaster - 0,2 cm
									Beyond NZEB: Reinforced concrete - 25 cm; ECOSE Rock wool - 25 cm; Plaster - 0,2 cm https://www.knaufinsulation.com/sites/default/files/pages/GMW_032_-_033_Slabs_with_ECOSE(1).pdf
ROOF	400 m2								SS1: Reinforced concrete - 20 cm; Rock wool - 35 cm; Gravel - 20 cm
Insulation	m3	128	140	140	140	140	140	140	SS2: Reinforced concrete - 20 cm; Rock wool - 35 cm; Gravel - 20 cm
Construktion	m3	80	80	80	80	80	80	80	SS3: Reinforced concrete - 20 cm; Rock wool - 35 cm; Gravel - 20 cm
Cover	m3	80	80	80	80	80	80	80	SS4: Reinforced concrete - 20 cm; Rock wool - 35 cm; Gravel - 20 cm
									Beyond NZEB: Reinforced concrete - 20 cm; ECOSE Rock wool - 35 cm; Gravel - 20 cm https://www.knaufinsulation.com/sites/default/files/pages/GMW_032_-_033_Slabs_with_ECOSE(1).pdf
FLOOR SLAP ON GROUND									SS1:
Insulation	m3	-	-	-	-	-	-	-	SS2:
Construktion	m3	-	-	-	-	-	-	-	SS3:
Cover	m3	-	-	-	-	-	-	-	SS4:
FLOOR SLAP ABOVE BASEMENT	362 m2								SS1: Reinforced concrete - 25 cm; Rock wool - 25 cm
Insulation	m3	83	91	91	91	91	91	91	SS2: Reinforced concrete - 25 cm; Rock wool - 25 cm
Construktion	m3	91	91	91	91	91	91	91	SS3: Reinforced concrete - 25 cm; Rock wool - 25 cm
Cover	m3	-	-	-	-	-	-	-	SS4: Reinforced concrete - 25 cm; Rock wool - 25 cm
									Beyond NZEB: Reinforced concrete - 20 cm; ECOSE Rock wool - 25 cm https://www.knaufinsulation.com/sites/default/files/pages/GMW_032_-_033_Slabs_with_ECOSE(1).pdf
BASEMENT WALL	200 m2								SS1: description of materials and thickness of insulation
Insulation	m3	-	-	-	-	-	-	-	SS2: description of materials and thickness of insulation
Construktion	m3	40	40	40	40	40	40	40	SS3: description of materials and thickness of insulation
Cover	m3	-	-	-	-	-	-	-	SS4: description of materials and thickness of insulation
WINDOWS									SS1: Double glazing windows - Uw = 1,3 W/m2k
Glass	m2	373	373	373	373	373	373	373	SS2: Triple glazing windows - Uw = 0,88 W/m2k
Frame	m	1074	1074	1074	1074	1074	1074	1074	SS3: Triple glazing windows - Uw = 0,88 W/m2k
									SS4: Triple glazing windows - Uw = 0,88 W/m2k
VENTILATION									SS1: Use of mechanical ventilation system with heat recovery; Vertical Ducts are neglected - same in all SS; Unit: https://www.oekobaudat.de/OEKOBAU.DAT/datasetdetail/process.xhtml?uuid=efabdf2d-993e-418c-ba86-85a3a91562a2&stock=OBD_2017_I&lang=en
Decentral unit (n=21)	unit and m3/h per unit	2100 (each apartment 1 unit - 100 m3/h)	2100 (each apartment 1 unit - 100 m3/h)	2520 (each apartment 1 unit - 120 m3/h)	2520 (each apartment 1 unit - 120 m3/h)	2520 (each apartment 1 unit - 120 m3/h)	2100 (each apartment 1 unit - 100 m3/h)	2520 (each apartment 1 unit - 120 m3/h)	SS2: Use of mechanical ventilation system with heat recovery; Vertical Ducts are neglected - same in all SS; Unit: https://www.oekobaudat.de/OEKOBAU.DAT/datasetdetail/process.xhtml?uuid=efabdf2d-993e-418c-ba86-85a3a91562a2&stock=OBD_2017_I&lang=en
Ducts	kg (or meter,diameter and material)	0,9	0,9	13,5	13,5	13,5	0,9	13,5	SS3: Use of mechanical ventilation system with heat recovery; Vertical Ducts are neglected - same in all SS; Unit: https://www.oekobaudat.de/OEKOBAU.DAT/datasetdetail/process.xhtml?uuid=efabdf2d-993e-418c-ba86-85a3a91562a2&stock=OBD_2017_I&lang=en
									SS4: Use of hygro-ventilation system; Vertical Ducts are neglected - same in all SS; Unit: https://www.oekobaudat.de/OEKOBAU.DAT/datasetdetail/process.xhtml?uuid=c8cf7494-2f23-4193-a185-f7d4fdfa36b6&stock=OBD_2017_I&lang=en

HEAT SUPPLY			district heating: DHW + heating	condensing gas boiler: DHW + heating	district heating: DHW + heating	heat pump: DHW + heating	condensing gas boiler: heating	heat pump: DHW + heating	heat pump: DHW + heating	SS1: Floor heating: PEX material --> https://www.oekobaudat.de/OEKOBAU.DAT/datasetdetail/process.xhtml?uuid=243f619c-c8ee-4339-9bbd-4df03737aa1a&stock=OBD_2017_I&lang=en ; heating pipe distribution: PEX material (density:950 kg/m3)
	Unit Central/ descentral	kW per unit **(for building)**	57	52	52	49	26	49	49	SS2: Floor heating: PEX material --> https://www.oekobaudat.de/OEKOBAU.DAT/datasetdetail/process.xhtml?uuid=243f619c-c8ee-4339-9bbd-4df03737aa1a&stock=OBD_2017_I&lang=en ; heating pipe distribution: PEX material (density:950 kg/m3)
	Pipes distribution	kg (or meter, diameter and materia)l	78	78	78	78	78	78	78	SS3: Floor heating: PEX material --> https://www.oekobaudat.de/OEKOBAU.DAT/datasetdetail/process.xhtml?uuid=243f619c-c8ee-4339-9bbd-4df03737aa1a&stock=OBD_2017_I&lang=en ; heating pipe distribution: PEX material (density:950 kg/m3)
	Heating system (radiator, floor heating…)	kg	1774	1774	1774	1774	1774	1774	1774	SS4: Floor heating: PEX material --> https://www.oekobaudat.de/OEKOBAU.DAT/datasetdetail/process.xhtml?uuid=243f619c-c8ee-4339-9bbd-4df03737aa1a&stock=OBD_2017_I&lang=en ; heating pipe distribution: PEX material (density:950 kg/m3)
DHW SUPPLY			district heating: DHW + heating	condensing gas boiler: DHW + heating	district heating: DHW + heating	heat pump: DHW + heating	heat pump: DHW	heat pump: DHW + heating	heat pump: DHW + heating	SS1: Pipe distribution: Pipe length * Material (PEX) density * Φ * pipe thickness
	Unit Central/ descentral	kW per unit	57	52	52	49	23	49	49	SS2: Pipe distribution: Pipe length * Material (PEX) density * Φ * pipe thickness
	Pipes distribution	diameter and	35	35	35	35	35	35	35	SS3: Pipe distribution: Pipe length * Material (PEX) density * Φ * pipe thickness
										SS4: Pipe distribution: Pipe length * Material (PEX) density * Φ * pipe thickness
WATER SAVING System										SS1:
										SS2:
	Unit Central/ descentral	units	-	-	-	-	-	-		SS3:
	Pipes distribution	diameter and	-	-	-	-	-	-		SS4:

Technology	Total cost per building, Euros							Life time SLO	Mainten. %	Replace %
	EP min	NZEB reference building	SS1	SS2	SS3	SS4	Beyond NZEB			
SOLAR HEATING										
190 m² flat-plate solar thermal collector		147.101						20	1,5	125
PHOTOVOLTAIC										
200 m2 polychrystalline silicium PV cells - 31 kWp						51.250	51.250	25	1,5	125
EXTERNAL WALL										
Reinforced concrete wall 0,22 m rock wool	214000							60	2,0	125
Reinforced concrete wall 0,24 m rock wool		214.693	214.693	214.693	214.693	214.693		60	2,0	125
Reinforced concrete wall 0,24 m rock woo - ECOSE technology							214.693	60	2,0	125
ROOF										
Flat reinforced concrete roof with 0,35 rock wool		51.736	51.736	51.736	51.736	51.736		60	1,0	125
Flat reinforced concrete roof with 0,32 rock wool	51000							60	1,0	125
Flat reinforced concrete roof with 0,32 rock wool - ECOSE technology							51.736	60	1,0	125
FLOOR										
Cellar ceiling 0,25 m wooden fiberboard	24590	24.590	24.590	24.590	24.590	24.590	24.590	50	1,0	125
WINDOWS										
Triple-glazed windows				54411	54411	54411	54411	30	0,5	125
Double-glazed windows	39606	39606	39606					30	0,5	125
VENTILATION										
De-central mechanical ventilation with heat recovery 85%			87.381	87.381	87.381		87.381	17	1,0	125
Hygro sensible ventilation	32.083	32.083				32.083		20	0,3	125
HEAT SUPPLY										
Gas condensing boiler, 50 kW		19.298						20	0,5	125
Gas condensing boiler, 30 kW					17.000			20	0,5	125
Thermal storage, 0,8 m3		1.000			1.000					
Heating distribution,emission and chimeny, floor heating	61.041	78.717	61.041	78.717	78.717	78.717	78.717	40	1,0	125
District Heating	8.677		8.677					20	0,5	125
Air/water heat pump 30 kW					27.500			20	1,0	125
Air/water heat pump 50 kW				33.500		33.500	33.500	20	1,0	125
DHW SUPPLY										
Thermal storage, 2 m^3	3.176	3.176	3.176	3.176		3.176	3.176	20	0,5	125
Thermal storage, 1.5 m^3		2.150			2.150			20	0,5	125
Total	434.173	614.149	490.900	548.204	559.178	544.156	599.454		5	

Italy - Rome

		Minimum EP	NZEB reference building	SS1	SS2	SS3	SS4	BEYOND NZEB	
Technology	**Units**		**Cuantity per apartment or whole building**						**Description of system**
SOLAR HEATING									SS1: vacuum solar collector Mounted on the tilted roof (-30° and 18°), on the south-east and south-west oriented pitches; 19 modules SS2: ABSENT SS3: vacuum solar collector Mounted on the tilted roof (-30° and 18°), on the south-east and south-west oriented pitches; 18 modules SS4: vacuum solar collector Mounted on the tilted roof (-30° and 18°), on the south-east and south-west oriented pitches; 19 Modules beyond NZEB: ABSENT
System	m2	12.5 m2	27 m2	34 m2	0	33 m2	34 m2	0	
PHOTOVOLTAIC									SS1: polycristalline PV system Mounted on the tilted roof, on the south-east and south-west oriented pitches 89 Modules azimut 120° tilt 18° SS2: polycristalline PV system Mounted on the tilted roof, on the south-east and south-west oriented pitches 89 Modules azimut 120° tilt 18° SS3: polycristalline PV system Mounted on the tilted roof, on the south-east and south-west oriented pitches 100 Modules azimut 120° tilt 18° SS4: polycristalline PV system Mounted on the tilted roof, on the south-east and south-west oriented pitches 6 Modules azimut 120° tilt 18° Beyond NZEB: polycristalline PV system Mounted on the tilted roof, on the south-east and south-west oriented pitches 200 Modules
System	m2 or KWp	57 m2	142 m2	142 m2	142 m2	163 m2	9.6 m2	326 m2	
EXTERNAL WALL									Minimum EP: two brick walls (20 Cm) with an EPS thermal coating (6.5 cm) covered by plaster (2 cm) NZEB REF building: two brick walls (20 Cm) with an EPS thermal coating (8 cm) covered by plaster (2 cm) SS1: large autoclaved concrete bricks with thermal insulating properties (30 cm) covered by plaster (2 cm) SS2: large autoclaved concrete bricks with thermal insulating properties (30 cm) covered by plaster (2 cm) SS3: large autoclaved concrete bricks with thermal insulating properties (30 cm) covered by plaster (2 cm) SS4: large autoclaved concrete bricks with thermal insulating properties (30 cm) covered by plaster (2 cm) Beyond NZEB: large autoclaved concrete bricks with thermal insulating properties (50 cm) covered by plaster (2 cm)
Insulation	m3	93	115	431	431	431	431	718	
Construktion	m3	287	287						
Cover	m3	29	29	29	29	29	29	29	
ROOF									Minimum EP:masonry tilted roof with an XPS thermal coating of 7cm covered by steel plate mounted on wooden planks. NZEB REF. masonry tilted roof with an XPS thermal coating of 9 cm covered by steel plate mounted on wooden planks. SS1:masonry tilted roof with an XPS thermal coating of 9 cm covered by steel plate mounted on wooden planks. SS2:masonry tilted roof with an XPS thermal coating of 9 cm covered by steel plate mounted on wooden planks. SS3:masonry tilted roof with an XPS thermal coating of 9 cm covered by steel plate mounted on wooden planks. SS4:masonry tilted roof with an XPS thermal coating of 9 cm covered by steel plate mounted on wooden planks. BEYOND NZEB :masonry tilted roof with an XPS thermal coating of 16 cm covered by steel plate mounted on wooden planks.
Insulation	m3	111	143	143	143	143	143	254	
Construktion	m3	507	507	507	507	507	507	507	
Cover	m3	16	16	16	16	16	16	16	
FLOOR SLAP BETWEEN APARTMENTS ON FIRST FLOOR AND THE GROUND FLOOR									Minimum EP: masonry floor with an XPS thermal coating of 3 cm and an additional insulating layer of EPS (4 cm) included in the floor heating system. Cover in ceramic tiles NZEB REF building: masonry floor with an XPS thermal coating of 4 cm and an additional insulating layer of EPS (4 cm) included in the floor heating system. Cover in ceramic tiles SS1: masonry floor with an XPS thermal coating of 8 cm. Cover in ceramic tiles SS2: masonry floor with an XPS thermal coating of 8 cm. Cover in ceramic tiles SS3: masonry floor with an XPS thermal coating of 8 cm. Cover in ceramic tiles SS4: masonry floor with an XPS thermal coating of 8 cm. Cover in ceramic tiles BEYOND NZEB: masonry floor with an XPS thermal coating of 18 cm. Cover in ceramic tiles
Insulation	m3	31	41	82	82	82	82	185	
Construktion	m3	421	421	380	380	380	380	380	
Cover	m3	15	15	15	15	15	15	15	

FLOOR SLAP ABOVE BASEMENT AT GROUND FLOOR									SS1: reinforced concrete slab with with ventilated under-floor cavities and XPS thermal coating of 8 cm
Insulation	m3	122	122	122	122	122	122	122	SS2: reinforced concrete slab with with ventilated under-floor cavities and XPS thermal coating of 8 cm
Construktion	m3	1373	1373	1373	1373	1373	1373	1373	SS3: reinforced concrete slab with with ventilated under-floor cavities and XPS thermal coating of 8 cm
									SS4: reinforced concrete slab with with ventilated under-floor cavities and XPS thermal coating of 8 cm
Cover	m3	17	17	17	17	17	17	17	BEYOND NZEB: reinforced concrete slab with with ventilated under-floor cavities and XPS thermal coating of 8 cm
BASEMENT WALL									SS1: description of materials and thickness of insulation
Insulation	m3	absent	absent	absent	absent	absent	absent	absent	SS2: description of materials and thickness of insulation
Construktion	m3	-	-	-	-	-	-	-	SS3: description of materials and thickness of insulation
Cover	m3	-	-	-	-	-	-	-	SS4: description of materials and thickness of insulation
WINDOWS									SS1: Mono-block window assembled window with its own roller shutter box
Glass	m2	212	212	212	212	212	212	212	SS2: Mono-block window assembled window with its own roller shutter box
Frame	m2	91	91	91	91	91	91	91	SS3: Mono-block window assembled window with its own roller shutter box
									SS4: Mono-block window assembled window with its own roller shutter box
									BEYOND nzeb: Mono-block window assembled window with its own roller shutter box
VENTILATION									SS1:
Unit	unit and m3/h per unit	absent	absent	absent	absent	absent	absent	absent	SS2:
Ducts	g (or meter,diameter and materia	-	-	-	-	-	-	-	SS3:
									SS4:
HEAT SUPPLY									SS1:
Unit Central/ descentra	kW per unit	171 kW Heat pump + 94 kW back up condensing boiler as back up system	171 kW Heat pump + 94 kW back up condensing boiler as back up system	94 kW condensing boiler	171 kW Heat pump + 94 kW back up condensing boiler as back up system	Absent	94 kW condensing boiler	171 kW Heat pump + 94 kW back up condensing boiler as back up system	SS2:
Pipes distribution	g (or meter, diameter and materia	1262 kg; 1058 m (lenght); 0.040 m (average diameter)	1262 kg; 1058 m (lenght); 0.040 m (average diameter)	1010 kg; 846 m (lenght); 0.040 m (average diameter)	1010 kg; 846 m (lenght); 0.040 m (average diameter)	-	1010 kg; 846 m (lenght); 0.040 m (average diameter)	1010 kg; 846 m (lenght); 0.040 m (average diameter)	SS3:
Heating system(radiator, floor h	units or kg	2026 mq of floor heating	2026 mq of floor heating	Number of total pipes/section of the radiators: 354	Number of total pipes/section of low-temperature radiators: 631	Number of total eletric radiators: 145	Number of total pipes/section of the radiators: 354	Number of total pipes/section of low-temperature radiators: 631	SS4:
DHW SUPPLY									SS1:
Unit Central/ descentra	kW per unit	94 kW condensing boiler	94 kW condensing boiler	94 kW condensing boiler	171 kW Heat pump + 94 kW back up condensing boiler as back up system	94 kW condensing boiler	94 kW condensing boiler	171 kW Heat pump + 94 kW back up condensing boiler as back up system	SS2:
Pipes distribution	g (or meter, diameter and materia	555 kg; 2575 m (lenght); 0.035 m (average diameter)	555 kg; 2575 m (lenght); 0.035 m (average diameter)	555 kg; 2575 m (lenght); 0.035 m (average diameter)	555 kg; 2575 m (lenght); 0.035 m (average diameter)	555 kg; 2575 m (lenght); 0.035 m (average diameter)	555 kg; 2575 m (lenght); 0.035 m (average diameter)	555 kg; 2575 m (lenght); 0.035 m (average diameter)	SS3:
									SS4:
									SS1:
WATER SAVING System									SS2:
Unit Central/ descentra	units	absent	absent	absent	absent	absent	absent	absent	SS3:
Pipes distribution	g (or meter, diameter and materia)l								SS4:

Technology	MIN. EP	NZEB reference	Solution 1	Solution 2	Solution 3	Solution 4	Beyond NZEB	unit of Prices
SOLAR HEATING	330	709	898	ABSENT	851	898	ABSENT	euros/ apartment
PHOTOVOLTAIC	1545	1545	1545	1545	1596	1567	1596	euros / kWp
PHOTOVOLTAIC (euro/m2)	245	245	245	245	245	245	245	euros /m2
EXTERNAL WALL	523	500	421	421	421	421	355	euros /m^3
ROOF	299	291	291	291	291	291	271	euros /m^3
FLOOR SLAP BETWEEN APARTMENTS ON FIRST FLOOR AND THE GROUND FLOOR	265	260	266	266	266	266	229	euros /m^3
FLOOR SLAP ABOVE BASEMENT	-	-	-	-	-		-	euros /m^3
BASEMENT WALL	-	-	-	-	-	-	-	euros /m^3
WINDOWS	311	311	270	270	270	270	270	euros /m^2 window
VENTILATION	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	euros/ apartment
HEAT SUPPLY	7654	7654	2828	4765	1700	2828	4765	euros/ apartment
DHW SUPPLY	904	904	904	657	904	904	657	euros/ apartment
WATER SAVING System	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	euros /entired installation in the building
COOLING SYSTEM	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	euros /m^2 heated area

Italy - Turin

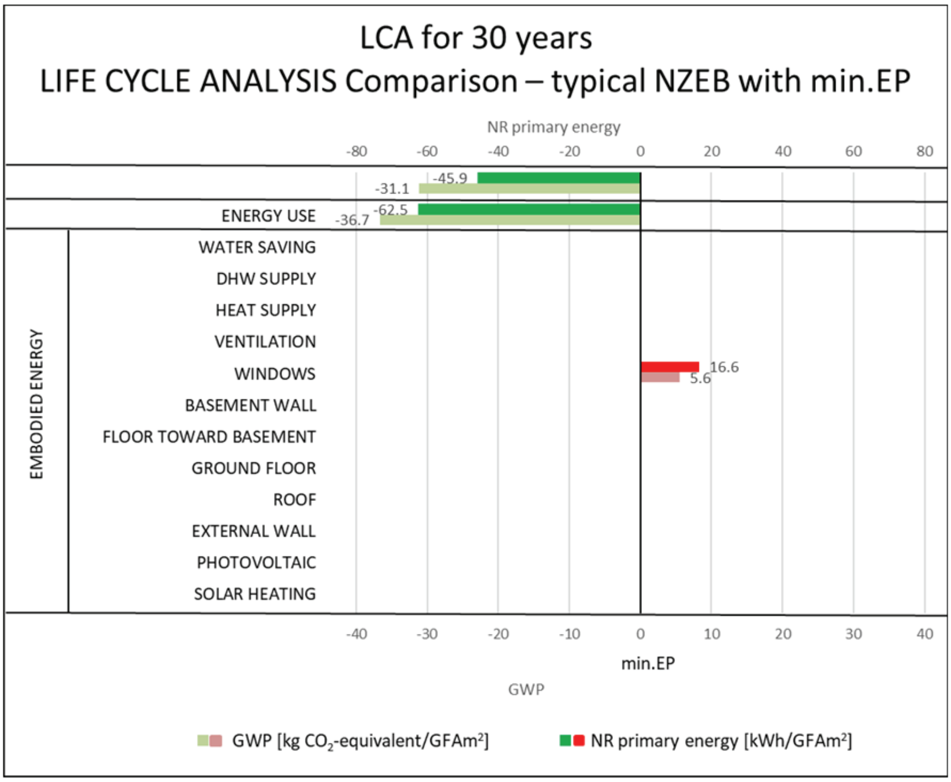
Technology		Units	Min. EP	NZEB reference building	SS1	SS2	SS3	SS4	SS5	Beyond NZEB	Description of system
				Cuantity per apartment or whole building							
SOLAR HEATING	System	m2	12,5	40	79	79	-	-	54	-	SS1: vacuum solar collector Mounted on the tilted roof (-30° and 18°), on the south-east and south-west oriented pitches; 19 modules SS2: vacuum solar collector Mounted on the tilted roof (-30° and 18°), on the south-east and south-west oriented pitches; 18 modules SS3: ABSENT SS4:ABSENT SS5: vacuum solar collector Mounted on the tilted roof (-30° and 18°), on the south-east and south-west oriented pitches; 19 Modules Beyond NZEB ABSENT
PHOTOVOLTAIC	System	m2	57	142	142	142	142	142	163	626	SS1: polycristalline PV system Mounted on the tilted roof, on the south-east and south-west oriented pitches 89 Modules azimut 120° tilt 18° SS2: polycristalline PV system Mounted on the tilted roof, on the south-east and south-west oriented pitches 89 Modules azimut 120° tilt 18° SS3: polycristalline PV system Mounted on the tilted roof, on the south-east and south-west oriented pitches 89 Modules azimut 120° tilt 18° SS4: polycristalline PV system Mounted on the tilted roof, on the south-east and south-west oriented pitches 89 Modules azimut 120° tilt 18° SS5: polycristalline PV system Mounted on the tilted roof, on the south-east and south-west oriented pitches 100 Modules azimut 120° tilt 18° Beyond NZEB: polycristalline PV system Mounted on the tilted roof, on the south-east and south-west oriented pitches, South pitch and South Facade 384 modules
EXTERNAL WALL	Insulation	m3	158	187	517	646	517	646	646	718	Minimum EP: two brick walls (20 Cm) with an EPS thermal coating (11 cm) covered by plaster (2 cm) NZEB REF building: two brick walls (20 Cm) with an EPS thermal coating (13 cm) covered by plaster (2 cm) SS1: large autoclaved concrete bricks with thermal insulating properties (36 cm) covered by plaster (2 cm) SS2: supernzeb large autoclaved concrete bricks with thermal insulating properties (45 cm) covered by plaster (2 cm)
	Construktion	m3	287	287							SS3: large autoclaved concrete bricks with thermal insulating properties (36 cm) covered by plaster (2 cm) SS4: supernzeb large autoclaved concrete bricks with thermal insulating properties (45 cm) covered by plaster (2 cm) SS5: supernzeb large autoclaved concrete bricks with thermal insulating properties (45 cm) covered by plaster (2 cm)
	Cover	m3	29	29	29	29	29	29	29	86	BEYOND NZEB: supernzeb large autoclaved concrete bricks with thermal insulating properties (50 cm) covered by termoinsulated plaster (3+3 cm)
WALL BETWEEN APARTMENTS AND STAIRCASES											Minimum EP: brick wall (20 cm) with insulation in textile fibre (10 cm) covered by plaster (3 cm) NZEB: brick wall (20 cm) with insulation in textile fibre (10 cm) covered by plaster (3 cm) SS1 brick wall (20 cm) with insulation in textile fibre (10 cm) covered by plaster (3 cm)
	Insulation	m3	86	86	86	86	86	86	86	171	SS2: brick wall (20 cm) with insulation in textile fibre (10 cm) covered by plaster (3 cm) SS3 brick wall (20 cm) with insulation in textile fibre (10 cm) covered by plaster (3 cm)
	Construktion	m3	171	171	171	171	171	171	171	171	SS4: brick wall (20 cm) with insulation in textile fibre (10 cm) covered by plaster (3 cm) SS5: brick wall (20 cm) with insulation in textile fibre (10 cm) covered by plaster (3 cm)
Cover		m3	26	26	26	26	26	26	26	26	beyond nzeb: brick wall (20 cm) with insulation in textile fibre (20 cm) covered by plaster (3 cm)
ROOF	Insulation	m3	143	174	174	428	174	428	428	555	Minimum EP: masonry tilted roof with an XPS thermal coating of 9 cm covered by steel plate mounted on wooden planks. NZEB REF building: masonry tilted roof with an XPS thermal coating of 11 cm covered by steel plate mounted on wooden planks. SS1:masonry tilted roof with an XPS thermal coating of 11 cm covered by steel plate mounted on wooden planks. SS2:masonry tilted roof with an XPS thermal coating of 27 cm covered by steel plate mounted on wooden planks.
	Construktion	m3	507	507	507	507	507	507	507	507	SS3:masonry tilted roof with an XPS thermal coating of 11 cm covered by steel plate mounted on wooden planks. SS4:masonry tilted roof with an XPS thermal coating of 27 cm covered by steel plate mounted on wooden planks.
	Cover	m3	16	16	16	16	16	16	16	16	SS5:masonry tilted roof with an XPS thermal coating of 27 cm covered by steel plate mounted on wooden planks. BEYOND NZEB :masonry tilted roof with an XPS thermal coating of 35 cm covered by steel plate mounted on wooden planks.

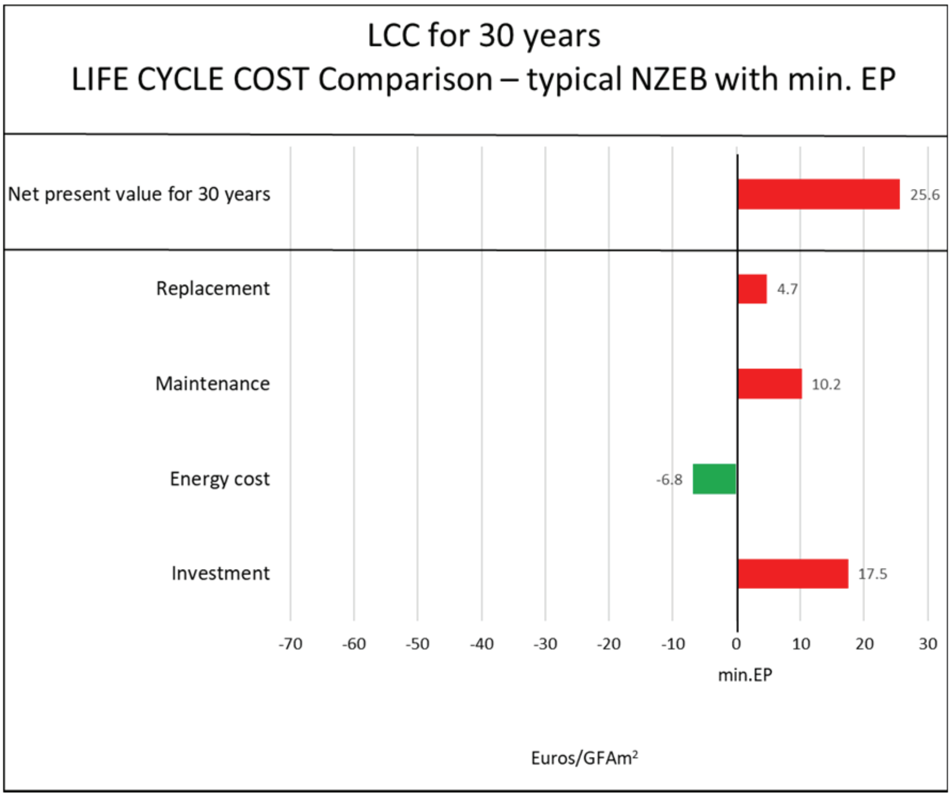
FLOOR SLAP BETWEEN APARTMENTS ON FIRST FLOOR AND THE GROUND FLOOR											Minimum EP: masonry floor with an XPS thermal coating of 4 cm cm and an additional insulating layer of EPS (4 cm) included in the floor heating system. Cover in ceramic tiles
											NZEB REF building: masonry floor with an XPS thermal coating of 7 cm cm and an additional insulating layer of EPS (4 cm) included in the floor heating system. Cover in ceramic tiles
											SS1: masonry floor with an XPS thermal coating of 11 cm. Cover in ceramic tiles
	Insulation	m3	41	72	113	205	113	205	205	308	SS2: masonry floor with an XPS thermal coating of 20 (16+4) cm. Cover in ceramic tiles
	Construktion	m3	421	421	380	380	380	380	380	380	SS3: masonry floor with an XPS thermal coating of 11 cm. Cover in ceramic tiles
											SS4: masonry floor with an XPS thermal coating of 20 (16+4) cm. Cover in ceramic tiles
											SS5: masonry floor with an XPS thermal coating of 20 (16+4) cm. Cover in ceramic tiles
	Cover	m3	15	15	15	15	15	15	15	15	BEYOND NZEB: masonry floor with an XPS thermal coating of 30 (26+4) cm. Cover in ceramic tiles
FLOOR SLAP ABOVE BASEMENT AT GROUND FLOOR											SS1: reinforced concrete slab with with ventilated under-floor cavities and XPS thermal coating of 8 cm
	Insulation	m3	122	122	122	122	122	122	122	122	SS2: reinforced concrete slab with with ventilated under-floor cavities and XPS thermal coating of 8 cm
	Construktion	m3	1373	1373	1373	1373	1373	1373	1373	1373	SS3: reinforced concrete slab with with ventilated under-floor cavities and XPS thermal coating of 8 cm
											SS4: reinforced concrete slab with with ventilated under-floor cavities and XPS thermal coating of 8 cm
											SS5: reinforced concrete slab with with ventilated under-floor cavities and XPS thermal coating of 8 cm
	Cover	m3	17	17	17	17	17	17	17	17	BEYOND NZEB: reinforced concrete slab with with ventilated under-floor cavities and XPS thermal coating of 8 cm
BASEMENT WALL											SS1: description of materials and thickness of insulation
	Insulation	m3	absent	absent	absent	absent	absent	absent	absent	absent	SS2: description of materials and thickness of insulation
	Construktion	m3	-	-	-	-	-	-	-	-	SS3: description of materials and thickness of insulation
	Cover	m3	-	-	-	-	-	-	-	-	SS4: description of materials and thickness of insulation
WINDOWS											NZEB REF: aluminium windows
											SS1: Mono-block window assembled window with its own roller shutter box
	Glass	m2	212	212	212	212	212	212	212	212	SS2: Mono-block window assembled window with its own roller shutter box
	Frame	m2	91	91	91	91	91	91	91	91	SS3: Mono-block window assembled window with its own roller shutter box
											SS4: Mono-block window assembled window with its own roller shutter box
											SS5: Mono-block window assembled window with its own roller shutter box
											beyond nzeb: Mono-block window assembled window with its own roller shutter box
VENTILATION											NZEB REF: MVHR
	Unit	unit and m3/h per unit		29 units (one per apartment); 72 m3/h per apartment	29 units (one per apartment); 72 m3/h per apartment	29 units (one per apartment); 72 m3/h per apartment	29 units (one per apartment); 72 m3/h per apartment	29 units (one per apartment); 72 m3/h per apartment	29 units (one per apartment); 72 m3/h per apartment	29 units (one per apartment); 72 m3/h per apartment	SS1: MVHR
	Ducts	kg (or meter,diameter and material)	Natural ventilation	435 m (lenght); 511 kg;0.22 m (average diameter)	435 m (lenght); 511 kg;0.22 m (average diameter)	145 m (lenght); 171 kg;0.22 m (average diameter)	435 m (lenght); 511 kg;0.22 m (average diameter)	145 m (lenght); 171 kg;0.22 m (average diameter)	435 m (lenght); 511 kg;0.22 m (average diameter)	435 m (lenght); 511 kg;0.22 m (average diameter)	SS2: MEV only extraction
											SS3: MVHR
											SS4: MEV only extraction
											SS5: MVHR
											BEYOND NZEB: MVHR
HEAT SUPPLY											SS1:
	Unit Central/ descentral	kW per unit	171 kW Heat pump + 94 kW back up condensing boiler as back up system	171 kW Heat pump + 94 kW back up condensing boiler as back up system	94 kW condensing boiler	94 kW condensing boiler	171 kW Heat pump + 94 kW back up condensing boiler as back up system	171 kW Heat pump + 94 kW back up condensing boiler as back up system	absent	171 kW Heat pump + 94 kW back up condensing boiler as back up system	SS2:
	Pipes distribution	kg (or meter, diameter and materia)l	1262 kg; 1058 m (lenght); 0.040 m (average diameter)	1262 kg; 1058 m (lenght); 0.040 m (average diameter)	1010 kg; 846 m (lenght); 0.040 m (average diameter)	1010 kg; 846 m (lenght); 0.040 m (average diameter)	1010 kg; 846 m (lenght); 0.040 m (average diameter)	1010 kg; 846 m (lenght); 0.040 m (diameter)	absent	1010 kg; 846 m (lenght); 0.040 m (diameter)	SS3:
	Heating system(radiator, floor heating…)	units or kg	2026 mq of floor heating	2026 mq of floor heating	Number of total pipes/section of the radiators: 534	Number of total pipes/section of the radiators: 534	Number of total pipes/sections of the low-temperature radiators: 954	Number of total pipes/sections of the low-temperature radiators: 954	Number of electric radiators: 145	Number of total pipes/sections of the low-temperature radiators: 954	SS4:
DHW SUPPLY											SS1:
	Unit Central/ descentral	kW per unit	94 kW condensing boiler	94 kW condensing boiler	94 kW condensing boiler	94 kW condensing boiler	171 kW Heat pump + 94 kW back up condensing boiler as back up system	171 kW Heat pump + 94 kW back up condensing boiler as back up system	94 kW condensing boiler	171 kW Heat pump + 94 kW back up condensing boiler as back up system	SS2:
	Pipes distribution	kg (or meter, diameter and materia)l	555 kg; 2575 m (lenght); 0.035 m (average diameter)	555 kg; 2575 m (lenght); 0.035 m (average diameter)	555 kg; 2575 m (lenght); 0.035 m (average diameter)	555 kg; 2575 m (lenght); 0.035 m (average diameter)	555 kg; 2575 m (lenght); 0.035 m (average diameter)	555 kg; 2575 m (lenght); 0.035 m (average diameter)	555 kg; 2575 m (lenght); 0.035 m (average diameter)	555 kg; 2575 m (lenght); 0.035 m (average diameter)	SS3:
											SS4:
WATER SAVING System											SS1:
											SS2:
	Unit Central/ descentral	units	absent	absent	absent	absent	absent	absent	absent	absent	SS3:
	Pipes distribution	kg (or meter, diameter and materia)l									SS4:

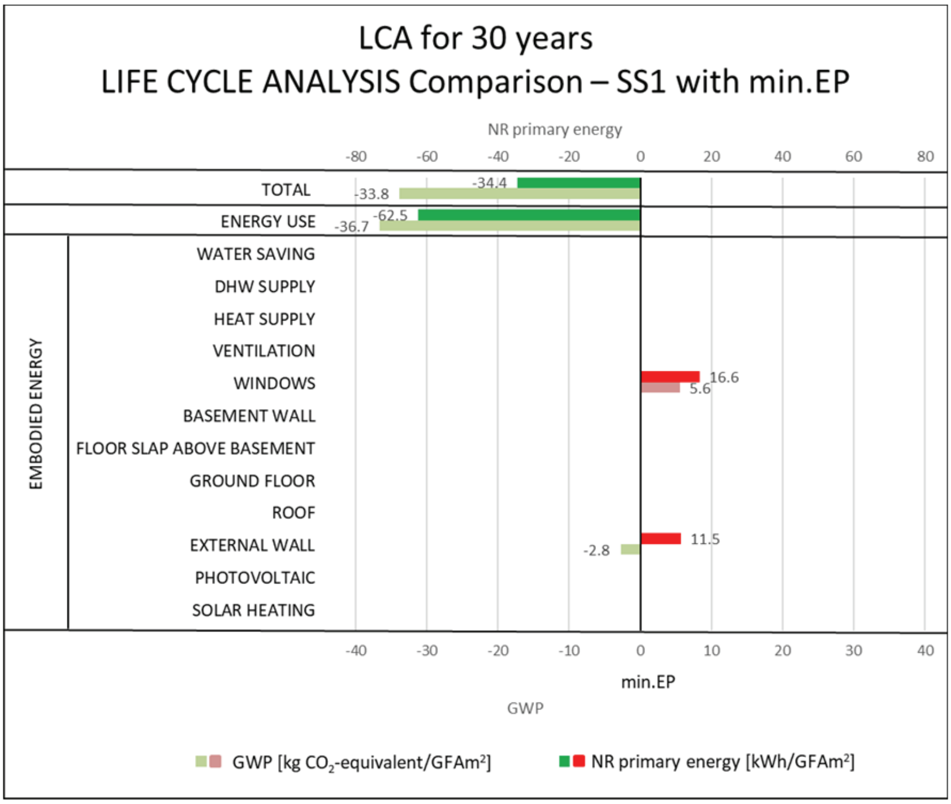
Technology	Minimum EP	NZEB reference	Solution 1	Solution 2	Solution 3	Solution 4	Solution 5	BEYOND NZEB	unit of Prices
SOLAR HEATING	330	1040	2082	2082	0	0	1418	0	euros/ apartment
PHOTOVOLTAIC	1545	1545	1545	1545	1545	1545	1596	1596	euros / kWp
PHOTOVOLTAIC (euro/m2)	245	245	245	245	245	245	245	245	euros /m2
EXTERNAL WALL	494	472	392	341	392	341	341	351	euros /m^3
WALL BETWEEN APARTMENTS AND STAIRCASES	302	302	302	302	302	302	302	253	euros /m^3
ROOF	291	285	285	248	285	248	248	237	euros /m^3
FLOOR SLAP BETWEEN APARTMENTS ON FIRST FLOOR AND THE GROUND FLOO	259	248	252	223	252	223	223	200	euros /m^3
FLOOR SLAP ABOVE BASEMENT	-	-	-	-	-	-	-	-	euros /m^3
BASEMENT WALL	-	-	-	-	-	-	-	-	euros /m^3
WINDOWS	311	311	270	270	270	270	270	270	euros /m^2 window
VENTILATION	ABSENT	2935	2935	880	2935	880	2935	2935	euros/ apartment
HEAT SUPPLY	7654	7654	3159	3159	5356	5356	2100	5356	euros/ apartment
DHW SUPPLY	904	904	904	904	657	657	904	657	euros/ apartment
WATER SAVING System	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	euros /entired installation in the building
COOLING SYSTEM	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	ABSENT	euros /m^2 heated area

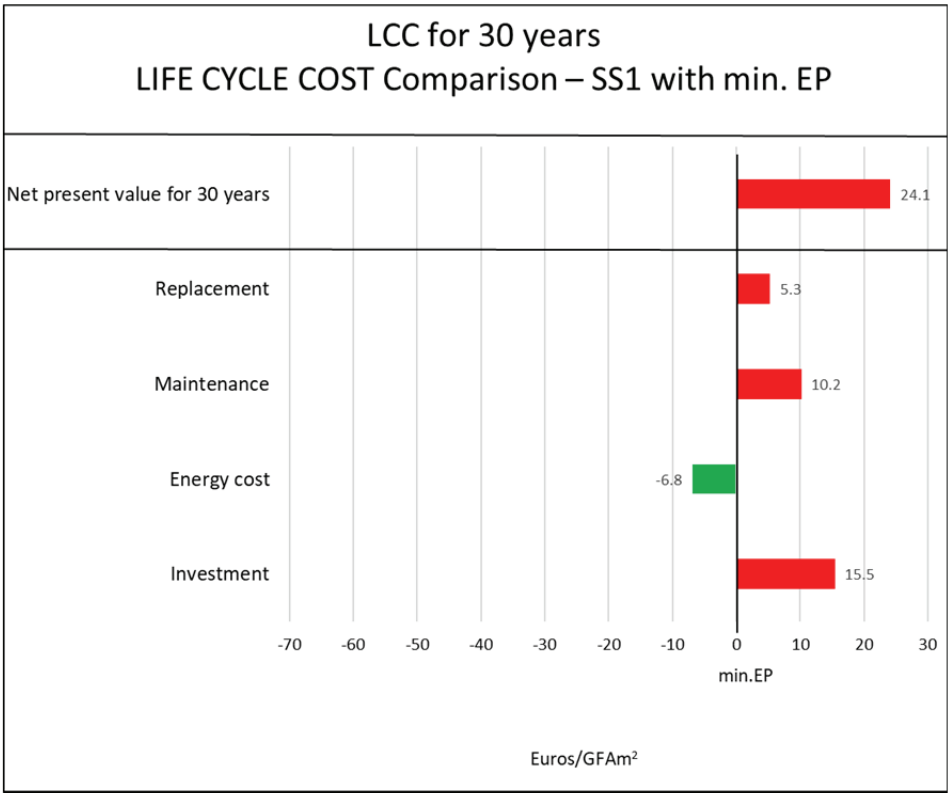
9.2 Plots of all solution sets compared to the min. EP building level

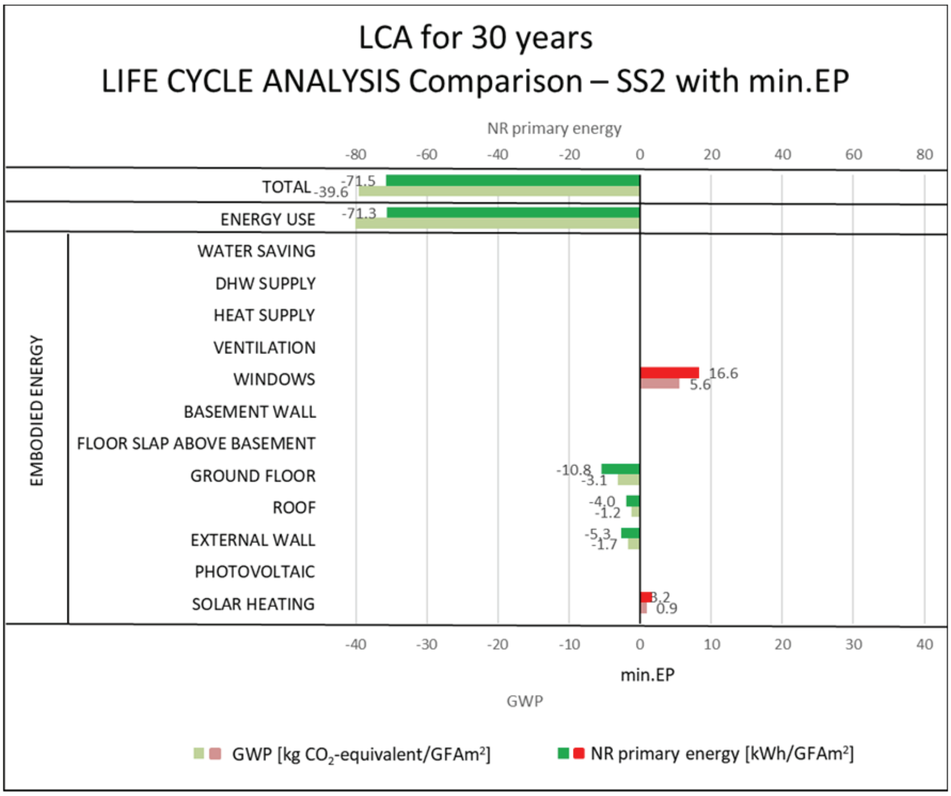
Denmark

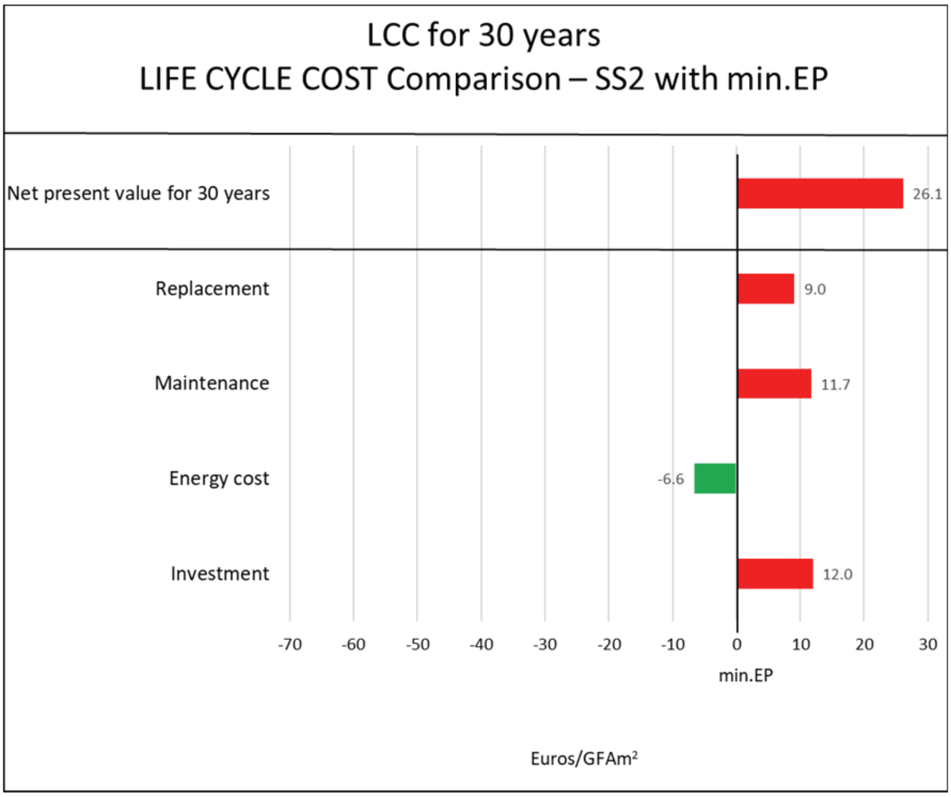


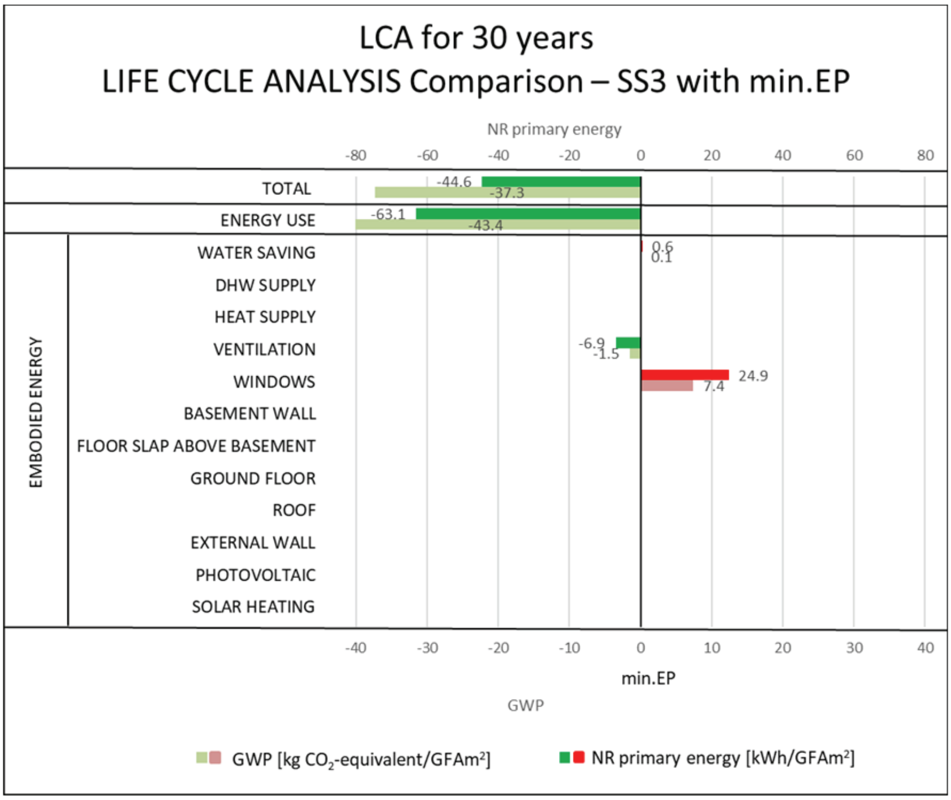


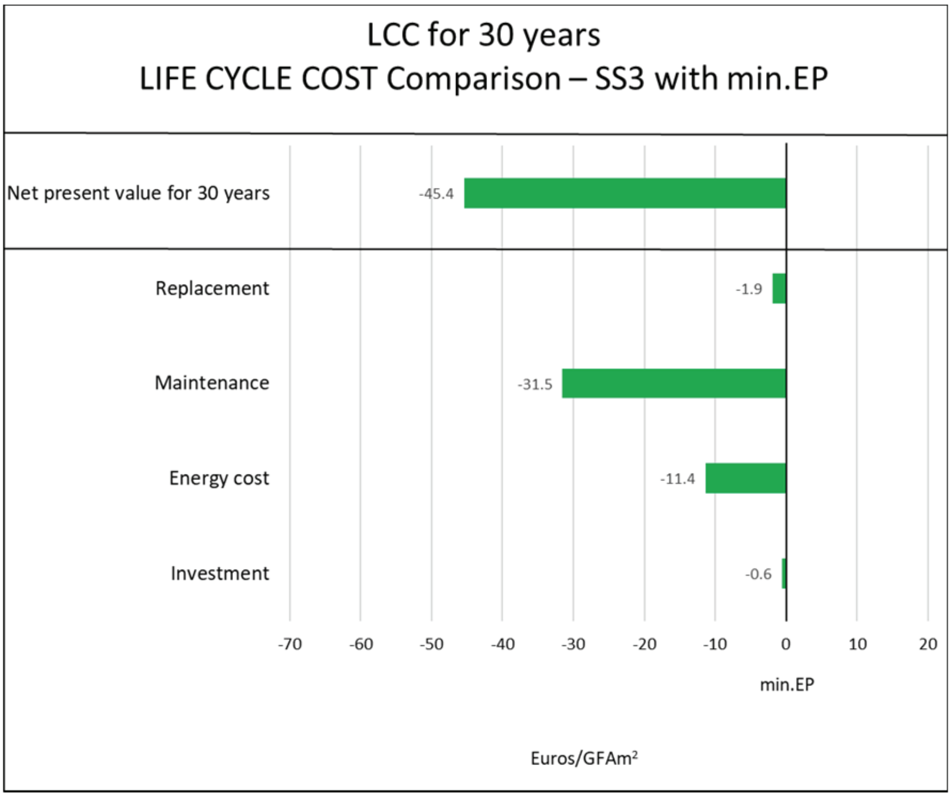

LCA for 30 years
LIFE CYCLE ANALYSIS Comparison – SS1 with min.EP
NR primary energy
-80 -60 -40 -20 0 20 40 60 80
TOTAL
ENERGY USE
EMBODIED ENERGY
WATER SAVING
DHW SUPPLY
HEAT SUPPLY
VENTILATION
WINDOWS
BASEMENT WALL
FLOOR SLAB ABOVE BASEMENT
GROUND FLOOR
ROOF
EXTERNAL WALL
PHOTOVOLTAIC
SOLAR HEATING
-34.4
-33.8
-62.5
-36.7
16.6
5.6
11.5
-2.8
-40 -30 -20 -10 0 10 20 30 40
min.EP
GWP
GWP [kg CO2-equivalent/GFAm²]
NR primary energy [kWh/GFAm²]

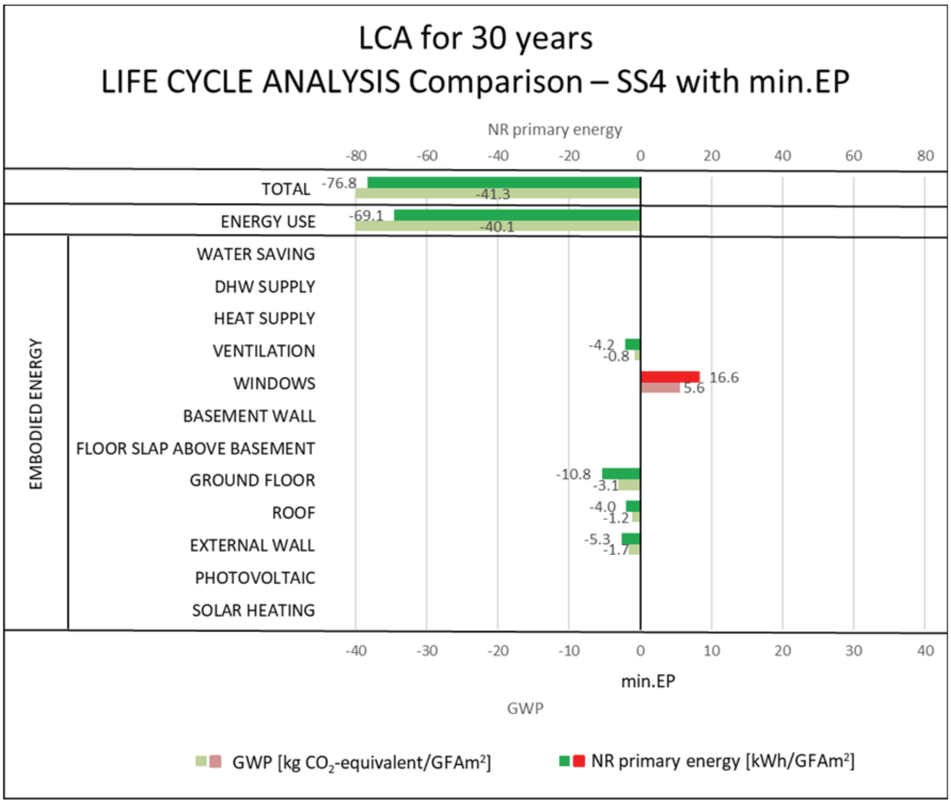

LCC for 30 years
LIFE CYCLE COST Comparison – SS1 with min. EP
Net present value for 30 years
Replacement
Maintenance
Energy cost
Investment
24.1
5.3
10.2
-6.8
15.5
-70 -60 -50 -40 -30 -20 -10 0 10 20 30
min.EP
Euros/GFAm²

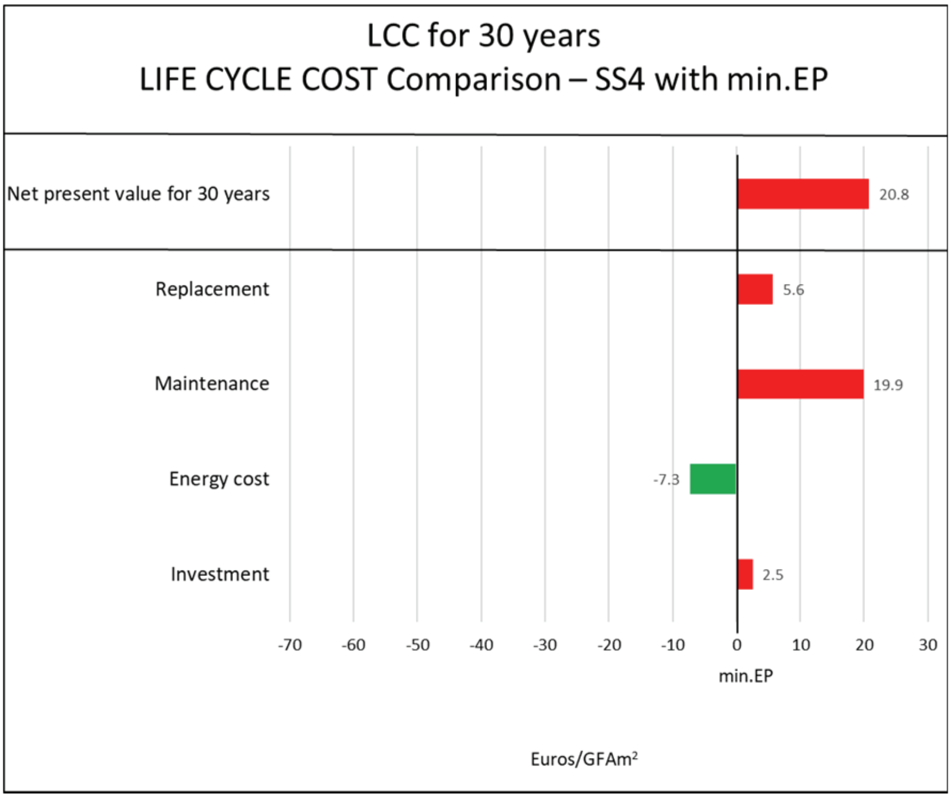

LCA for 30 years
LIFE CYCLE ANALYSIS Comparison – SS2 with min.EP
NR primary energy
-80
-60
-40
-20
0
20
40
60
80
TOTAL
-71.5
-39.6
ENERGY USE
-71.3
EMBODIED ENERGY
WATER SAVING
DHW SUPPLY
HEAT SUPPLY
VENTILATION
WINDOWS
16.6
5.6
BASEMENT WALL
FLOOR SLAP ABOVE BASEMENT
GROUND FLOOR
-10.8
-3.1
ROOF
-4.0
-1.2
EXTERNAL WALL
-5.3
-1.7
PHOTOVOLTAIC
SOLAR HEATING
3.2
0.9
-40
-30
-20
-10
0
10
20
30
40
min.EP
GWP
GWP [kg CO_2-equivalent/GFAm²]
NR primary energy [kWh/GFAm²]

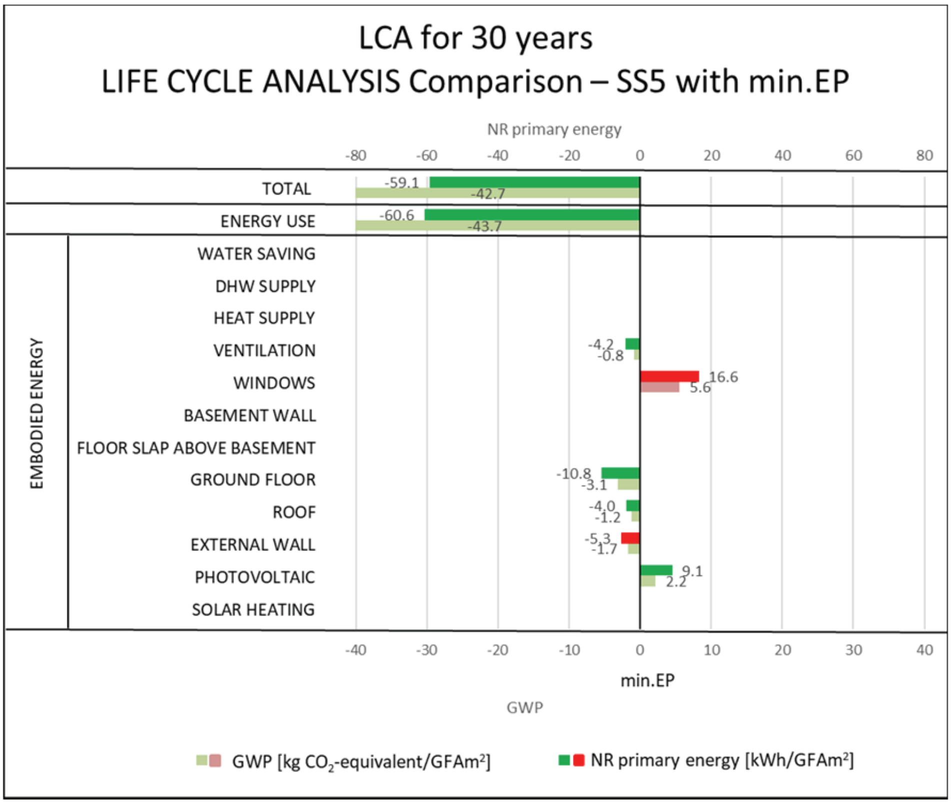

LCC for 30 years
LIFE CYCLE COST Comparison – SS2 with min.EP
Net present value for 30 years
26.1
Replacement
9.0
Maintenance
11.7
Energy cost
-6.6
Investment
12.0
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
min.EP
Euros/GFAm²

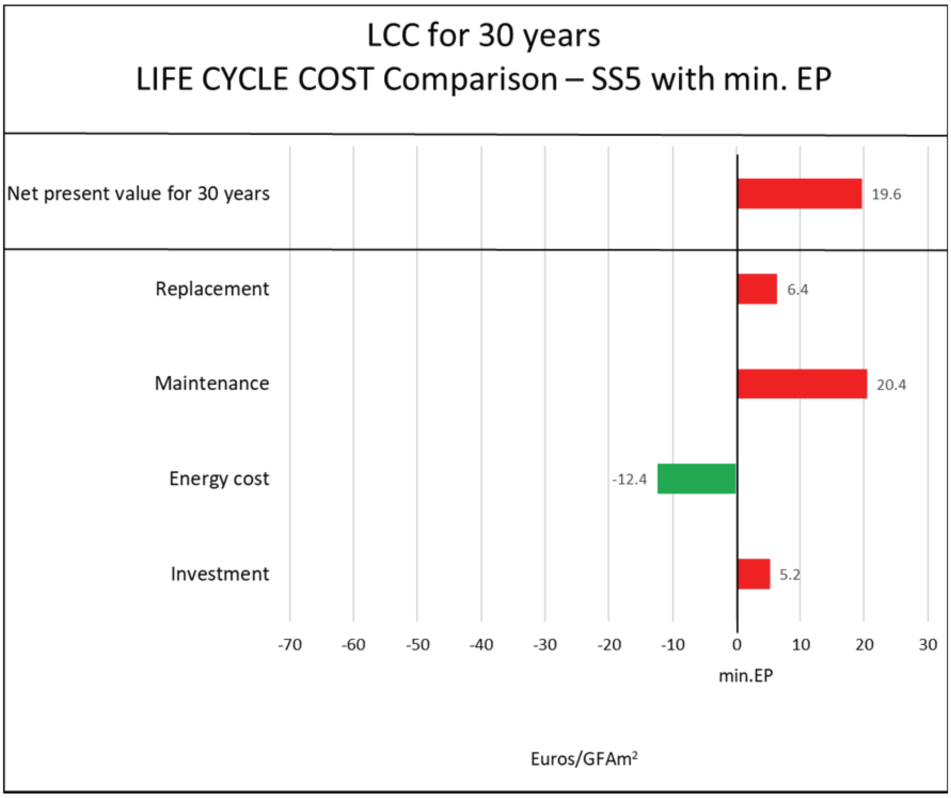

LCA for 30 years
LIFE CYCLE ANALYSIS Comparison – SS3 with min.EP
NR primary energy
TOTAL
ENERGY USE
EMBODIED ENERGY
WATER SAVING
DHW SUPPLY
HEAT SUPPLY
VENTILATION
WINDOWS
BASEMENT WALL
FLOOR SLAB ABOVE BASEMENT
GROUND FLOOR
ROOF
EXTERNAL WALL
PHOTOVOLTAIC
SOLAR HEATING
-44.6
-37.3
-63.1
-43.4
0.6
0.1
-6.9
-1.5
24.9
7.4
min.EP
GWP
GWP [kg CO2-equivalent/GFAm²]
NR primary energy [kWh/GFAm²]

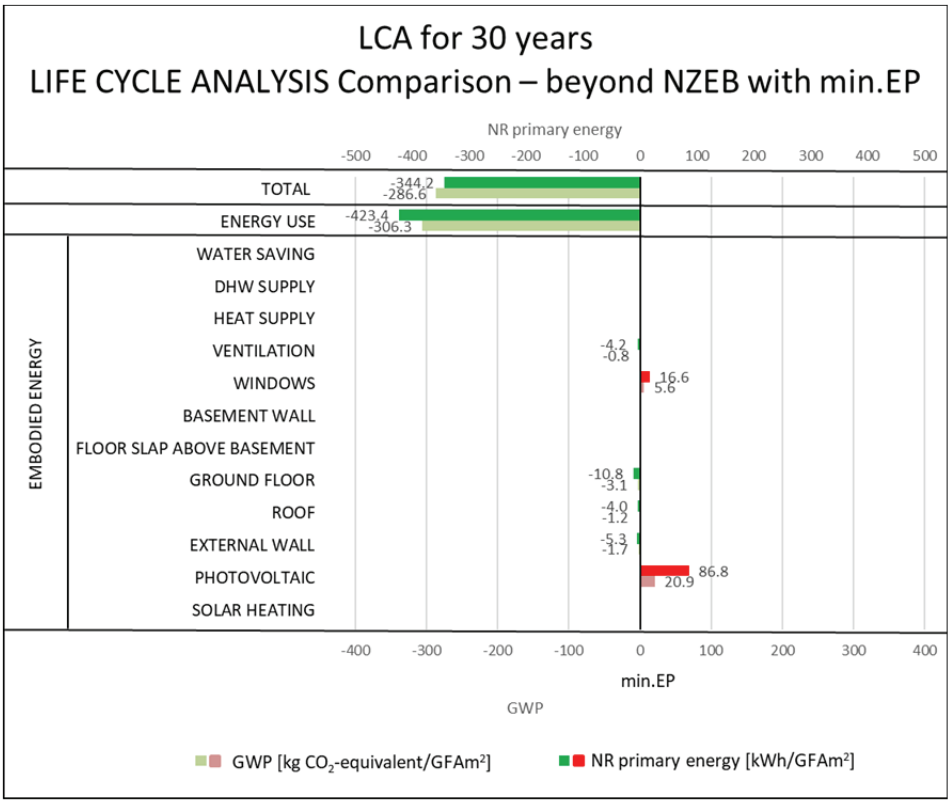

LCC for 30 years
LIFE CYCLE COST Comparison – SS3 with min.EP
Net present value for 30 years
Replacement
Maintenance
Energy cost
Investment
-45.4
-1.9
-31.5
-11.4
-0.6
min.EP
Euros/GFAm²

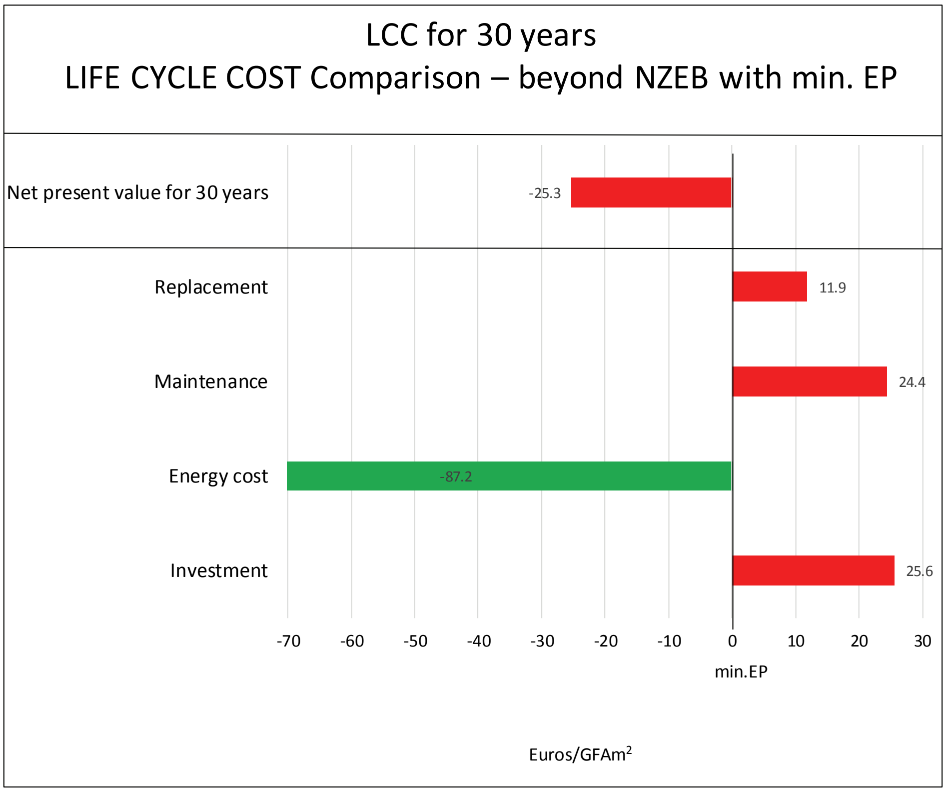

LCA for 30 years
LIFE CYCLE ANALYSIS Comparison – SS4 with min.EP
NR primary energy
TOTAL -76.8 -41.3
ENERGY USE -69.1 -40.1
EMBODIED ENERGY
WATER SAVING
DHW SUPPLY
HEAT SUPPLY
VENTILATION -4.2 -0.8
WINDOWS 16.6 5.6
BASEMENT WALL
FLOOR SLAP ABOVE BASEMENT
GROUND FLOOR -10.8 -3.1
ROOF -4.0 -1.2
EXTERNAL WALL -5.3 -1.7
PHOTOVOLTAIC
SOLAR HEATING
min.EP
GWP
GWP [kg CO_2-equivalent/GFAm²]
NR primary energy [kWh/GFAm²]


LCC for 30 years
LIFE CYCLE COST Comparison – SS4 with min.EP
Net present value for 30 years 20.8
Replacement 5.6
Maintenance 19.9
Energy cost -7.3
Investment 2.5
min.EP
Euros/GFAm²

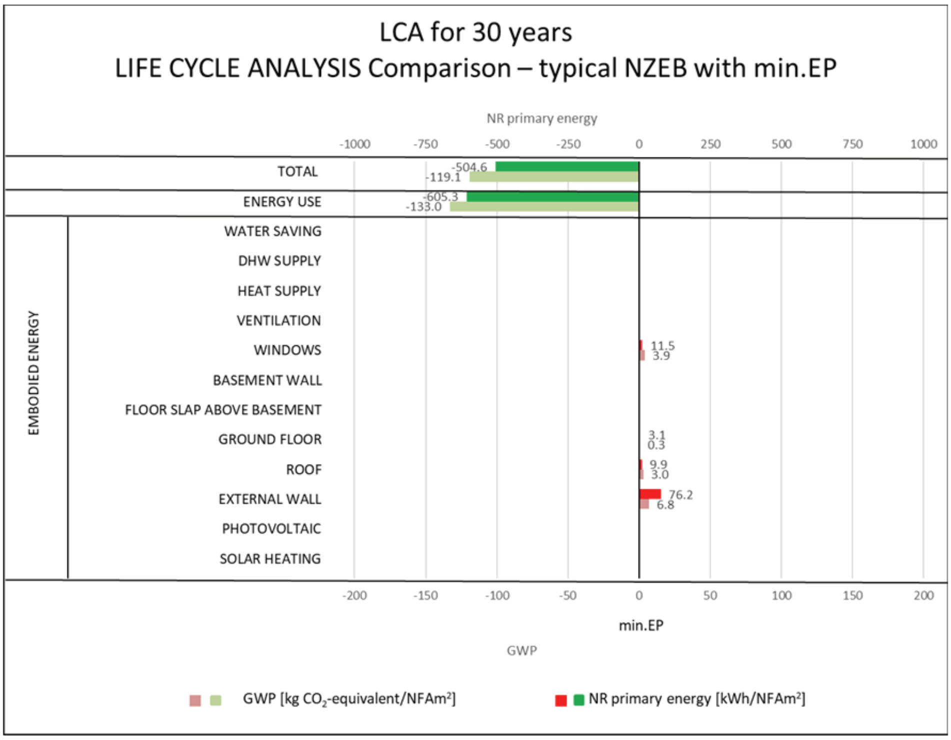

LCA for 30 years
LIFE CYCLE ANALYSIS Comparison – SS5 with min.EP
NR primary energy
TOTAL
ENERGY USE
EMBODIED ENERGY
WATER SAVING
DHW SUPPLY
HEAT SUPPLY
VENTILATION
WINDOWS
BASEMENT WALL
FLOOR SLAP ABOVE BASEMENT
GROUND FLOOR
ROOF
EXTERNAL WALL
PHOTOVOLTAIC
SOLAR HEATING
-59.1
-42.7
-60.6
-43.7
-4.2
-0.8
16.6
5.6
-10.8
-3.1
-4.0
-1.2
-5.3
-1.7
9.1
2.2
min.EP
GWP
GWP [kg CO2-equivalent/GFAm²]
NR primary energy [kWh/GFAm²]

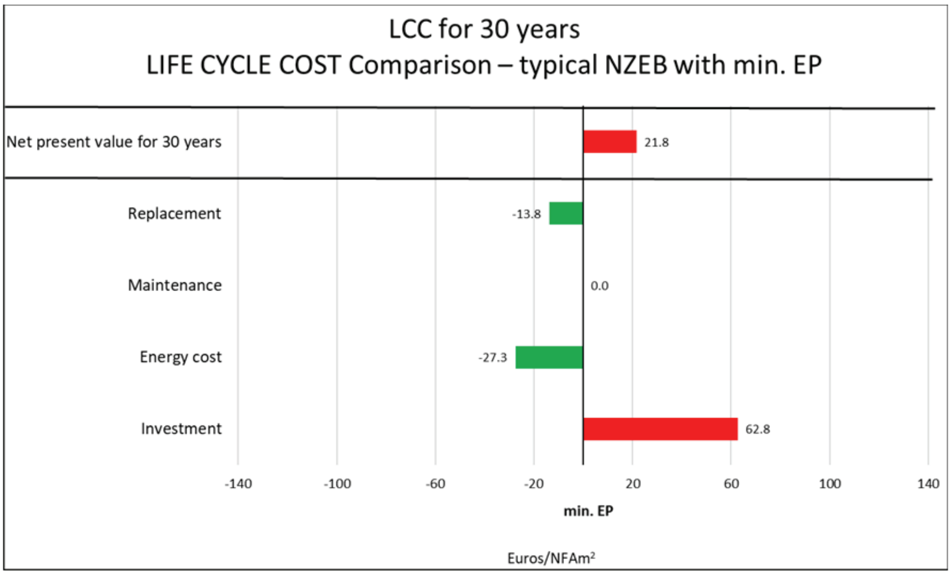

LCC for 30 years
LIFE CYCLE COST Comparison – SS5 with min. EP
Net present value for 30 years
Replacement
Maintenance
Energy cost
Investment
19.6
6.4
20.4
-12.4
5.2
min.EP
Euros/GFAm²

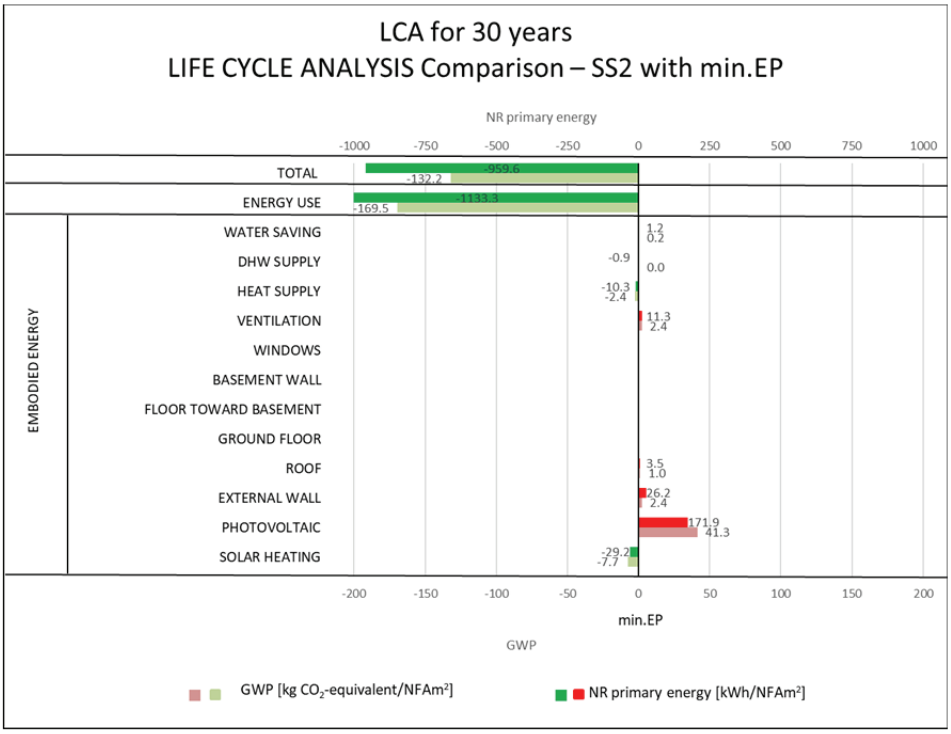

LCA for 30 years
LIFE CYCLE ANALYSIS Comparison – beyond NZEB with min.EP
NR primary energy
-500 -400 -300 -200 -100 0 100 200 300 400 500
TOTAL
-344.2
-286.6
ENERGY USE
-423.4
-306.3
EMBODIED ENERGY
WATER SAVING
DHW SUPPLY
HEAT SUPPLY
VENTILATION
-4.2
-0.8
WINDOWS
16.6
5.6
BASEMENT WALL
FLOOR SLAP ABOVE BASEMENT
GROUND FLOOR
-10.8
-3.1
ROOF
-4.0
-1.2
EXTERNAL WALL
-5.3
-1.7
PHOTOVOLTAIC
86.8
20.9
SOLAR HEATING
-400 -300 -200 -100 0 100 200 300 400
min.EP
GWP
GWP [kg CO2-equivalent/GFAm2]
NR primary energy [kWh/GFAm2]

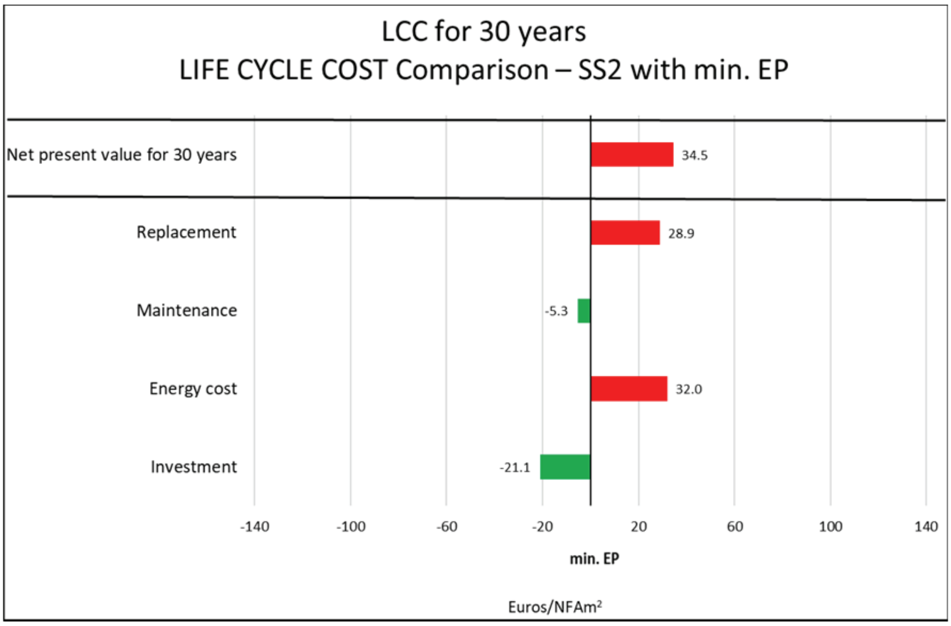

LCC for 30 years
LIFE CYCLE COST Comparison – beyond NZEB with min. EP
Net present value for 30 years
-25.3
Replacement
11.9
Maintenance
24.4
Energy cost
-87.2
Investment
25.6
-70 -60 -50 -40 -30 -20 -10 0 10 20 30
min.EP
Euros/GFAm2

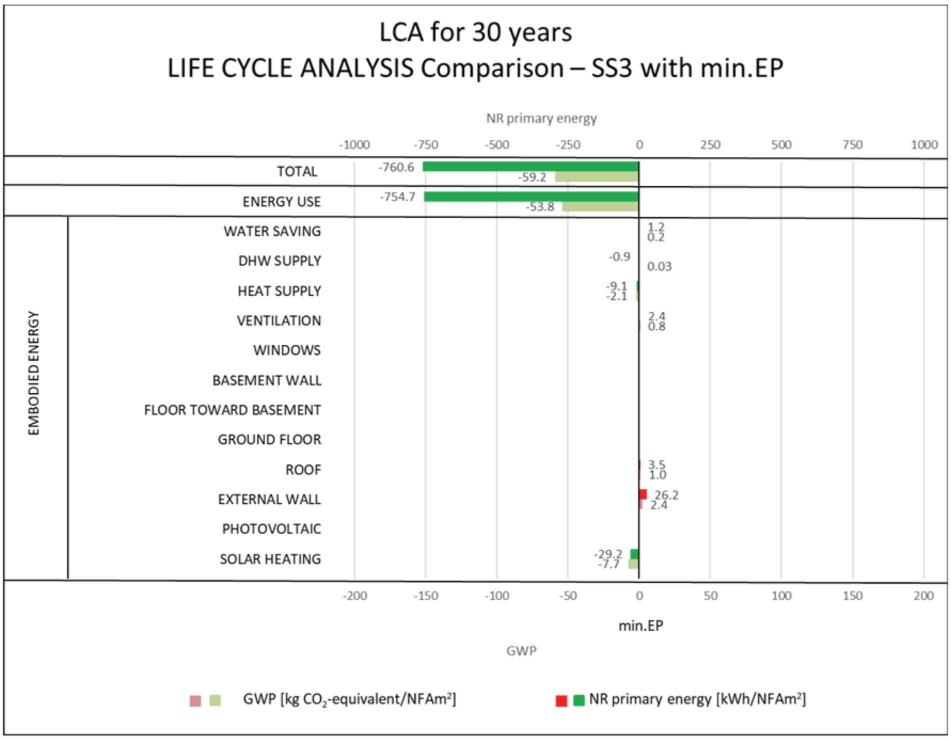
Germany

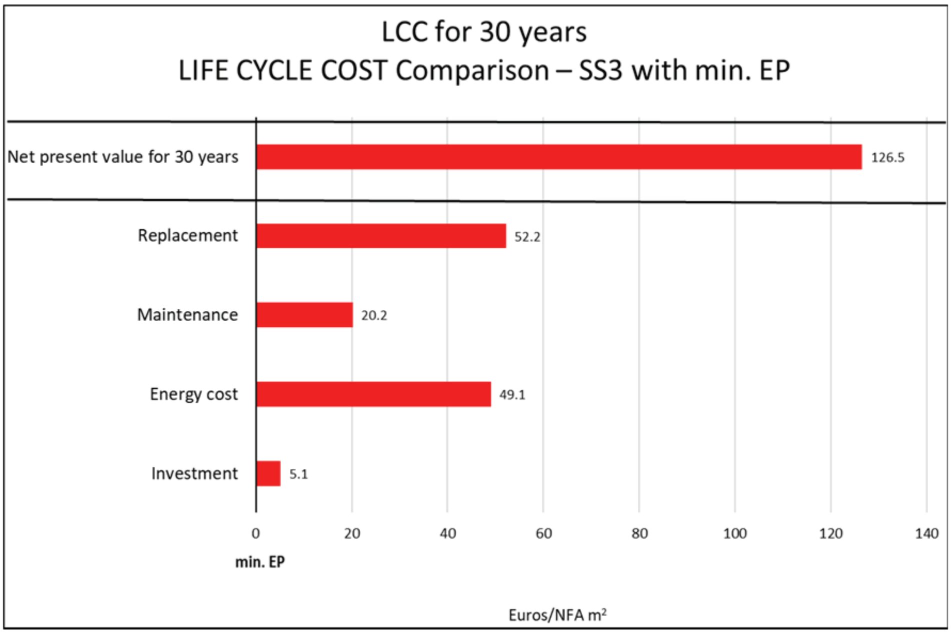

LCA for 30 years
LIFE CYCLE ANALYSIS Comparison – typical NZEB with min.EP
NR primary energy
-1000
-750
-500
-250
0
250
500
750
1000
TOTAL
-504.6
-119.1
ENERGY USE
-605.3
-133.0
EMBODIED ENERGY
WATER SAVING
DHW SUPPLY
HEAT SUPPLY
VENTILATION
WINDOWS
11.5
3.9
BASEMENT WALL
FLOOR SLAB ABOVE BASEMENT
GROUND FLOOR
3.1
0.3
ROOF
9.9
3.0
EXTERNAL WALL
76.2
6.8
PHOTOVOLTAIC
SOLAR HEATING
-200
-150
-100
-50
0
50
100
150
200
min.EP
GWP
GWP [kg CO_2-equivalent/NFAm²]
NR primary energy [kWh/NFAm²]

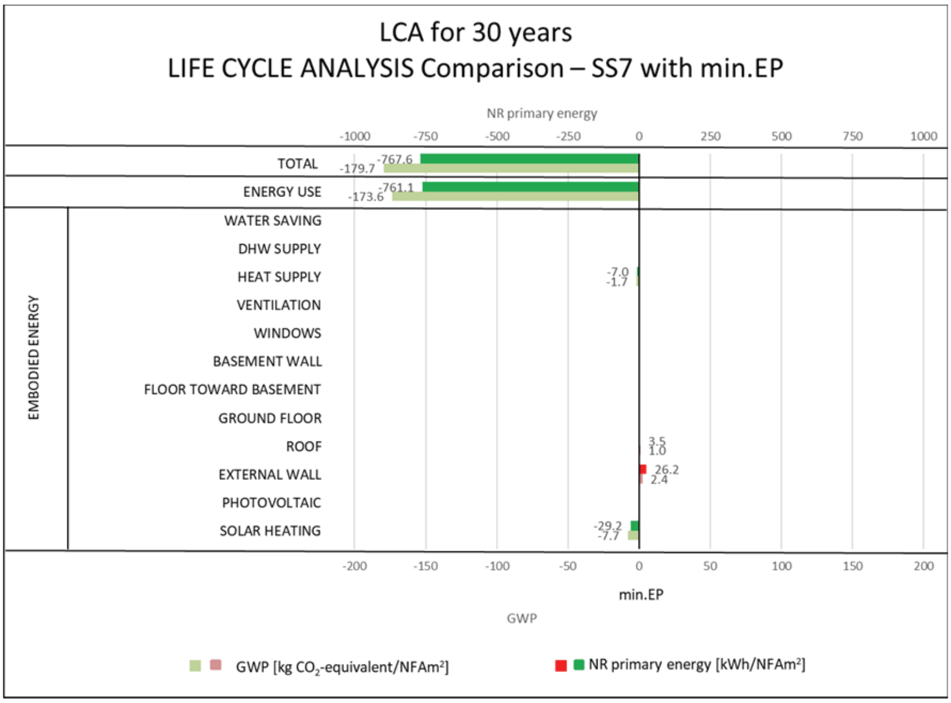

LCC for 30 years
LIFE CYCLE COST Comparison – typical NZEB with min. EP
Net present value for 30 years
21.8
Replacement
-13.8
Maintenance
0.0
Energy cost
-27.3
Investment
62.8
-140
-100
-60
-20
20
60
100
140
min. EP
Euros/NFAm²

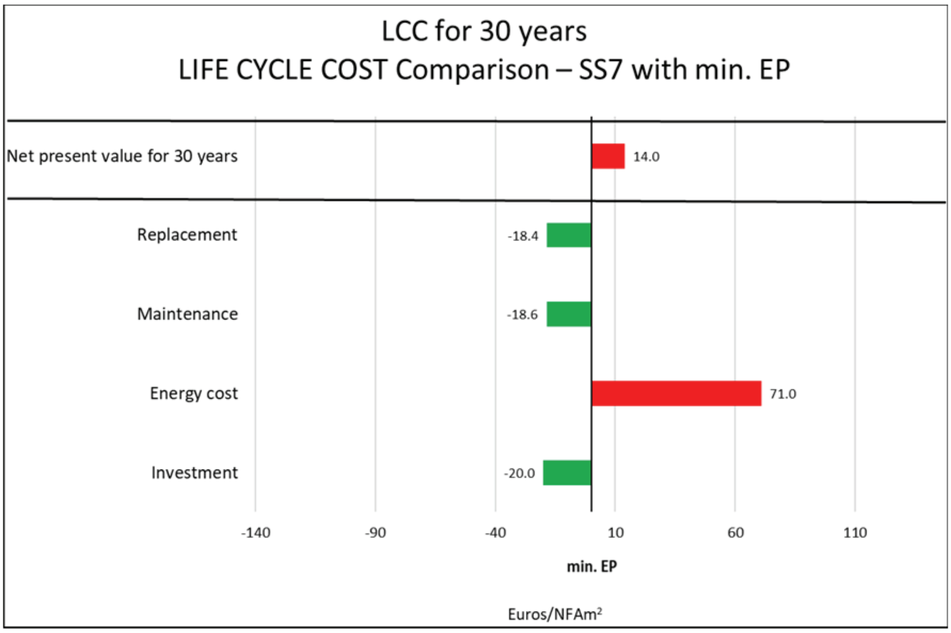

LCA for 30 years
LIFE CYCLE ANALYSIS Comparison – SS2 with min.EP
NR primary energy
TOTAL
ENERGY USE
EMBODIED ENERGY
WATER SAVING
DHW SUPPLY
HEAT SUPPLY
VENTILATION
WINDOWS
BASEMENT WALL
FLOOR TOWARD BASEMENT
GROUND FLOOR
ROOF
EXTERNAL WALL
PHOTOVOLTAIC
SOLAR HEATING
-959.6
-132.2
-1133.3
-169.5
1.2
0.2
-0.9
0.0
-10.3
-2.4
11.3
2.4
3.5
1.0
26.2
2.4
171.9
41.3
-29.2
-7.7
min.EP
GWP
GWP [kg CO_2-equivalent/NFAm²]
NR primary energy [kWh/NFAm²]

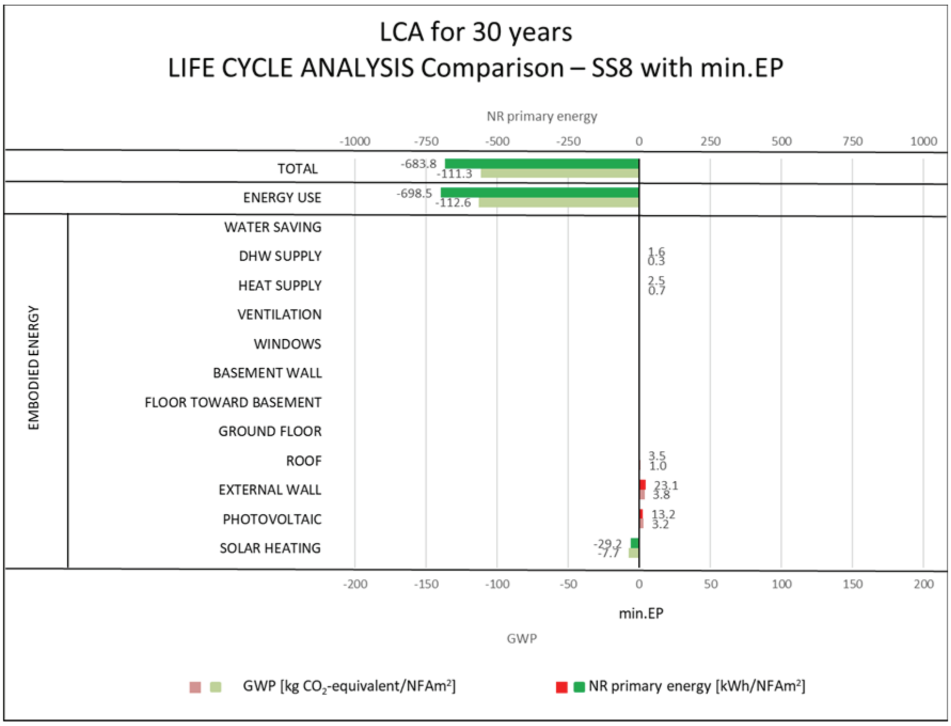

LCC for 30 years
LIFE CYCLE COST Comparison – SS2 with min. EP
Net present value for 30 years
Replacement
Maintenance
Energy cost
Investment
34.5
28.9
-5.3
32.0
-21.1
min. EP
Euros/NFAm²

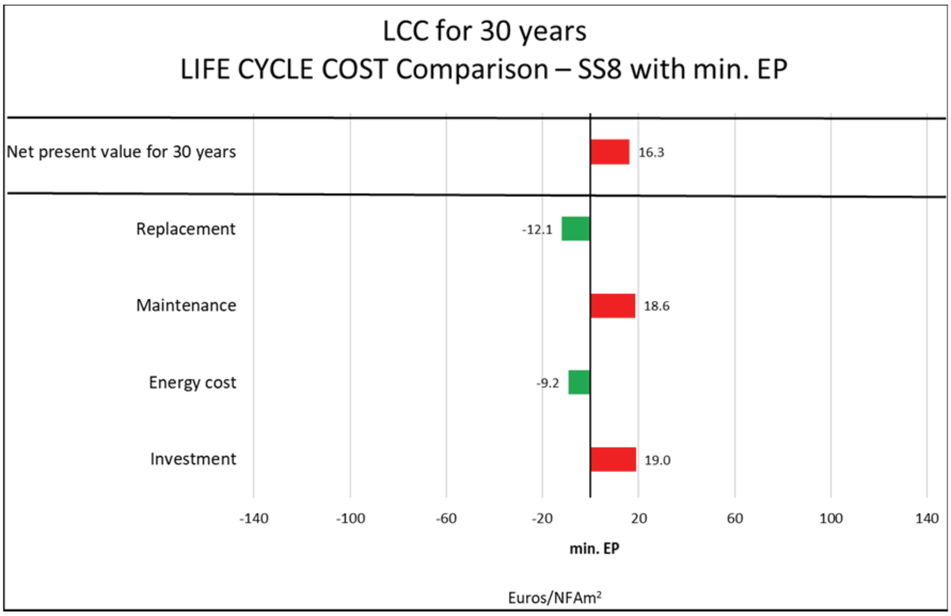

LCA for 30 years
LIFE CYCLE ANALYSIS Comparison – SS3 with min.EP
NR primary energy
TOTAL
ENERGY USE
EMBODIED ENERGY
WATER SAVING
DHW SUPPLY
HEAT SUPPLY
VENTILATION
WINDOWS
BASEMENT WALL
FLOOR TOWARD BASEMENT
GROUND FLOOR
ROOF
EXTERNAL WALL
PHOTOVOLTAIC
SOLAR HEATING
-760.6
-59.2
-754.7
-53.8
min.EP
GWP
GWP [kg CO2-equivalent/NFAm2]
NR primary energy [kWh/NFAm2]

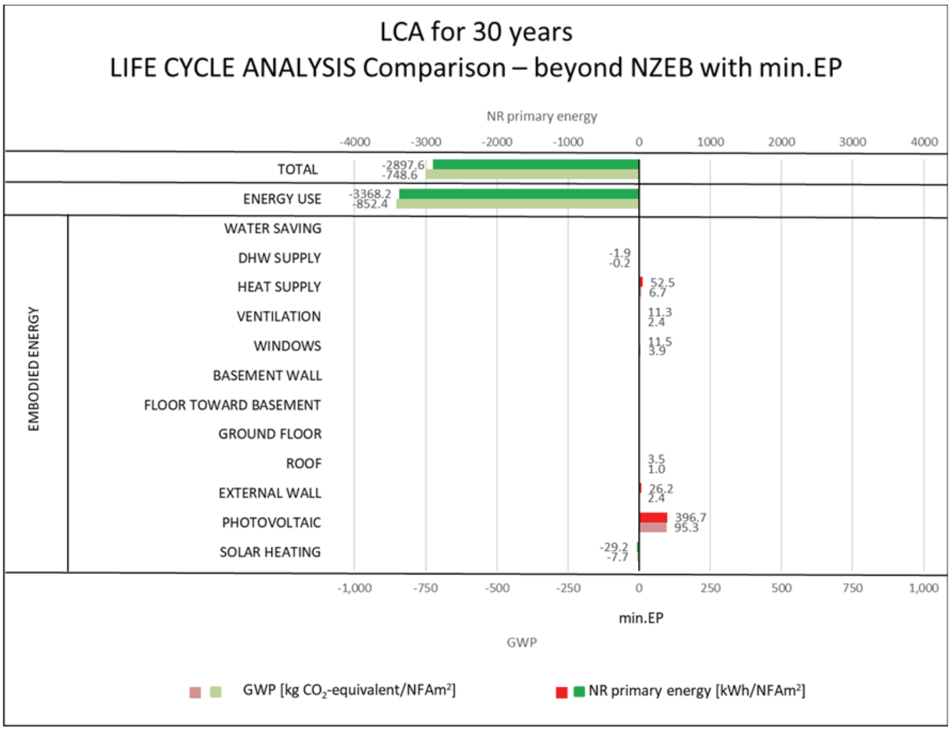

LCC for 30 years
LIFE CYCLE COST Comparison – SS3 with min. EP
Net present value for 30 years
Replacement
Maintenance
Energy cost
Investment
126.5
52.2
20.2
49.1
5.1
min. EP
Euros/NFA m2

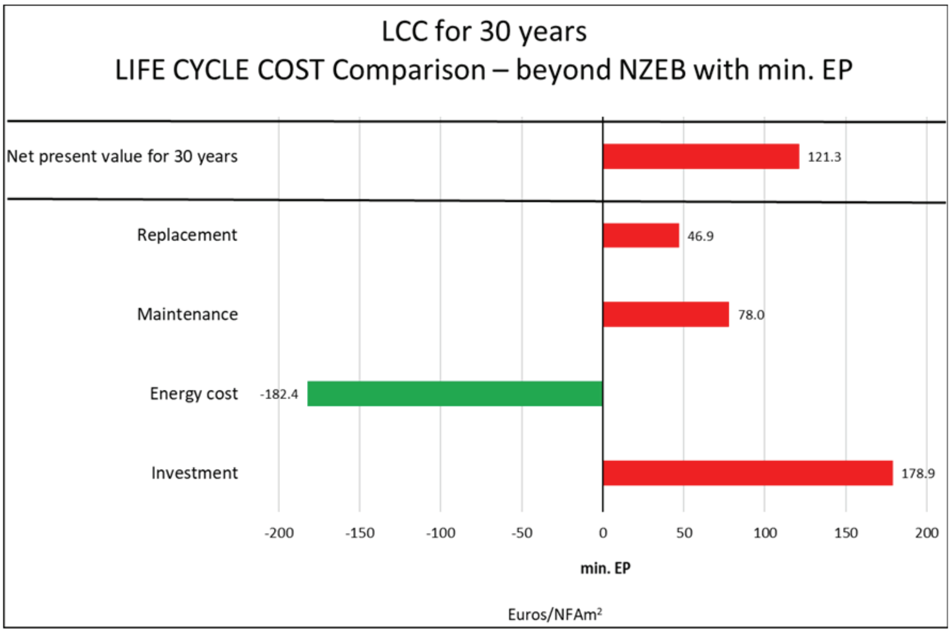

LCA for 30 years
LIFE CYCLE ANALYSIS Comparison – SS7 with min.EP
NR primary energy
-1000 -750 -500 -250 0 250 500 750 1000
TOTAL
-767.6
-179.7
ENERGY USE
-761.1
-173.6
EMBODIED ENERGY
WATER SAVING
DHW SUPPLY
HEAT SUPPLY
-7.0
-1.7
VENTILATION
WINDOWS
BASEMENT WALL
FLOOR TOWARD BASEMENT
GROUND FLOOR
ROOF
3.5
1.0
EXTERNAL WALL
26.2
2.4
PHOTOVOLTAIC
SOLAR HEATING
-29.2
-7.7
-200 -150 -100 -50 0 50 100 150 200
min.EP
GWP
GWP [kg CO2-equivalent/NFAm2]
NR primary energy [kWh/NFAm2]


LCC for 30 years
LIFE CYCLE COST Comparison – SS7 with min. EP
Net present value for 30 years
14.0
Replacement
-18.4
Maintenance
-18.6
Energy cost
71.0
Investment
-20.0
-140 -90 -40 10 60 110
min. EP
Euros/NFAm2

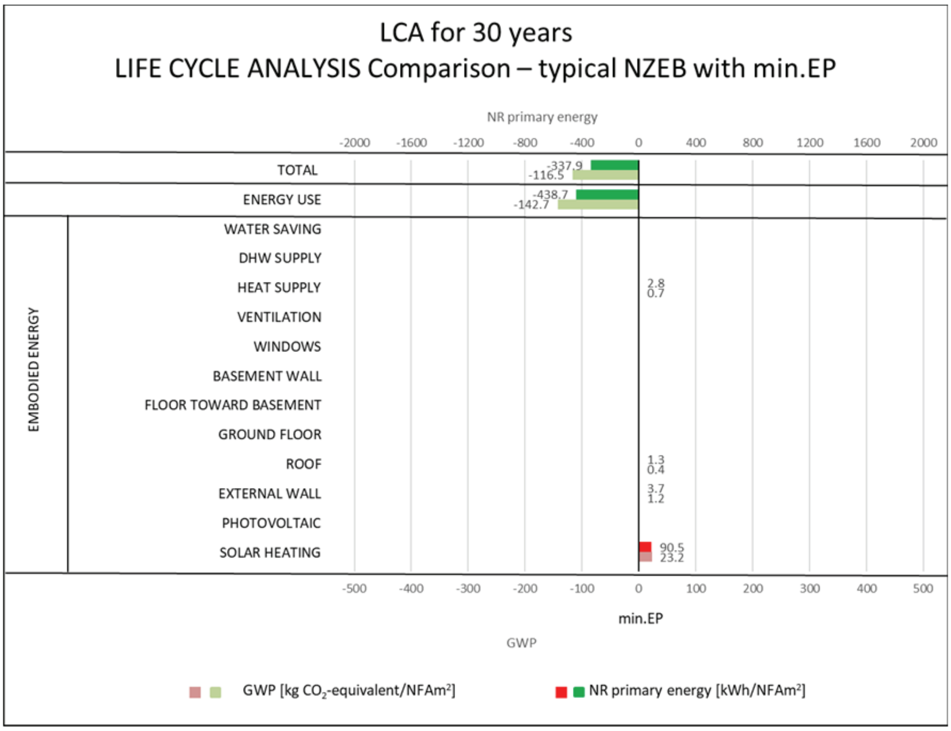

LCA for 30 years
LIFE CYCLE ANALYSIS Comparison – SS8 with min.EP
NR primary energy
TOTAL
ENERGY USE
EMBODIED ENERGY
WATER SAVING
DHW SUPPLY
HEAT SUPPLY
VENTILATION
WINDOWS
BASEMENT WALL
FLOOR TOWARD BASEMENT
GROUND FLOOR
ROOF
EXTERNAL WALL
PHOTOVOLTAIC
SOLAR HEATING
-683.8
-111.3
-698.5
-112.6
1.6
0.3
2.5
0.7
3.5
1.0
23.1
3.8
13.2
3.2
-29.2
-7.7
min.EP
GWP
GWP [kg CO2-equivalent/NFAm2]
NR primary energy [kWh/NFAm2]

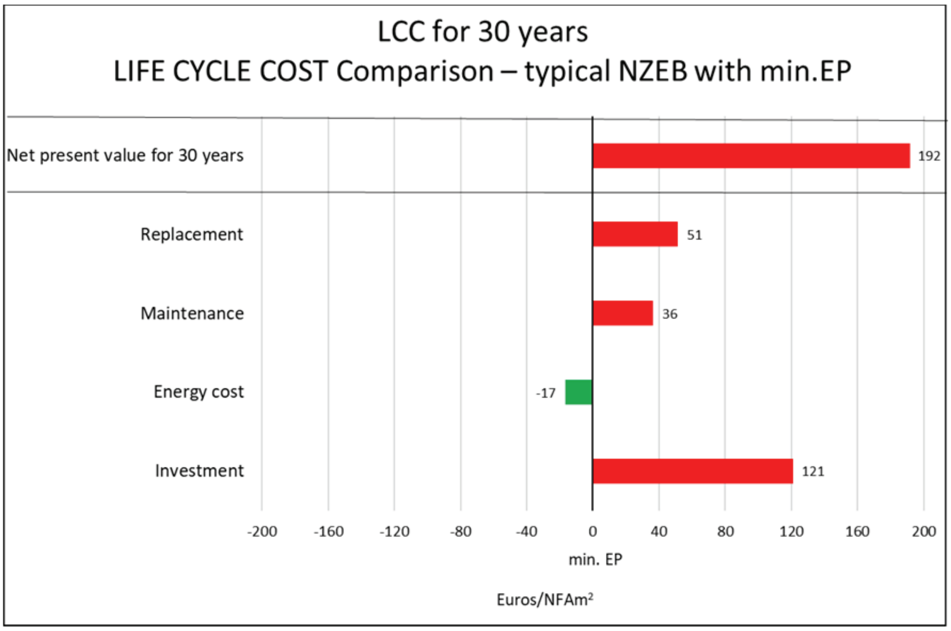

LCC for 30 years
LIFE CYCLE COST Comparison – SS8 with min. EP
Net present value for 30 years
Replacement
Maintenance
Energy cost
Investment
16.3
-12.1
18.6
-9.2
19.0
min. EP
Euros/NFAm2

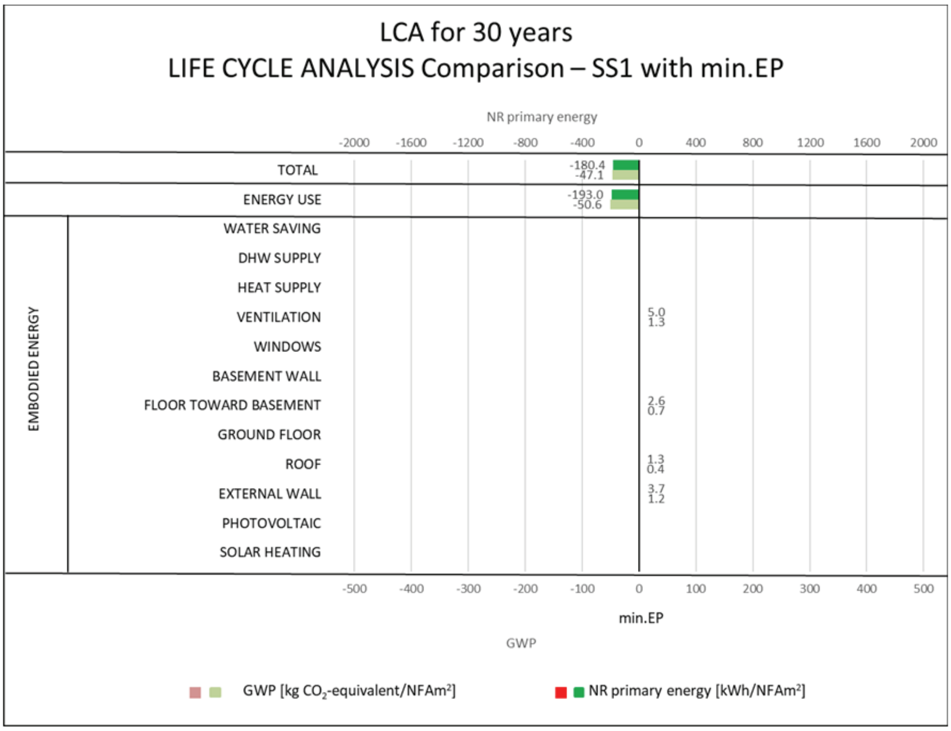

LCA for 30 years
LIFE CYCLE ANALYSIS Comparison – beyond NZEB with min.EP
NR primary energy
-4000
-3000
-2000
-1000
0
1000
2000
3000
4000
TOTAL
-2897.6
-748.6
ENERGY USE
-3368.2
-852.4
EMBODIED ENERGY
WATER SAVING
DHW SUPPLY
-1.9
-0.2
HEAT SUPPLY
52.5
6.7
VENTILATION
11.3
2.4
WINDOWS
11.5
3.9
BASEMENT WALL
FLOOR TOWARD BASEMENT
GROUND FLOOR
ROOF
3.5
1.0
EXTERNAL WALL
26.2
2.4
PHOTOVOLTAIC
396.7
95.3
SOLAR HEATING
-29.2
-7.7
-1,000
-750
-500
-250
0
250
500
750
1,000
min.EP
GWP
GWP [kg CO_2-equivalent/NFAm²]
NR primary energy [kWh/NFAm²]

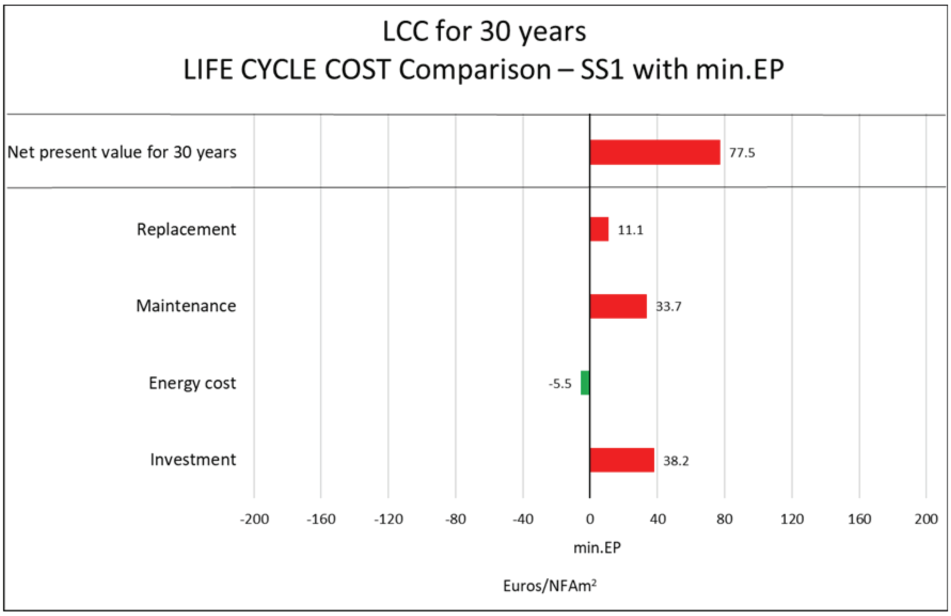

LCC for 30 years
LIFE CYCLE COST Comparison – beyond NZEB with min. EP
Net present value for 30 years
121.3
Replacement
46.9
Maintenance
78.0
Energy cost
-182.4
Investment
178.9
-200
-150
-100
-50
0
50
100
150
200
min. EP
Euros/NFAm²

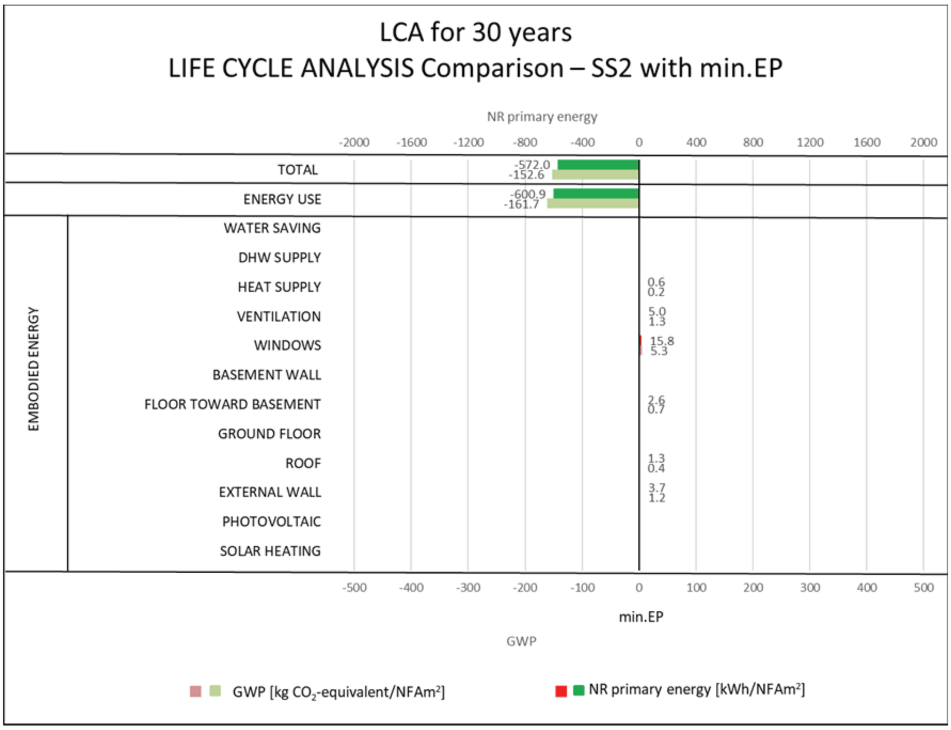
Slovenia

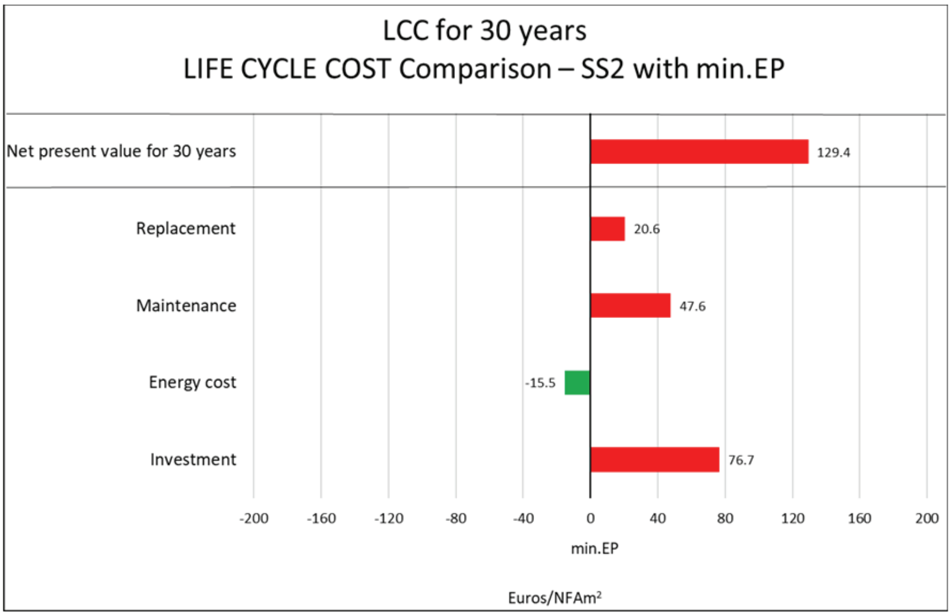

LCA for 30 years
LIFE CYCLE ANALYSIS Comparison – typical NZEB with min.EP
NR primary energy
-2000 -1600 -1200 -800 -400 0 400 800 1200 1600 2000
TOTAL
-337.9
-116.5
ENERGY USE
-438.7
-142.7
EMBODIED ENERGY
WATER SAVING
DHW SUPPLY
HEAT SUPPLY
2.8
0.7
VENTILATION
WINDOWS
BASEMENT WALL
FLOOR TOWARD BASEMENT
GROUND FLOOR
ROOF
1.3
0.4
EXTERNAL WALL
3.7
1.2
PHOTOVOLTAIC
SOLAR HEATING
90.5
23.2
-500 -400 -300 -200 -100 0 100 200 300 400 500
min.EP
GWP
GWP [kg CO2-equivalent/NFAm²]
NR primary energy [kWh/NFAm²]

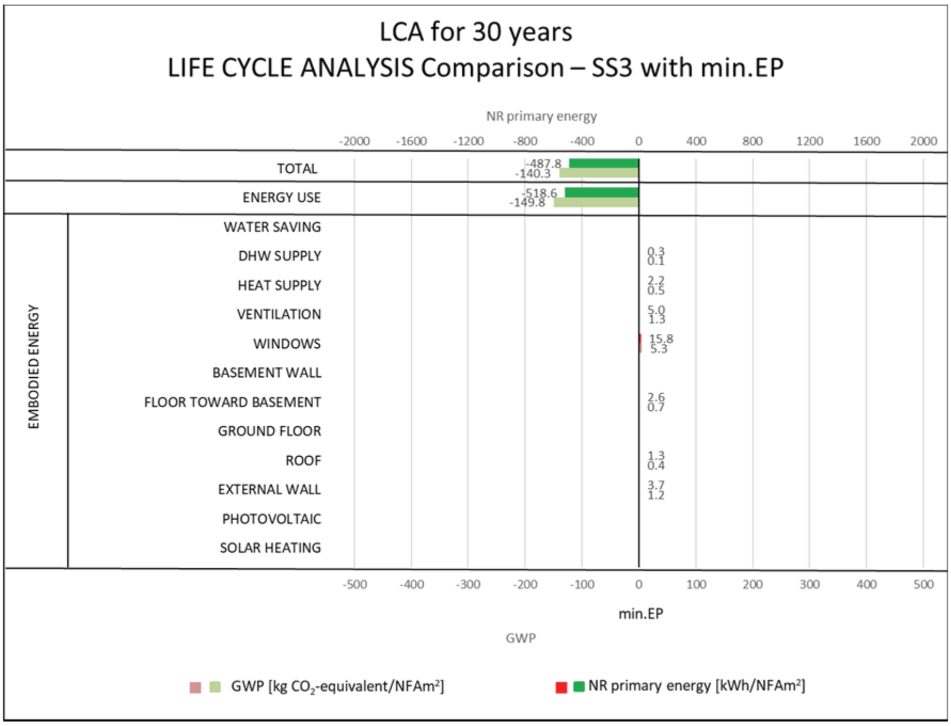

LCC for 30 years
LIFE CYCLE COST Comparison – typical NZEB with min.EP
Net present value for 30 years
192
Replacement
51
Maintenance
36
Energy cost
-17
Investment
121
-200 -160 -120 -80 -40 0 40 80 120 160 200
min. EP
Euros/NFAm²

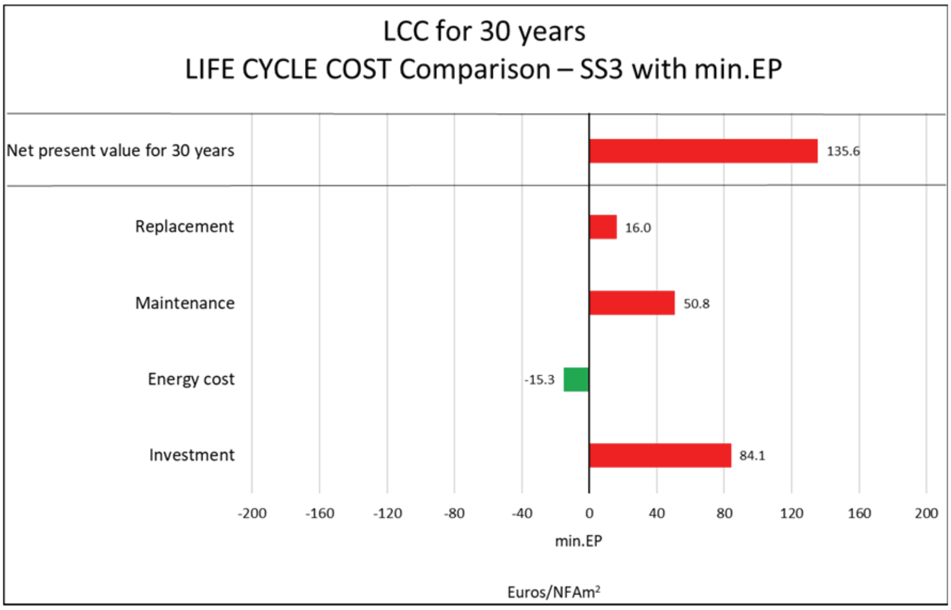

LCA for 30 years
LIFE CYCLE ANALYSIS Comparison – SS1 with min.EP
NR primary energy
TOTAL
ENERGY USE
EMBODIED ENERGY
WATER SAVING
DHW SUPPLY
HEAT SUPPLY
VENTILATION
WINDOWS
BASEMENT WALL
FLOOR TOWARD BASEMENT
GROUND FLOOR
ROOF
EXTERNAL WALL
PHOTOVOLTAIC
SOLAR HEATING
-180.4
-47.1
-193.0
-50.6
5.0
1.3
2.6
0.7
1.3
0.4
3.7
1.2
min.EP
GWP
GWP [kg CO2-equivalent/NFAm²]
NR primary energy [kWh/NFAm²]

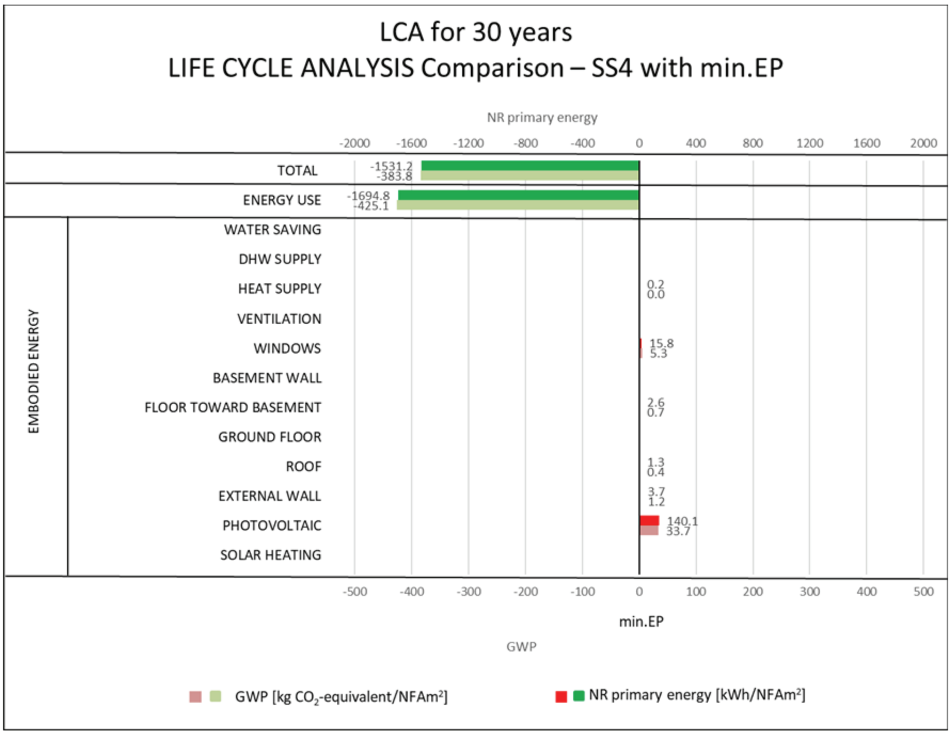

LCC for 30 years
LIFE CYCLE COST Comparison – SS1 with min.EP
Net present value for 30 years
Replacement
Maintenance
Energy cost
Investment
77.5
11.1
33.7
-5.5
38.2
min.EP
Euros/NFAm²

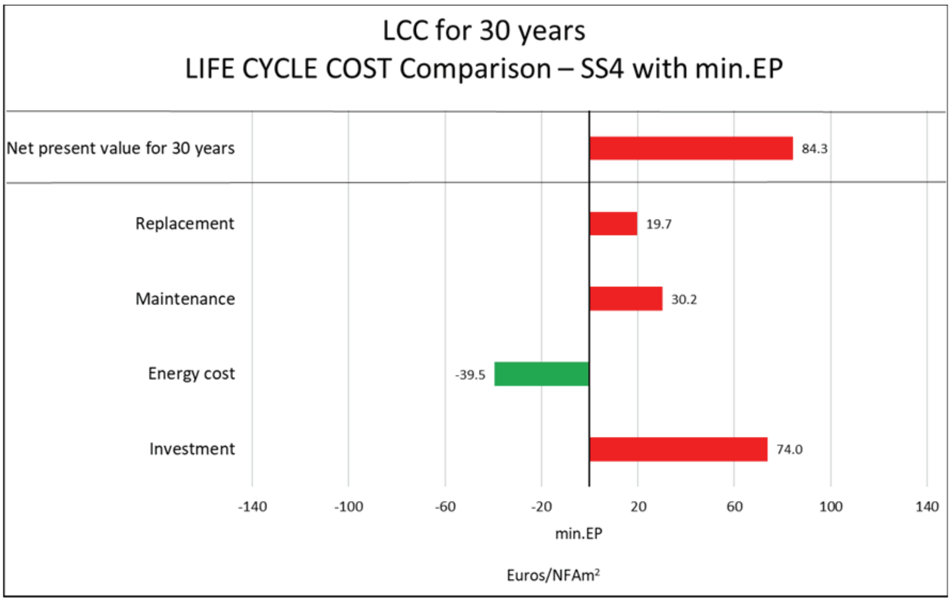

LCA for 30 years
LIFE CYCLE ANALYSIS Comparison – SS2 with min.EP
NR primary energy
TOTAL
ENERGY USE
EMBODIED ENERGY
WATER SAVING
DHW SUPPLY
HEAT SUPPLY
VENTILATION
WINDOWS
BASEMENT WALL
FLOOR TOWARD BASEMENT
GROUND FLOOR
ROOF
EXTERNAL WALL
PHOTOVOLTAIC
SOLAR HEATING
-572.0
-152.6
-600.9
-161.7
0.6
0.2
5.0
1.3
15.8
5.3
2.6
0.7
1.3
0.4
3.7
1.2
min.EP
GWP
GWP [kg CO_2-equivalent/NFAm²]
NR primary energy [kWh/NFAm²]

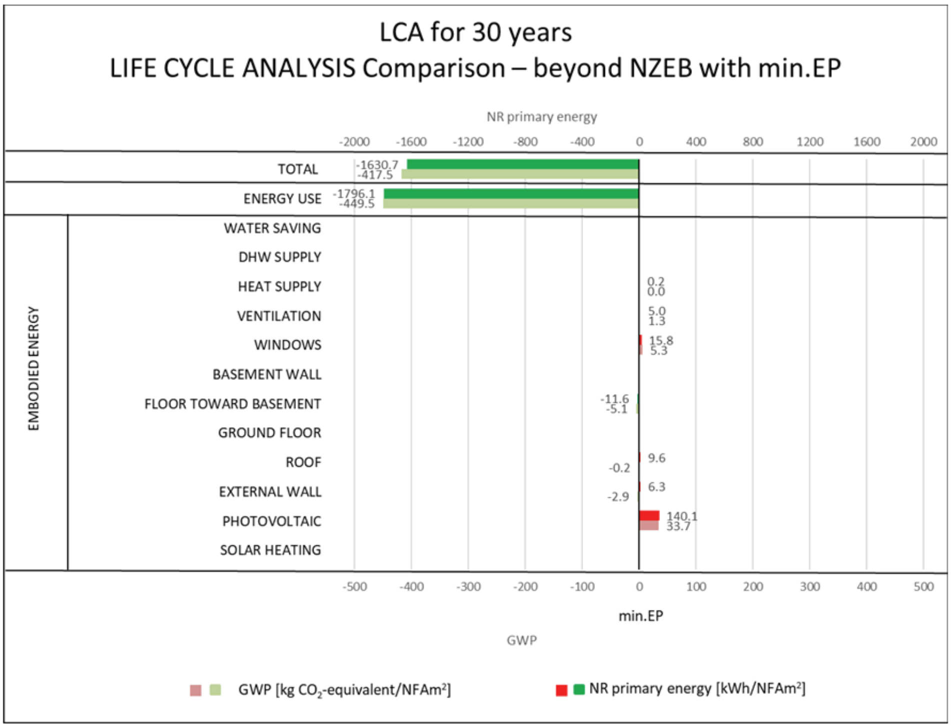

LCC for 30 years
LIFE CYCLE COST Comparison – SS2 with min.EP
Net present value for 30 years
Replacement
Maintenance
Energy cost
Investment
129.4
20.6
47.6
-15.5
76.7
min.EP
Euros/NFAm²

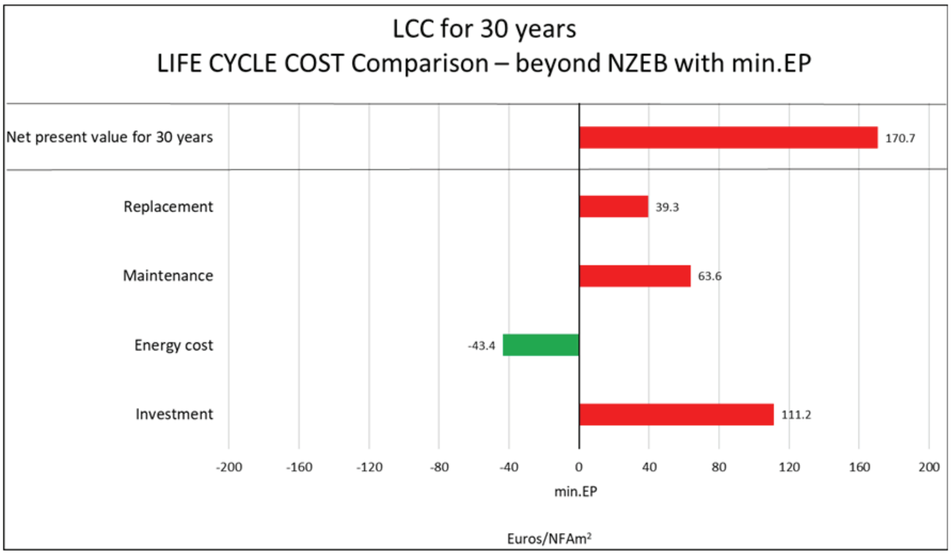

LCA for 30 years
LIFE CYCLE ANALYSIS Comparison – SS3 with min.EP
NR primary energy
TOTAL
ENERGY USE
EMBODIED ENERGY
WATER SAVING
DHW SUPPLY
HEAT SUPPLY
VENTILATION
WINDOWS
BASEMENT WALL
FLOOR TOWARD BASEMENT
GROUND FLOOR
ROOF
EXTERNAL WALL
PHOTOVOLTAIC
SOLAR HEATING
-487.8
-140.3
-518.6
-149.8
0.3
0.1
2.2
0.5
5.0
1.3
15.8
5.3
2.6
0.7
1.3
0.4
3.7
1.2
min.EP
GWP
GWP [kg CO2-equivalent/NFAm²]
NR primary energy [kWh/NFAm²]


LCC for 30 years
LIFE CYCLE COST Comparison – SS3 with min.EP
Net present value for 30 years
Replacement
Maintenance
Energy cost
Investment
135.6
16.0
50.8
-15.3
84.1
min.EP
Euros/NFAm²

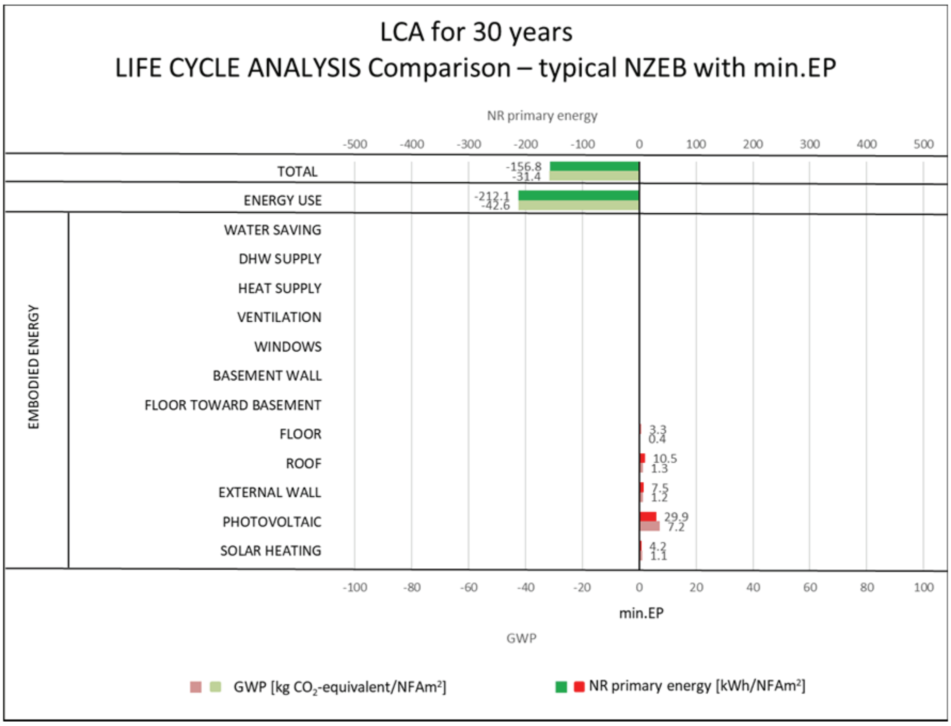

LCA for 30 years
LIFE CYCLE ANALYSIS Comparison – SS4 with min.EP
NR primary energy
TOTAL
ENERGY USE
EMBODIED ENERGY
WATER SAVING
DHW SUPPLY
HEAT SUPPLY
VENTILATION
WINDOWS
BASEMENT WALL
FLOOR TOWARD BASEMENT
GROUND FLOOR
ROOF
EXTERNAL WALL
PHOTOVOLTAIC
SOLAR HEATING
-1531.2
-383.8
-1694.8
-425.1
0.2
0.0
15.8
5.3
2.6
0.7
1.3
0.4
3.7
1.2
140.1
33.7
min.EP
GWP
GWP [kg CO2-equivalent/NFAm²]
NR primary energy [kWh/NFAm²]

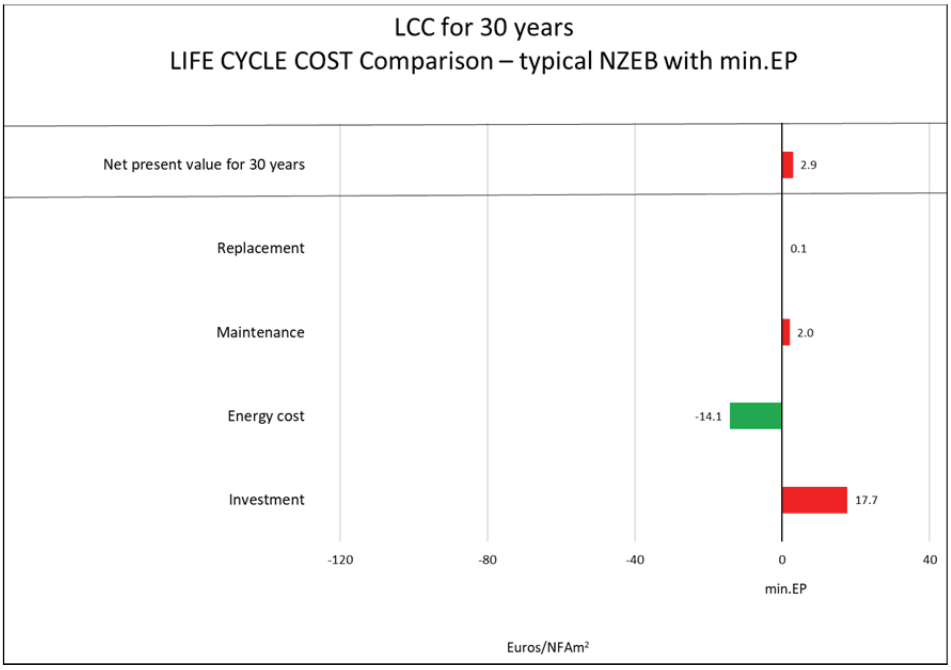

LCC for 30 years
LIFE CYCLE COST Comparison – SS4 with min.EP
Net present value for 30 years
Replacement
Maintenance
Energy cost
Investment
84.3
19.7
30.2
-39.5
74.0
min.EP
Euros/NFAm²

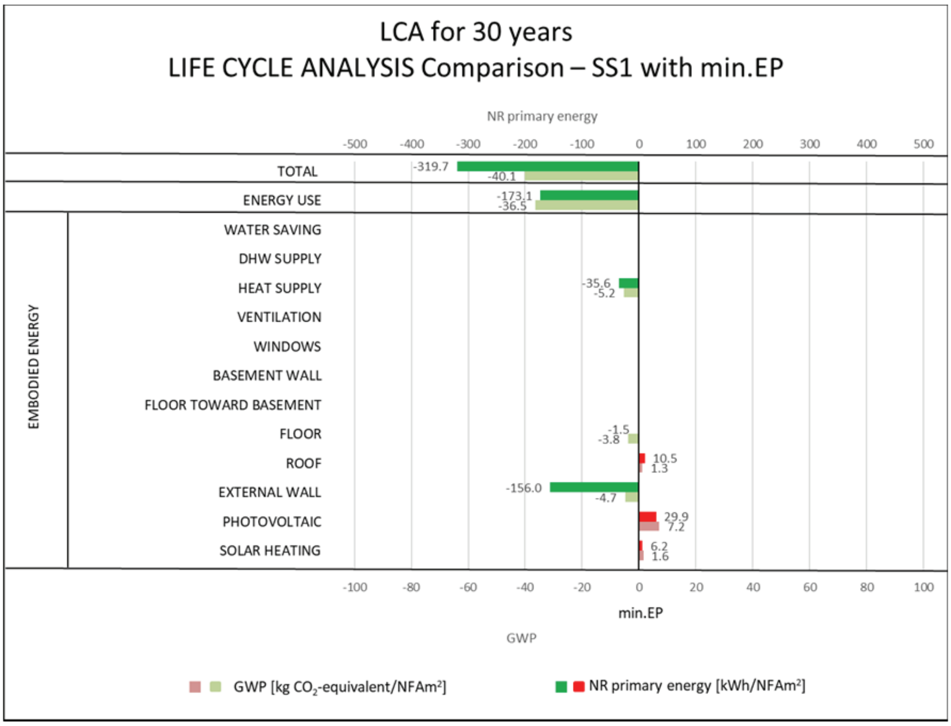

LCA for 30 years
LIFE CYCLE ANALYSIS Comparison – beyond NZEB with min.EP
NR primary energy
TOTAL
ENERGY USE
EMBODIED ENERGY
WATER SAVING
DHW SUPPLY
HEAT SUPPLY
VENTILATION
WINDOWS
BASEMENT WALL
FLOOR TOWARD BASEMENT
GROUND FLOOR
ROOF
EXTERNAL WALL
PHOTOVOLTAIC
SOLAR HEATING
-1630.7
-417.5
-1796.1
-449.5
0.2
0.0
5.0
1.3
15.8
5.3
-11.6
-5.1
9.6
-0.2
6.3
-2.9
140.1
33.7
min.EP
GWP
GWP [kg CO_2-equivalent/NFAm²]
NR primary energy [kWh/NFAm²]


LCC for 30 years
LIFE CYCLE COST Comparison – beyond NZEB with min.EP
Net present value for 30 years
Replacement
Maintenance
Energy cost
Investment
170.7
39.3
63.6
-43.4
111.2
min.EP
Euros/NFAm²

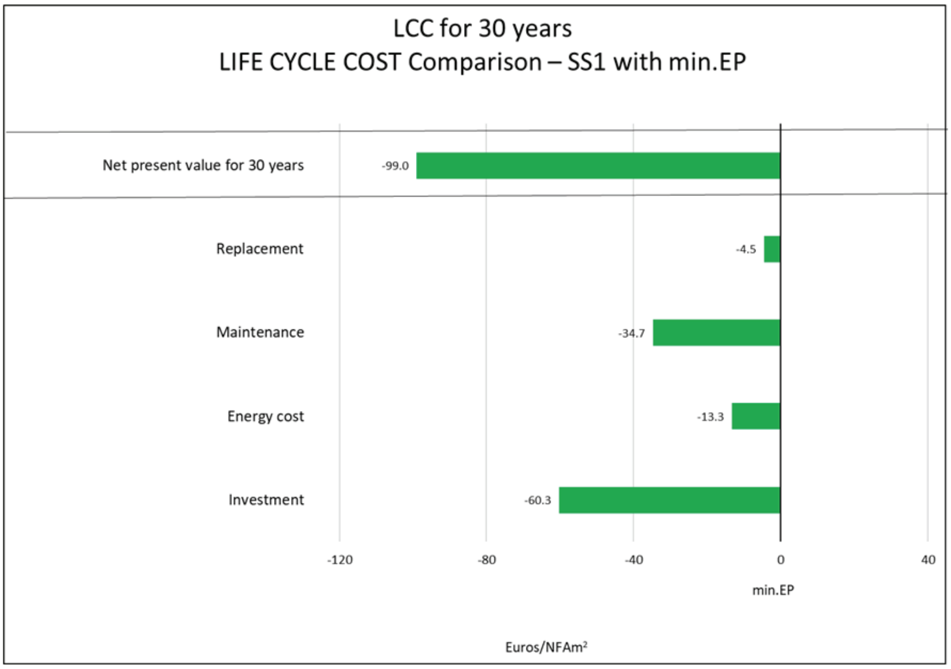
Italy - Rome


LCA for 30 years
LIFE CYCLE ANALYSIS Comparison – typical NZEB with min.EP
NR primary energy
-500 -400 -300 -200 -100 0 100 200 300 400 500
TOTAL
-156.8
-31.4
ENERGY USE
-212.1
-42.6
EMBODIED ENERGY
WATER SAVING
DHW SUPPLY
HEAT SUPPLY
VENTILATION
WINDOWS
BASEMENT WALL
FLOOR TOWARD BASEMENT
FLOOR
3.3
0.4
ROOF
10.5
1.3
EXTERNAL WALL
7.5
1.2
PHOTOVOLTAIC
29.9
7.2
SOLAR HEATING
4.2
1.1
-100 -80 -60 -40 -20 0 20 40 60 80 100
min.EP
GWP
GWP [kg CO2-equivalent/NFAm²]
NR primary energy [kWh/NFAm²]

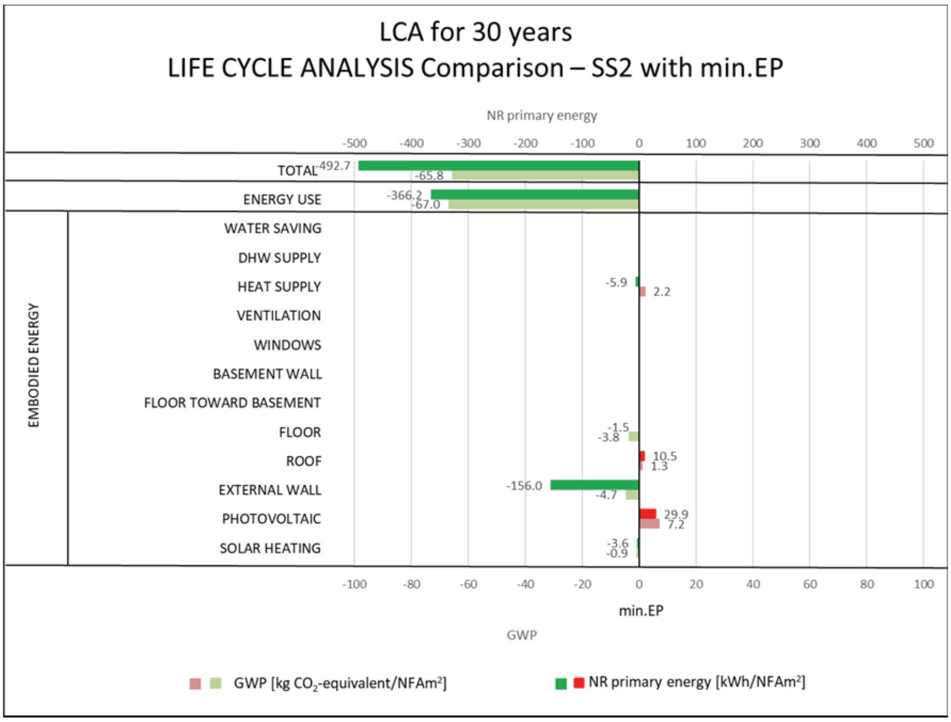

LCC for 30 years
LIFE CYCLE COST Comparison – typical NZEB with min.EP
Net present value for 30 years
2.9
Replacement
0.1
Maintenance
2.0
Energy cost
-14.1
Investment
17.7
-120 -80 -40 0 40
min.EP
Euros/NFAm²

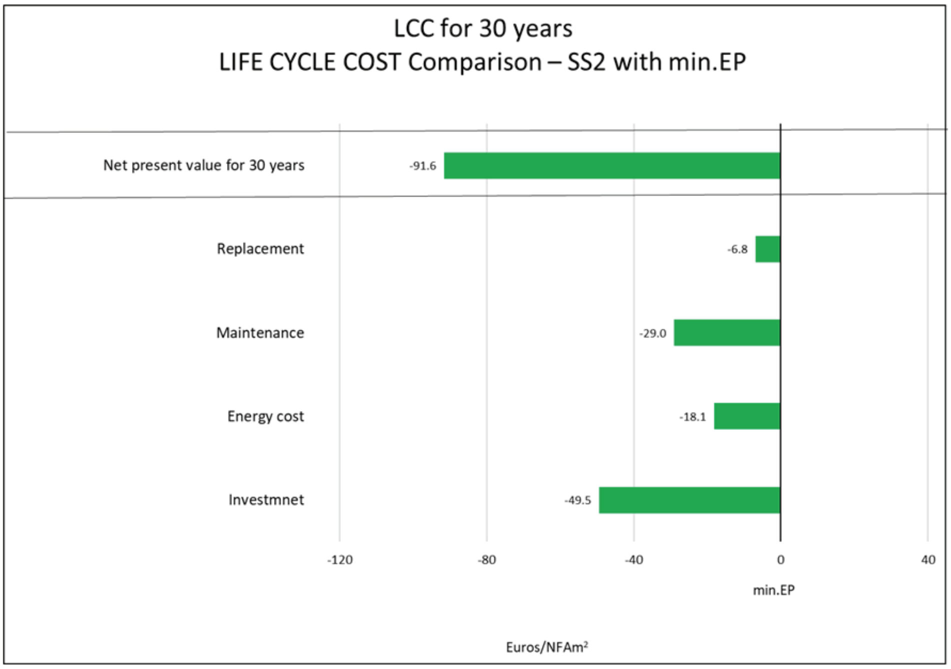


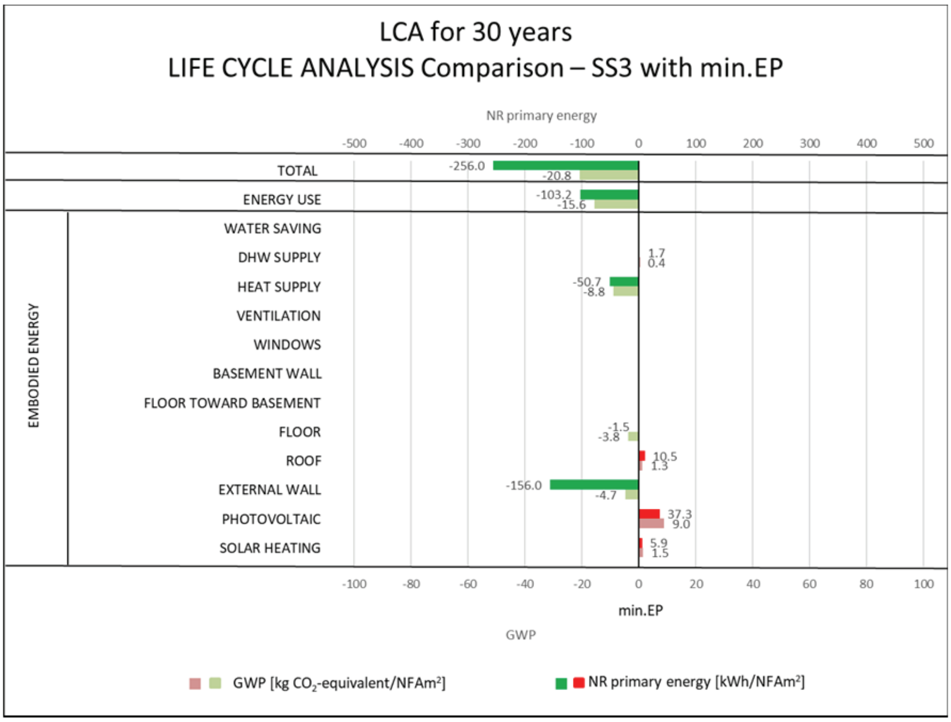
LCA for 30 years
LIFE CYCLE ANALYSIS Comparison – SS1 with min.EP
NR primary energy
TOTAL -319.7 -40.1
ENERGY USE -173.1 -36.5
EMBODIED ENERGY
WATER SAVING
DHW SUPPLY
HEAT SUPPLY -35.6 -5.2
VENTILATION
WINDOWS
BASEMENT WALL
FLOOR TOWARD BASEMENT
FLOOR -1.5 -3.8
ROOF 10.5 1.3
EXTERNAL WALL -156.0 -4.7
PHOTOVOLTAIC 29.9 7.2
SOLAR HEATING 6.2 1.6
min.EP
GWP
GWP [kg CO2-equivalent/NFAm2]
NR primary energy [kWh/NFAm2]

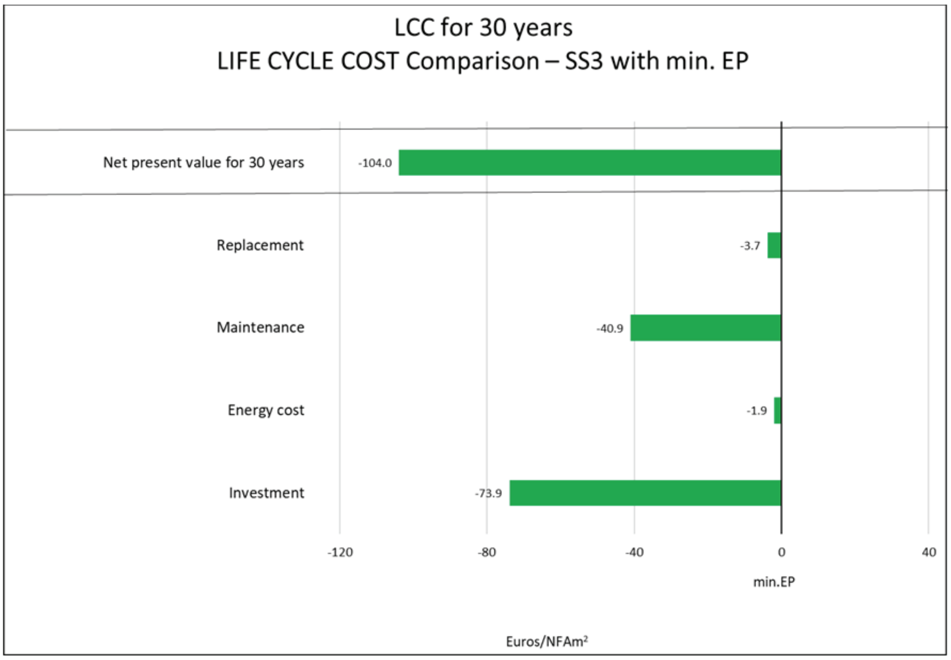


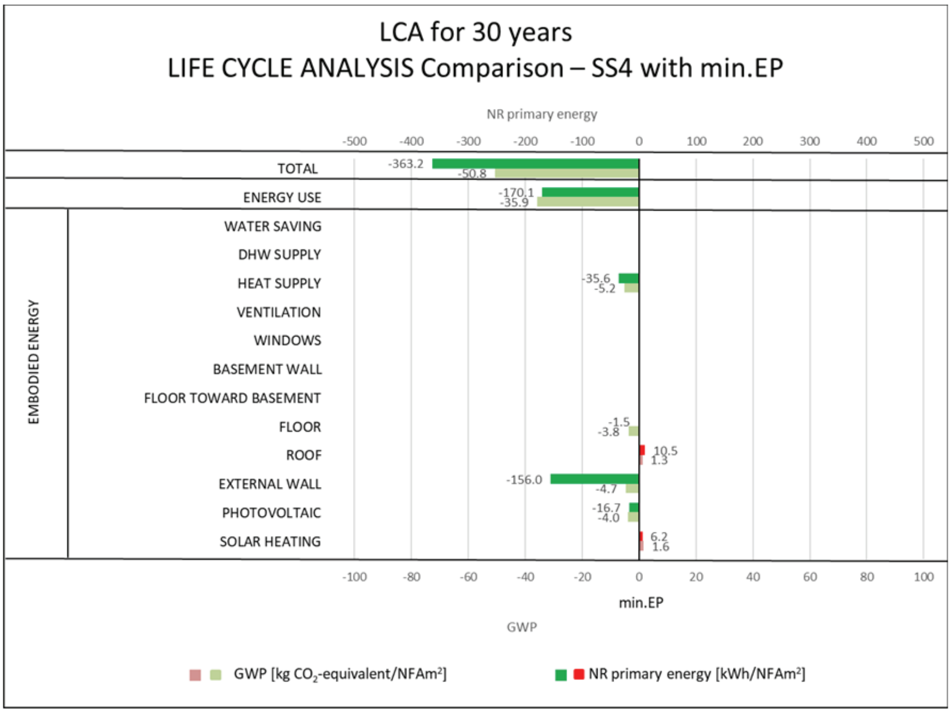
LCC for 30 years
LIFE CYCLE COST Comparison – SS1 with min.EP
Net present value for 30 years -99.0
Replacement -4.5
Maintenance -34.7
Energy cost -13.3
Investment -60.3
-120 -80 -40 0 40
min.EP
Euros/NFAm2

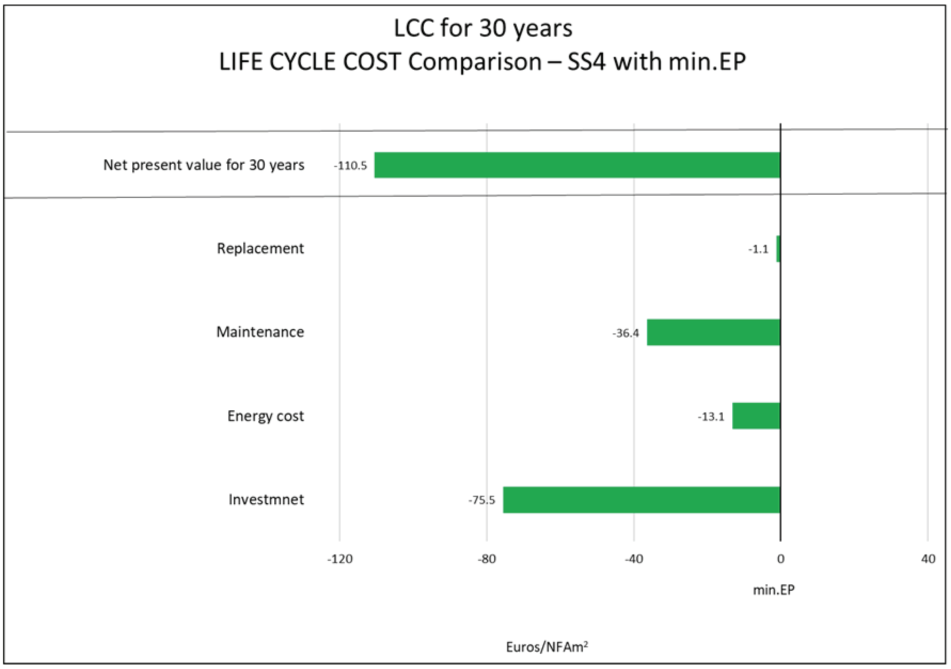

LCA for 30 years
LIFE CYCLE ANALYSIS Comparison – SS2 with min.EP
NR primary energy
-500 -400 -300 -200 -100 0 100 200 300 400 500
TOTAL
492.7
-65.8
ENERGY USE
-366.2
-67.0
EMBODIED ENERGY
WATER SAVING
DHW SUPPLY
HEAT SUPPLY
-5.9
2.2
VENTILATION
WINDOWS
BASEMENT WALL
FLOOR TOWARD BASEMENT
FLOOR
-1.5
-3.8
ROOF
10.5
1.3
EXTERNAL WALL
-156.0
-4.7
PHOTOVOLTAIC
29.9
7.2
SOLAR HEATING
-3.6
-0.9
-100 -80 -60 -40 -20 0 20 40 60 80 100
min.EP
GWP
GWP [kg CO_2-equivalent/NFAm²]
NR primary energy [kWh/NFAm²]

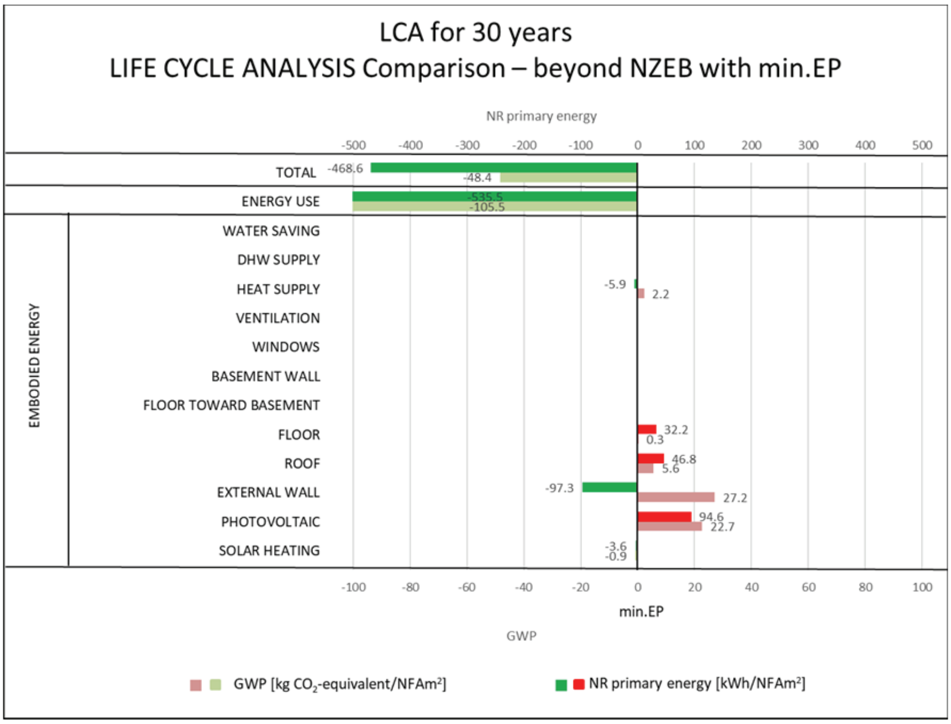

LCC for 30 years
LIFE CYCLE COST Comparison – SS2 with min.EP
Net present value for 30 years
-91.6
Replacement
-6.8
Maintenance
-29.0
Energy cost
-18.1
Investmnet
-49.5
-120 -80 -40 0 40
min.EP
Euros/NFAm²

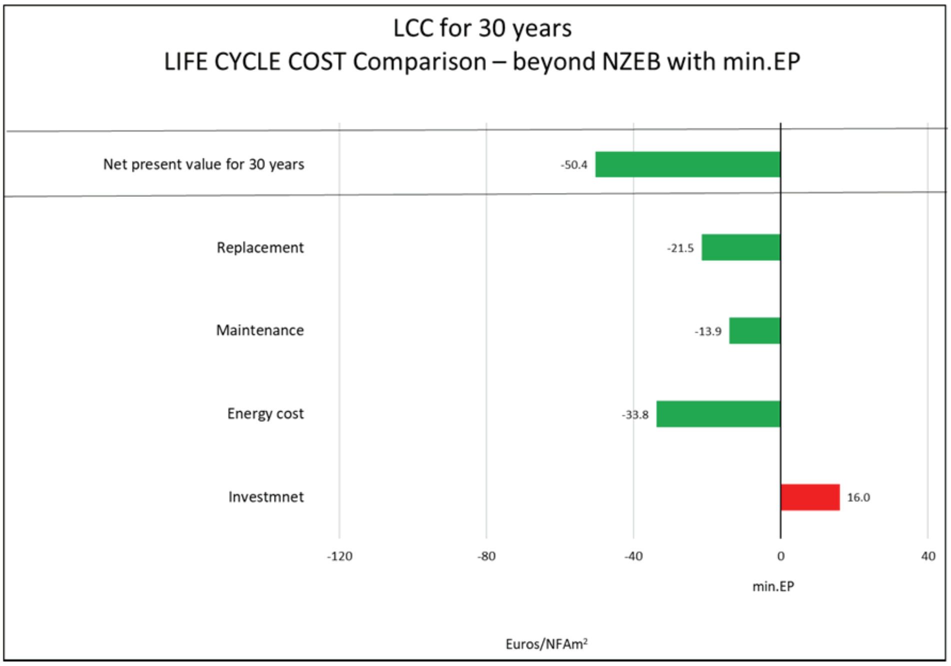

LCA for 30 years
LIFE CYCLE ANALYSIS Comparison – SS3 with min.EP
NR primary energy
TOTAL
ENERGY USE
EMBODIED ENERGY
WATER SAVING
DHW SUPPLY
HEAT SUPPLY
VENTILATION
WINDOWS
BASEMENT WALL
FLOOR TOWARD BASEMENT
FLOOR
ROOF
EXTERNAL WALL
PHOTOVOLTAIC
SOLAR HEATING
-256.0
-20.8
-103.2
-15.6
1.7
0.4
-50.7
-8.8
-1.5
-3.8
10.5
1.3
-156.0
-4.7
37.3
9.0
5.9
1.5
min.EP
GWP
GWP [kg CO2-equivalent/NFAm²]
NR primary energy [kWh/NFAm²]


LCC for 30 years
LIFE CYCLE COST Comparison – SS3 with min. EP
Net present value for 30 years
Replacement
Maintenance
Energy cost
Investment
-104.0
-3.7
-40.9
-1.9
-73.9
min.EP
Euros/NFAm²

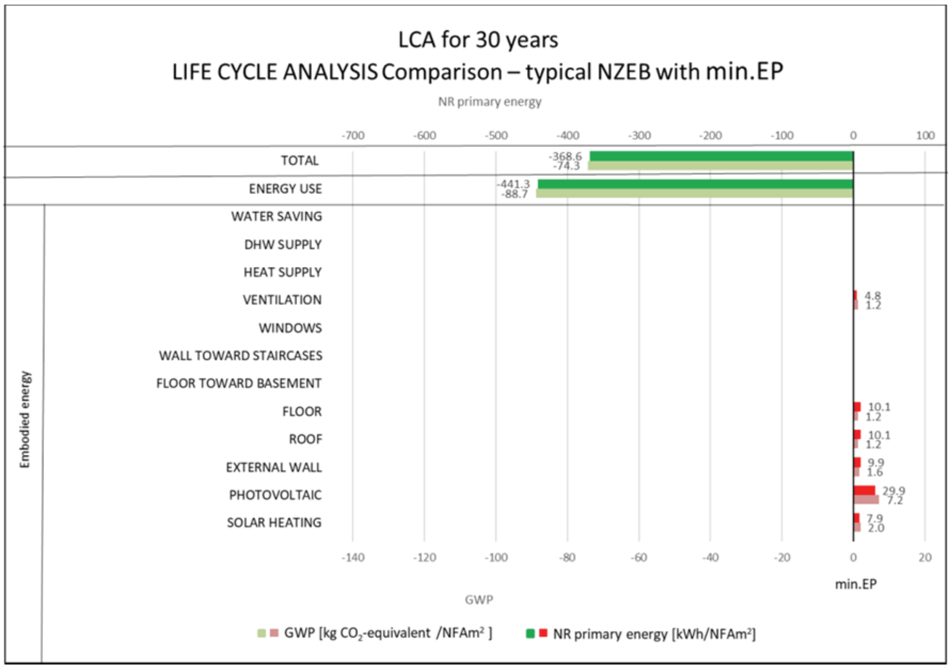

LCA for 30 years
LIFE CYCLE ANALYSIS Comparison – SS4 with min.EP
NR primary energy
-500 -400 -300 -200 -100 0 100 200 300 400 500
TOTAL -363.2 -50.8
ENERGY USE -170.1 -35.9
EMBODIED ENERGY
WATER SAVING
DHW SUPPLY
HEAT SUPPLY -35.6 -5.2
VENTILATION
WINDOWS
BASEMENT WALL
FLOOR TOWARD BASEMENT
FLOOR -1.5 -3.8
ROOF 10.5 1.3
EXTERNAL WALL -156.0 -4.7
PHOTOVOLTAIC -16.7 -4.0
SOLAR HEATING 6.2 1.6
-100 -80 -60 -40 -20 0 20 40 60 80 100
min.EP
GWP
GWP [kg CO2-equivalent/NFAm²]
NR primary energy [kWh/NFAm²]

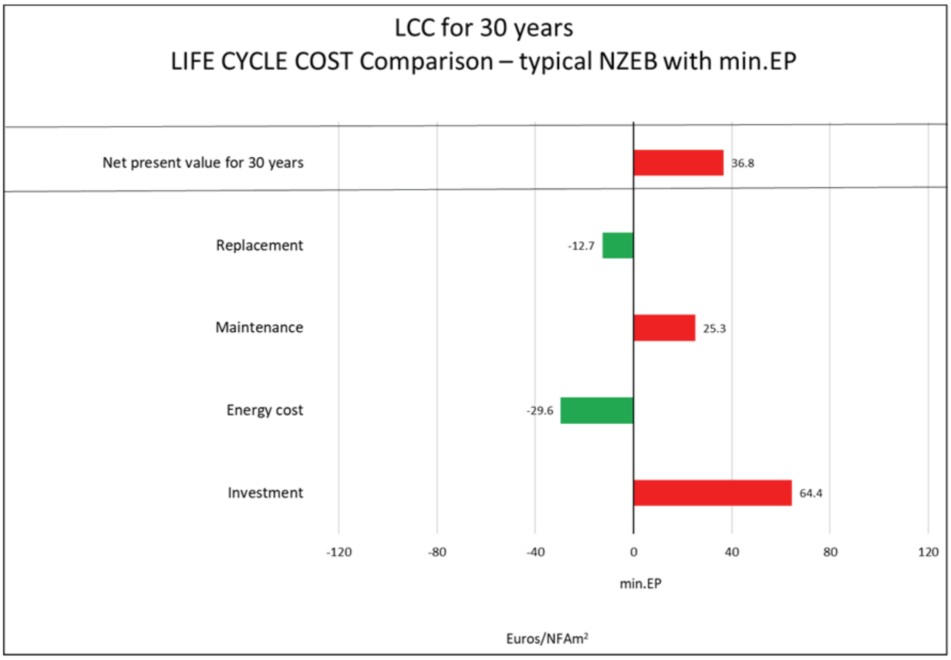

LCC for 30 years
LIFE CYCLE COST Comparison – SS4 with min.EP
Net present value for 30 years -110.5
Replacement -1.1
Maintenance -36.4
Energy cost -13.1
Investmnet -75.5
-120 -80 -40 0 40
min.EP
Euros/NFAm²

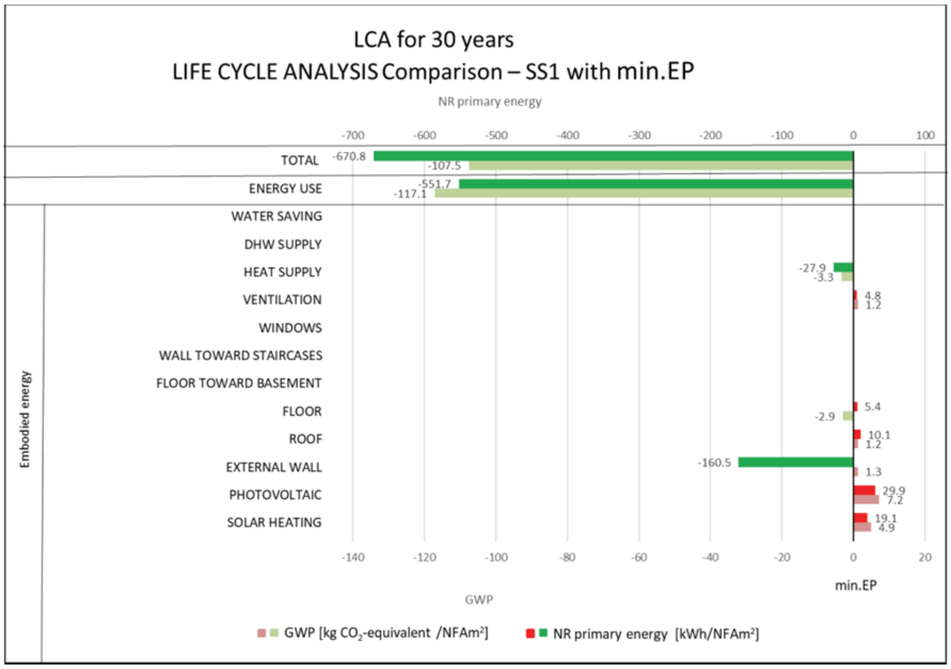

LCA for 30 years
LIFE CYCLE ANALYSIS Comparison – beyond NZEB with min.EP
NR primary energy
-500 -400 -300 -200 -100 0 100 200 300 400 500
TOTAL
-468.6
-48.4
ENERGY USE
-535.5
-105.5
EMBODIED ENERGY
WATER SAVING
DHW SUPPLY
HEAT SUPPLY
-5.9
2.2
VENTILATION
WINDOWS
BASEMENT WALL
FLOOR TOWARD BASEMENT
FLOOR
32.2
0.3
ROOF
46.8
5.6
EXTERNAL WALL
-97.3
27.2
PHOTOVOLTAIC
94.6
22.7
SOLAR HEATING
-3.6
-0.9
-100 -80 -60 -40 -20 0 20 40 60 80 100
min.EP
GWP
GWP [kg CO2-equivalent/NFAm²]
NR primary energy [kWh/NFAm²]

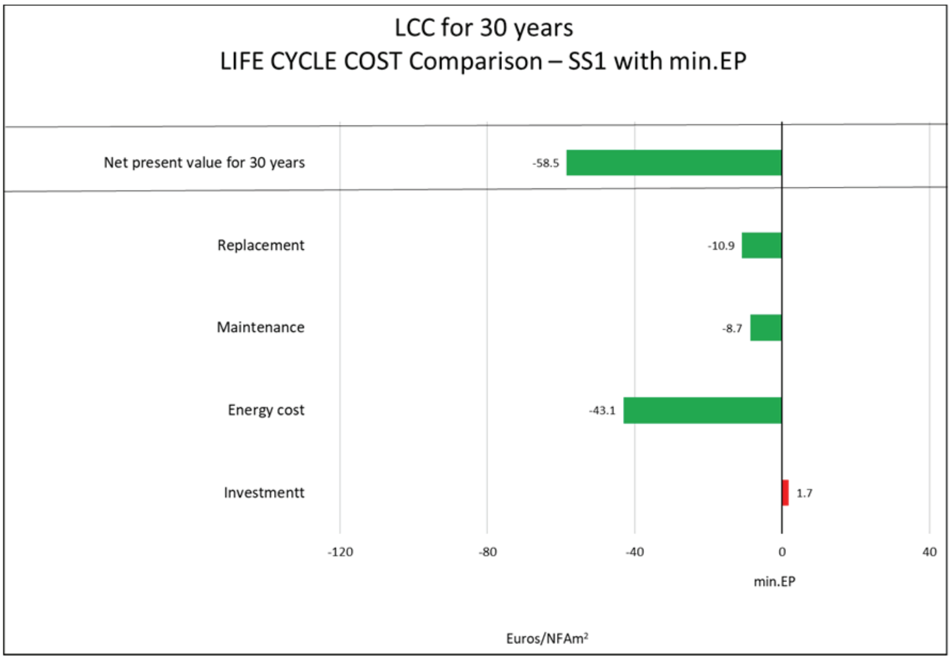

LCC for 30 years
LIFE CYCLE COST Comparison – beyond NZEB with min.EP
Net present value for 30 years
-50.4
Replacement
-21.5
Maintenance
-13.9
Energy cost
-33.8
Investmnet
16.0
-120 -80 -40 0 40
min.EP
Euros/NFAm²

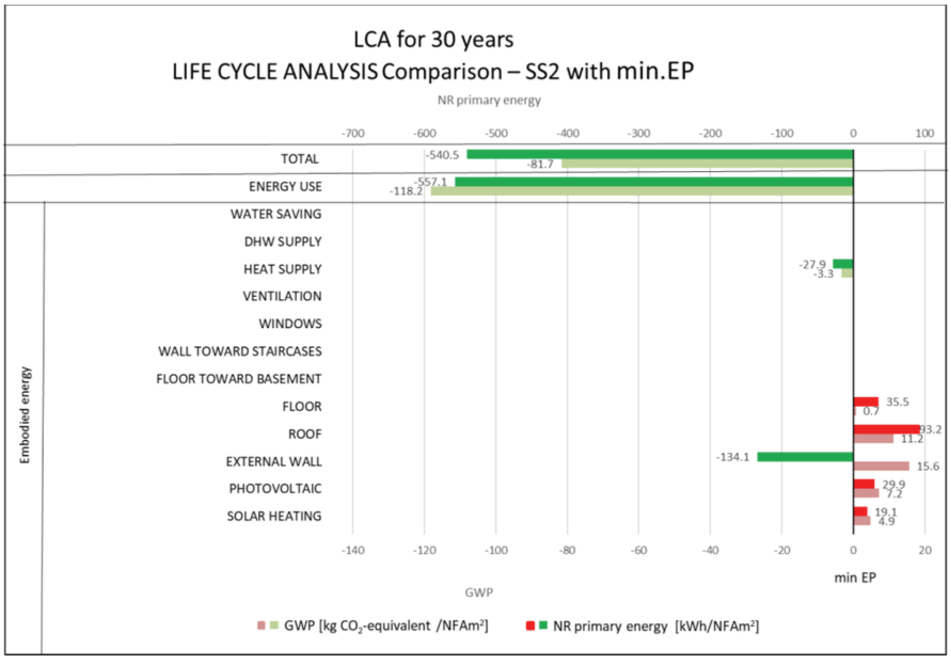
Italy - Turin

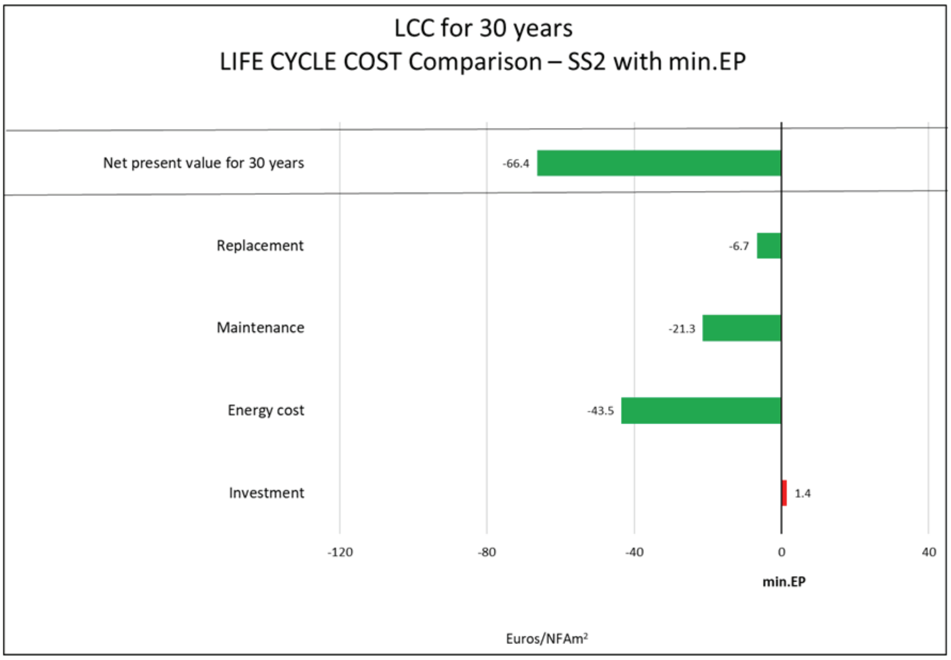

LCA for 30 years
LIFE CYCLE ANALYSIS Comparison – typical NZEB with min.EP
NR primary energy
TOTAL
ENERGY USE
WATER SAVING
DHW SUPPLY
HEAT SUPPLY
VENTILATION
WINDOWS
WALL TOWARD STAIRCASES
FLOOR TOWARD BASEMENT
FLOOR
ROOF
EXTERNAL WALL
PHOTOVOLTAIC
SOLAR HEATING
Embodied energy
-368.6
-74.3
-441.3
-88.7
4.8
1.2
10.1
1.2
10.1
1.2
9.9
1.6
29.9
7.2
7.9
2.0
min.EP
GWP
GWP [kg CO2-equivalent /NFAm²]
NR primary energy [kWh/NFAm²]

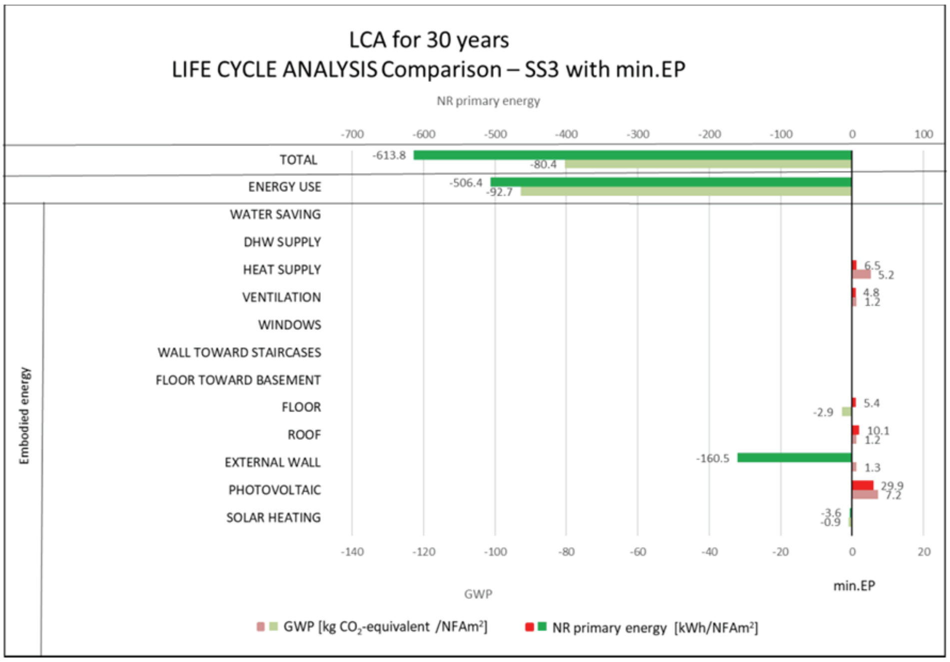

LCC for 30 years
LIFE CYCLE COST Comparison – typical NZEB with min.EP
Net present value for 30 years
Replacement
Maintenance
Energy cost
Investment
36.8
-12.7
25.3
-29.6
64.4
min.EP
Euros/NFAm²

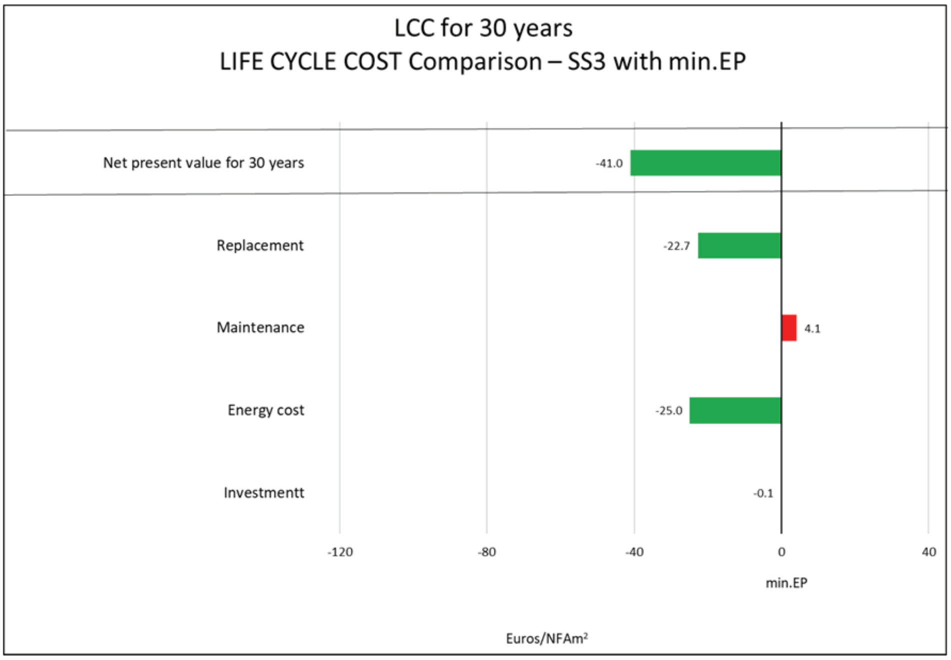

LCA for 30 years
LIFE CYCLE ANALYSIS Comparison – SS1 with min.EP
NR primary energy
TOTAL
ENERGY USE
WATER SAVING
DHW SUPPLY
HEAT SUPPLY
VENTILATION
WINDOWS
WALL TOWARD STAIRCASES
FLOOR TOWARD BASEMENT
FLOOR
ROOF
EXTERNAL WALL
PHOTOVOLTAIC
SOLAR HEATING
Embodied energy
-670.8
-107.5
-551.7
-117.1
-27.9
-3.3
4.8
1.2
5.4
-2.9
10.1
1.2
-160.5
1.3
29.9
7.2
19.1
4.9
min.EP
GWP
GWP [kg CO_2-equivalent /NFAm²]
NR primary energy [kWh/NFAm²]

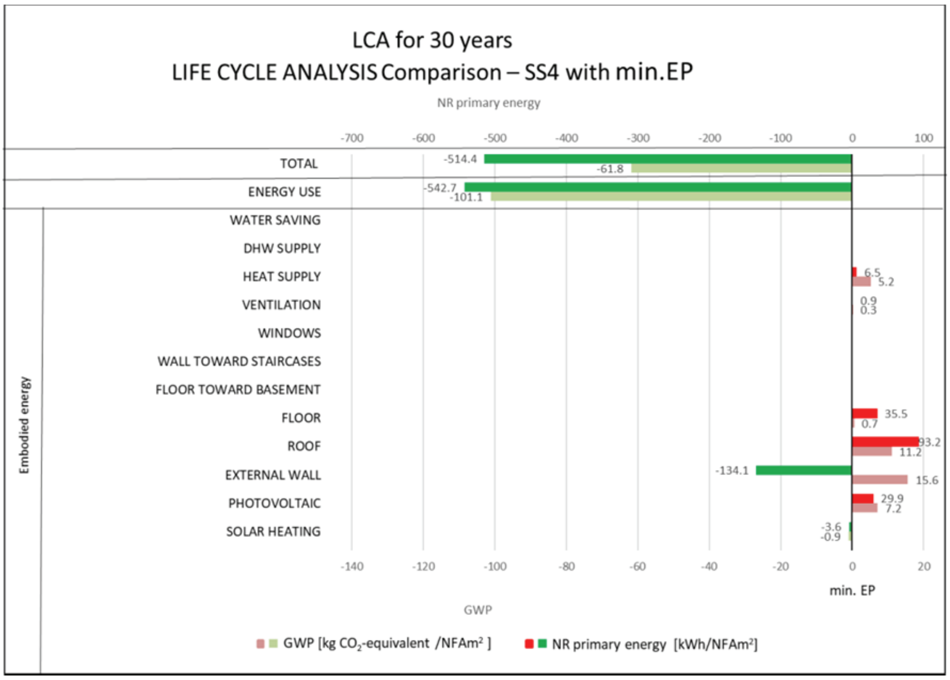

LCC for 30 years
LIFE CYCLE COST Comparison – SS1 with min.EP
Net present value for 30 years
Replacement
Maintenance
Energy cost
Investmentt
-58.5
-10.9
-8.7
-43.1
1.7
min.EP
Euros/NFAm²

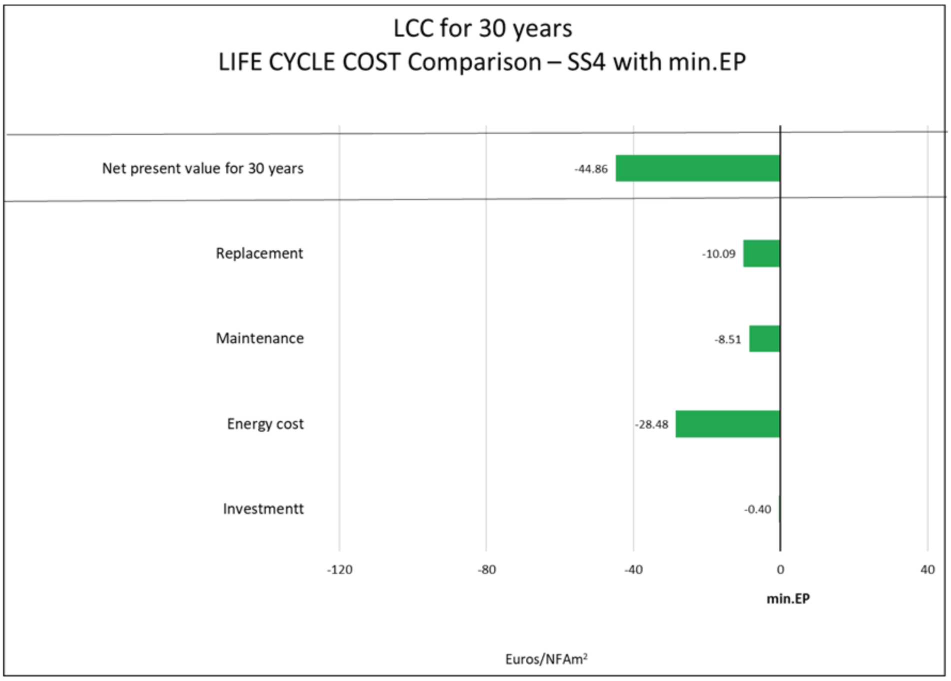

LCA for 30 years
LIFE CYCLE ANALYSIS Comparison – SS2 with min.EP
NR primary energy
-700
-600
-500
-400
-300
-200
-100
0
100
TOTAL
ENERGY USE
Embodied energy
WATER SAVING
DHW SUPPLY
HEAT SUPPLY
VENTILATION
WINDOWS
WALL TOWARD STAIRCASES
FLOOR TOWARD BASEMENT
FLOOR
ROOF
EXTERNAL WALL
PHOTOVOLTAIC
SOLAR HEATING
-540.5
-81.7
-557.1
-118.2
-27.9
-3.3
35.5
0.7
93.2
11.2
-134.1
15.6
29.9
7.2
19.1
4.9
-140
-120
-100
-80
-60
-40
-20
0
20
min EP
GWP
GWP [kg CO_2-equivalent /NFAm²]
NR primary energy [kWh/NFAm²]

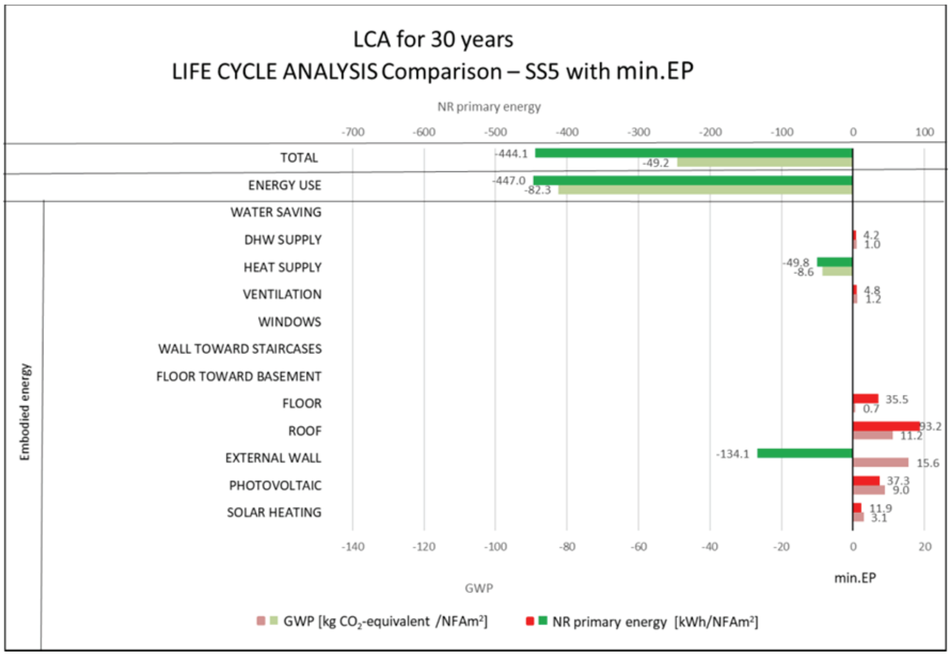

LCC for 30 years
LIFE CYCLE COST Comparison – SS2 with min.EP
Net present value for 30 years
Replacement
Maintenance
Energy cost
Investment
-66.4
-6.7
-21.3
-43.5
1.4
-120
-80
-40
0
40
min.EP
Euros/NFAm²

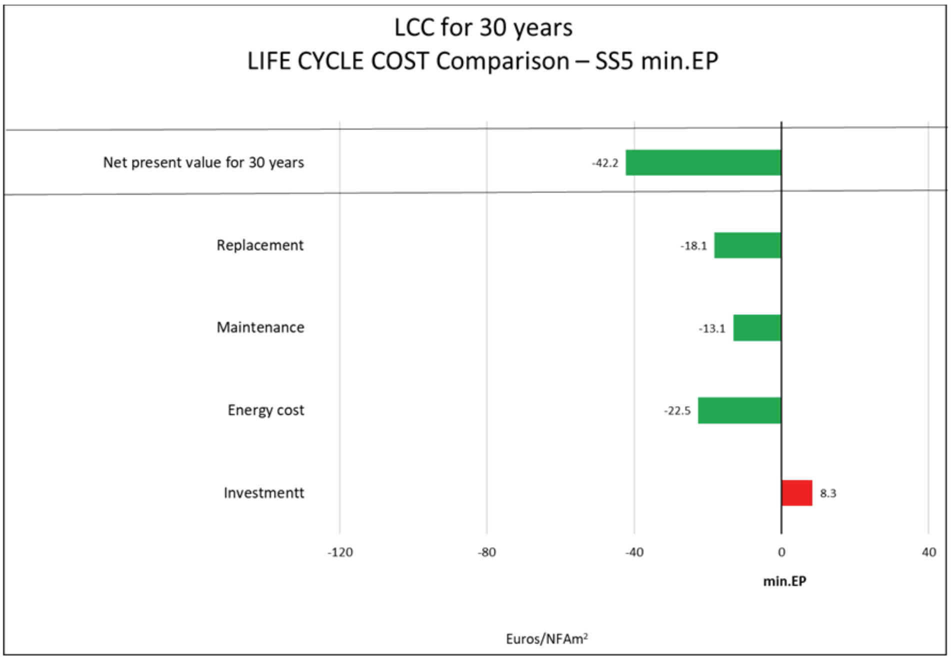

LCA for 30 years
LIFE CYCLE ANALYSIS Comparison – SS3 with min.EP
NR primary energy
TOTAL
ENERGY USE
WATER SAVING
DHW SUPPLY
HEAT SUPPLY
VENTILATION
WINDOWS
WALL TOWARD STAIRCASES
FLOOR TOWARD BASEMENT
FLOOR
ROOF
EXTERNAL WALL
PHOTOVOLTAIC
SOLAR HEATING
Embodied energy
-613.8
-80.4
-506.4
-92.7
6.5
5.2
4.8
1.2
5.4
-2.9
10.1
1.2
-160.5
1.3
29.9
7.2
-3.6
-0.9
GWP
min.EP
GWP [kg CO2-equivalent /NFAm²]
NR primary energy [kWh/NFAm²]

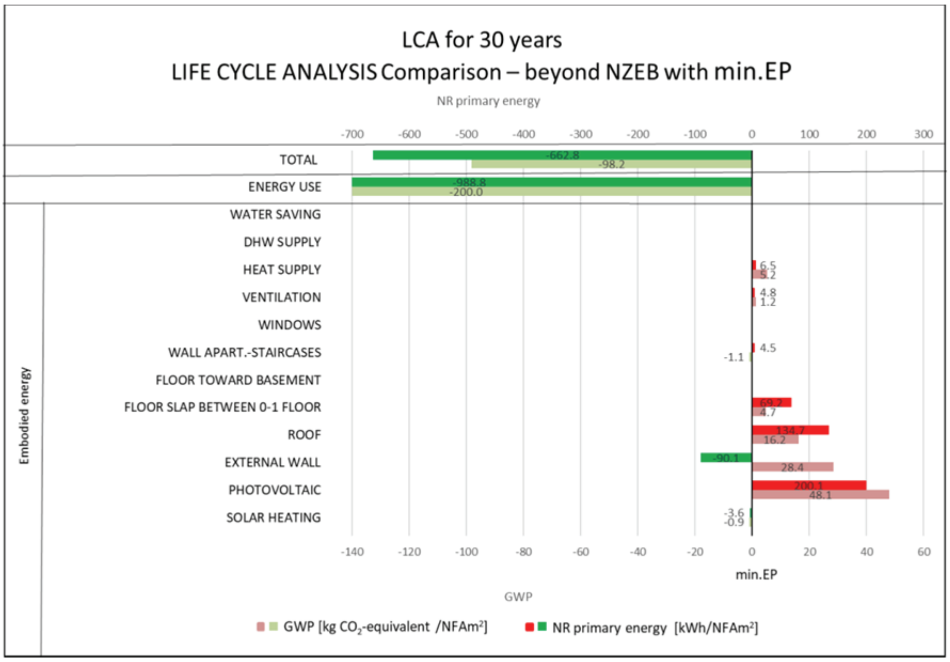

LCC for 30 years
LIFE CYCLE COST Comparison – SS3 with min.EP
Net present value for 30 years
Replacement
Maintenance
Energy cost
Investmentt
-41.0
-22.7
4.1
-25.0
-0.1
min.EP
Euros/NFAm²

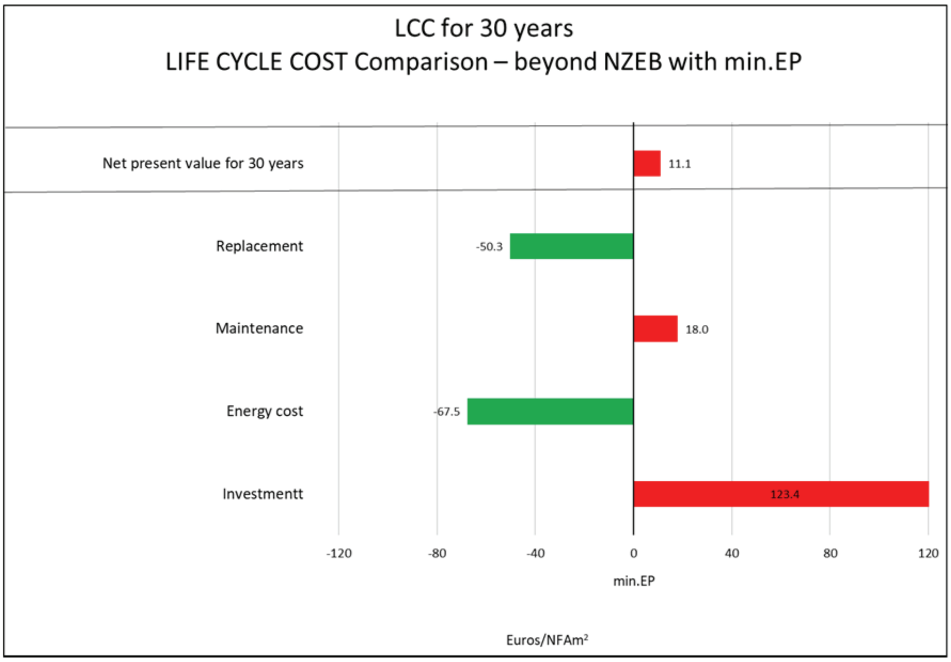

LCA for 30 years
LIFE CYCLE ANALYSIS Comparison – SS4 with min.EP
NR primary energy
TOTAL
ENERGY USE
WATER SAVING
DHW SUPPLY
HEAT SUPPLY
VENTILATION
WINDOWS
WALL TOWARD STAIRCASES
FLOOR TOWARD BASEMENT
FLOOR
ROOF
EXTERNAL WALL
PHOTOVOLTAIC
SOLAR HEATING
Embodied energy
-514.4
-61.8
-542.7
-101.1
6.5
5.2
0.9
0.3
35.5
0.7
93.2
11.2
-134.1
15.6
29.9
7.2
-3.6
-0.9
min. EP
GWP
GWP [kg CO2-equivalent /NFAm²]
NR primary energy [kWh/NFAm²]


LCC for 30 years
LIFE CYCLE COST Comparison – SS4 with min.EP
Net present value for 30 years
Replacement
Maintenance
Energy cost
Investmentt
-44.86
-10.09
-8.51
-28.48
-0.40
min.EP
Euros/NFAm²


LCA for 30 years
LIFE CYCLE ANALYSIS Comparison – SS5 with min.EP
NR primary energy
-700 -600 -500 -400 -300 -200 -100 0 100
TOTAL
ENERGY USE
WATER SAVING
DHW SUPPLY
HEAT SUPPLY
VENTILATION
WINDOWS
WALL TOWARD STAIRCASES
FLOOR TOWARD BASEMENT
FLOOR
ROOF
EXTERNAL WALL
PHOTOVOLTAIC
SOLAR HEATING
Embodied energy
-444.1
-49.2
-447.0
-82.3
4.2
1.0
-49.8
-8.6
4.8
1.2
35.5
0.7
11.2
-134.1
15.6
37.3
9.0
11.9
3.1
-140 -120 -100 -80 -60 -40 -20 0 20
GWP
min.EP
GWP [kg CO_2-equivalent /NFAm²]
NR primary energy [kWh/NFAm²]


LCC for 30 years
LIFE CYCLE COST Comparison – SS5 min.EP
Net present value for 30 years
-42.2
Replacement
-18.1
Maintenance
-13.1
Energy cost
-22.5
Investmentt
8.3
-120 -80 -40 0 40
min.EP
Euros/NFAm²


LCA for 30 years
LIFE CYCLE ANALYSIS Comparison – beyond NZEB with min.EP
NR primary energy
TOTAL
ENERGY USE
WATER SAVING
DHW SUPPLY
HEAT SUPPLY
VENTILATION
WINDOWS
WALL APART.-STAIRCASES
FLOOR TOWARD BASEMENT
FLOOR SLAB BETWEEN 0-1 FLOOR
ROOF
EXTERNAL WALL
PHOTOVOLTAIC
SOLAR HEATING
Embodied energy
-662.8
-98.2
-988.8
-200.0
6.5
5.2
4.8
1.2
4.5
-1.1
69.2
4.7
134.7
16.2
-90.1
28.4
200.1
48.1
-3.6
-0.9
min.EP
GWP
GWP [kg CO_2-equivalent /NFAm²]
NR primary energy [kWh/NFAm²]


LCC for 30 years
LIFE CYCLE COST Comparison – beyond NZEB with min.EP
Net present value for 30 years
Replacement
Maintenance
Energy cost
Investmentt
11.1
-50.3
18.0
-67.5
123.4
min.EP
Euros/NFAm²