Nearly Zero Energy Renovation of houses: Life cycle costs and environmental impact

Jeroen Vrijders
Deputy Head of Laboratory for Sustainable Development
Belgian Building Research Institute (BBRI)
JVR@bbri.be

Lisa Wastiels
Project Manager
Laboratory for Sustainable Development
Belgian Building Research Institute (BBRI)
LWA@bbri.be

Short Summary

This paper describes the results and conclusions from an LCC and LCA analysis performed on a case study. An actual deep energetic renovation example in Torhout, Belgium was studied on its cost efficiency and environmental impact, comparing it to different other renovation scenarios: standard renovation – in which measures were applied to obtain an energy consumption level similar to the minimal energy requirement (EPB) for new houses and NZE or Nearly Zero Energy renovation, where the as built (or as renovated) situation was used as starting point and additional renewable energy systems were installed to strive to zero energy consumption. This allows on the one hand to verify which scenario is the most interesting in terms of costs and environmental impact, and on the other hand to gain insight in the feasibility of obtaining a NZE level in renovation of houses.

Keywords: Deep Renovation; NZE; Life cycle assessment (LCA); Life cycle costing (LCC)

1. Introduction

In the renovation of single houses the ambitions on energy savings grow, as in the whole building market. The ERACOBUILD One Stop Shop project [1] was aimed to create a larger market for deep renovation of houses and investigated ways to motivate clients to do an integral holistic retrofit. In general, the motivation and reasons for renovating a house are related to comfort improvement, quality of living and the necessity of certain replacements and improvements, and is less about energy savings and cost benefits [2]. Nevertheless, the budget and long term perspectives (return on investment) are important parameters in the decision process in many projects. In a broader frame, also environmental issues gain importance.

Within One Stop Shop several existing ambitious renovation projects (‘low energy’ or ‘passive house’) were analyzed on their cost efficiency and environmental impact. The main question was ‘how far to go in the energetic renovation in order to be beneficial?’. Next to the costs and environmental loads of the ‘as built’ project over 30 and 60 years, the costs and impacts of other renovation scenarios with different ambition levels were compared: On the low end, a ‘Standard Renovation’ is considered, defined as an integral retrofit, but with limited efforts (measures to save energy, comparable to current new building standards in Flanders, Belgium). On the high end, the feasibility to obtain a Nearly Zero Energy (NZE) building by applying additional measures to the *as built* situation is investigated.
In this research, the NZE-level was defined based on the considerations from a BPIE report [3], with (1) a very low primary energy consumption in kWh/m²a on a yearly basis including heating, cooling, ventilation, lighting and aid energy, using nationally defined conversion factors, and (2) renewable energy production on-site, nearby and off-site, where 50-90% of the energy demand is

covered by renewable energy. This definition was translated in practice by ‘getting as near to zero energy consumption as possible within the project’s site boundary’ for the projects under study.

2. Case study

2.1 As built (post renovation) situation

Fig. 1: Retrofit of 2 row houses from the 1970s. Before (left) and after (right) © Benergie.be – Architect L. Dedeyne

Architect Luc Dedeyne renovated and transformed two neighbouring houses, dating from the early 1970s, into a single family house with private practice. As *Fig. 1* shows, one of the goals of the architect was to achieve an ‘architectural’ façade with all elements (doors, windows, façade finishing) within the same vertical plane. The most important measures in the actual renovation are:

- Replacement of the floor slab on the ground floor and installation 15 cm EPS insulation;
- Replacement of the roof and installation of 32 cm additional mineral wool;
- Renovation of the street façade by demolishing the external part of the cavity wall and installing 24cm of cellular glass with a ceramic materials as finishing layer;
- Replacement of old windows by triple glazed aluminium windows;
- Addition of Vacuum Insulation Panels (VIP) to the aluminium doors and garage door;
- Installation of a large (25m²) solar boiler, floor heating, heat pump and PV-installation (3.4 kWp).

2.2 Considered alternative scenarios

The as built ‘Low Energy’ renovation with a Heat Pump (coded **LE-HP**) as energy source for heating & hot water is compared to several alternative scenarios:

- A case where the same measures for the envelope were taken, but a condensing boiler on natural gas is used for heating & hot water (**LE-CB**)
- Based on the LE-HP scenario, additional PV panels and a larger solar boiler are added, in order to obtain the **NZE-HP** alternative – this is the most ambitious scenario, striving for Nearly Zero Energy consumption.
- A Standard Renovation scenario is defined, based on minimalistic insulation measures and a condensing boiler (on natural gas) system, coded **SR-CB**. Attention was paid that the same degree and type of façade finishing are kept, in order to be able to compare the costs for the different scenarios.

A summary of the measures in each scenario are given in *Table 1*.

	SR-CB	LE-CB	LE-HP	NZE-HP
Roof	20 cm mineral wool between existing battens	2x16 cm mineral wool on top of existing roof structure (16 cm MW)		
Walls	External insulation: 12 cm cellular glass & glued ceramic tiles	Demolition of external cavity wall, 2x12 cm cellular glass & glued ceramic tiles		
Floor	6 cm sprayed PU foam	15 cm EPS		
Doors & gates	Alu with PU-core	Alu with VIP-core		
Windows	Alu with 1.1 glass	Alu with triple glazing		
Thermal bridges	Not remediated	All solved		
Heating & hot water production	Condensing boiler on natural gas + radiators & floor heating		Heat pump (water/air) + radiators (LT) & underfloor heating	
Solar boiler	/	5 m²	5 m²	25 m²
PV panels	0.9 kWp	0.9 kWp	0.9 kWp	3.4 kWp
Ventilation	Natural ventilation	Mechanical ventilation + heat recovery (system D)		
Air tightn. (v50)	7	2		

3. Cost efficiency

3.1 Methodological approach

The cost efficiency evaluation of the different renovation scenarios considers the relevant life cycle costs over a period of 30 years. The investment costs are based on the real costs documented by the architect and include 6% VAT. Cost data for alternative solutions was obtained from similar projects and reference books, and include all relevant works to the envelope and the technical systems.
The Flemish EPB-software was used to determine a typical energy consumption. This software gives a characteristic value of the primary energy consumption for heating, cooling, hot water production and aid energy. The effects of air tightness and thermal bridges are taken into account. No cooling energy was considered, given that no real overheating risk was present. The same energy consumption data is used for the cost as for the environmental analysis.
For the economic analysis, a cost of 0.2 €/kWh for electricity and 0.08 €/kWh for natural are assumed. A yearly increase of prices of 2.25% is considered.
Maintenance & replacement costs are included, mainly for the technical systems, since these require the most annual maintenance and have a service life shorter than 30 years, and thus will need to be replaced.
The influence of financial incentives is taken into account, but in a way that allows the analysis to be done with or without the influence of subsidies. The subsidy mechanisms available in Flanders on April 1st 2012 are taken into consideration.

3.2 Investment cost

Fig. 2 shows the investment cost for the considered alternatives. The cost for the walls is very significant, because of the special solution chosen (cellular glass & glued ceramic tiles) and the bad condition of the bearing wall when the outer façade wall was demolished, which needed considerable reparation and preparation works.

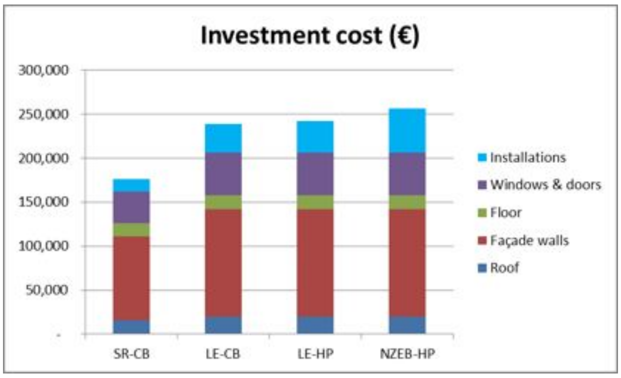

Fig. 2: Investment cost of different renovation scenarios investigated (SR=Standard Renovation, LE= Low Energy Renovation, NZEB = Nearly Zero Energy Building Renovation, CB = Condensing Boiler on Gas, HP = Heat Pump)

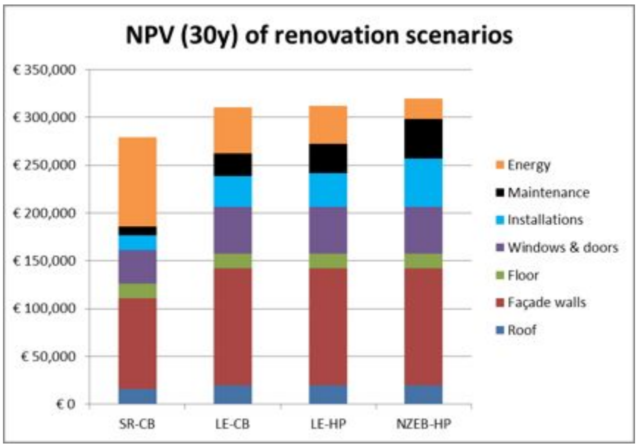

Fig. 3: Life cycle costs over 30 years of different renovation scenarios – without incorporation of subsidies

3.3 Life cycle costs

The energy and maintenance costs are discounted to Net Present Value using a real discount rate of 1.96%. If financial incentives and subsidies are not taken into account, the SR-scenario, which consists of insulating the considered case study house to the required minimal insulation level of new houses shows to be the most interesting in terms of Net Present Value over 30 years.
Fig. 3 clearly shows that the investment costs of the walls are very high, higher than the NPV of the energy consumption accumulated over 30 years. The combined cost of insulating the walls, triple glazing and adding more installation technology is not compensated by the lower energy use.

When taking subsidies anno 2012 into account, the SR-scenario remains the most interesting. The other three scenarios, that have the same envelope, are in the same range of NPV over 30 years. The additional energy savings & the (large) subsidies for PV panels to achieve a “NZE” level do weigh up against the higher maintenance and replacement costs of the larger system, and the NZE-alternative becomes competitive with the LE-scenarios.

4. Environmental impact

4.1 Methodological approach

The environmental impact of the different renovation approaches is analyzed using life cycle analysis (LCA). This technique considers the input (resources, energy) and output (emissions, waste) of the renovation process over its life cycle to quantify its contribution to several environmental issues, such as global warming, the depletion of the ozone layer, or particulate matter. This study makes use of the Ecoinvent life cycle inventory database (version 2.0) [4] and defines the environmental impact using the ReCiPe Mid/Endpoint method (version 1.06) [5]. This method allows to quantify various environmental indicators (each with their proper unit) as well as to determine a global environmental score (expressed in points - Pts) after a process of normalization, grouping and weighting (for this analysis ReCiPe Endpoint (H) / Europe ReCiPe H/A)[6].

The life cycle of the building renovation is set to 60 years for the analysis. Building elements with a shorter life span (like windows and installations) are considered to be replaced during this period. Whereas several interior materials (eg. wall finishes, bathroom or kitchen) are renovated in the *as built* renovation project, these are not considered in the environmental analysis. *Table 1* provides an overview of the different materials and installations included in the study. In addition, the energy consumption required for heating, ventilation and aid energy during the building's life cycle is considered in the environmental analysis and estimated as described for the cost analysis.

4.2 Impact of materials & installations

The aggregated scores show that the environmental impact of the materials (initially used) for the envelope is 28% higher for the LE (& NZE, since the same materials are used for the envelope) scenario compared to the SR scenario. The largest environmental impact originates, for all scenarios, from the materials used for the floor (*Fig. 4*). The environmental impact of the floor is slightly higher for the SR where sprayed PU foam is considered, than for the LE scenario which applies EPS panels. The large impact of the floor results from both the concrete floor slab and the ceramic tiling used as finishing material.
The global environmental impact of the installations also increases for scenarios with increasing energy performance. This is largely because of the larger number of photovoltaic panels in the NZE scenario. Windows are replaced once in 60 years, the installations are replaced every 15 or 20 years. The NZE-scenario has the highest environmental impact in terms of replacements, because of the large amount of installations (*Fig. 4*).

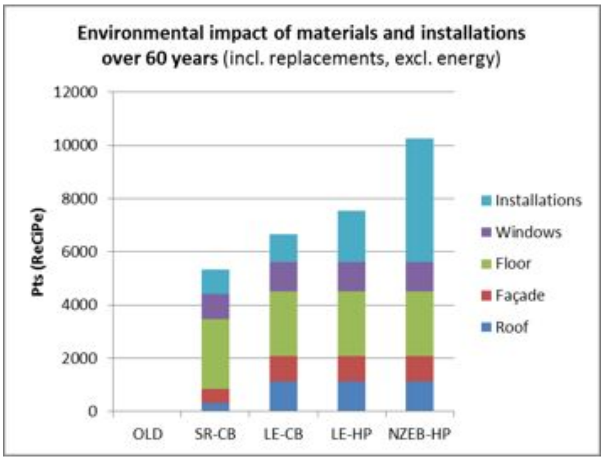

Fig. 4: Environmental impact of the materials and installations over the total life cycle of the building (60 years) for different renovation scenarios. Method: ReCiPe Endpoint (H) V1.06 / Europe ReCiPe H/A / Single score

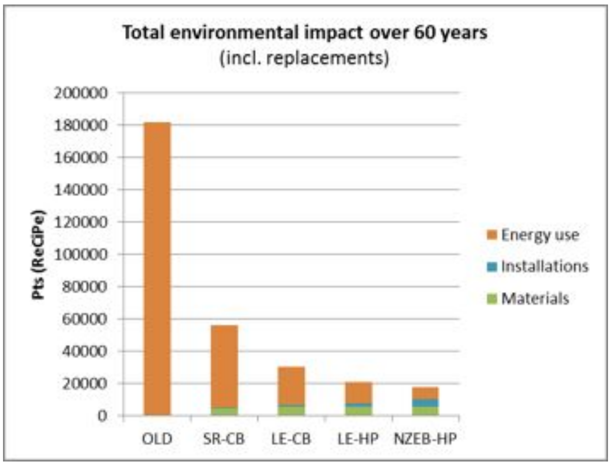

Fig. 5: Total environmental impact of different renovation scenarios over their life cycle. Remark: Different scale than Fig. 4! Method: ReCiPe Endpoint (H) V1.06 / Europe ReCiPe H/A / Single score

4.3 Impact of energy & total impact

The scenarios defined with better energy performances will use less energy for heating, ventilation and hot water. Next to the differences in amounts of energy used per year, also the energy carriers vary between the scenarios. The environmental impact related to the energy use diminishes for scenarios with increasing energy performance: from SR to NZE: -86%. A comparison between LE-CB and LE-HP (where the heating demand is the same) shows the environmental impact is smaller when using a heat pump for heating compared to a condensing gas boiler.

Adding the environmental impacts of materials, replacements and energy use over 60 years together, provides further insights in the total environmental impact of the different renovation measures. The impact related to the energy use clearly determines the total impact (*Fig. 5*). As a result, the environmental impact of the renovation measures decreases for renovations with increasing levels of energy performance (from SR to NZE: -68%).

For illustration, the impact 'over time' of the different scenarios is given in the figure below. It shows that the added materials to achieve lower energy consumption have a small 'environmental pay-back time'.

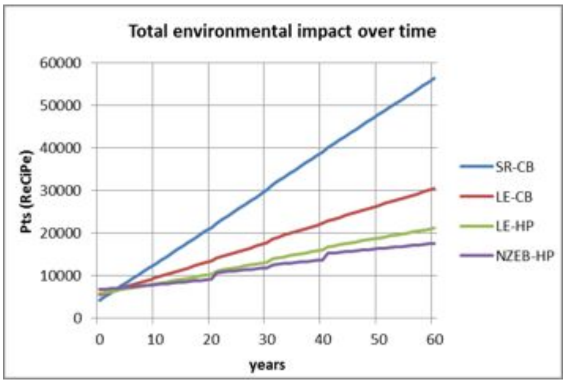

Fig. 6: The environmental 'impact over time' for the different scenarios

5. Discussion of results

5.1 Other case studies

Within the One Stop Shop project, another Flemish renovation case was studied using a similar approach: a renovation of row houses from the 1970s to passive house standard in Wachtebeke, see [7] & [8] for detailed information. The results of this case study lead to similar findings for both the cost and environmental analysis, which enforces the general trend from other research [9][10]. In the Wachtebeke case, the 'Standard Renovation' scenario (SR & K40 - with an insulation level similar to new construction anno 2012) is the most cost efficient over a period of 30 years. In both cases, some insulation was present in the 'old situation', which makes investing in extra insulation measures less efficient. Financial incentives, such as grants for investment and green power certificates for renewable energy, tend to flatten the differences between the more ambitious scenarios and the standard renovation.

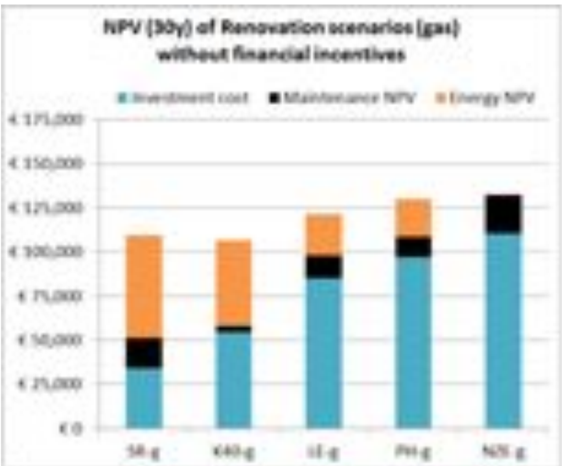

Fig. 7: Life cycle cost of renovation scenarios for Wachtebeke case(all on natural gas) without financial incentives – SR=Standard Renovation – only necessary measures, K40 = renovation to new build minimal standards, LE = low energy, PH = as built Passive House, NZE = Nearly Zero Energy [8]

In terms of total environmental impact, the Wachtebeke case also illustrates that the scenarios with the highest levels of energy performance have the smallest environmental impact over the renovation's life cycle. The global environmental impact of materials and installations increases when going from SR to LE to NZE, but the impact related to the energy use diminishes spectacularly and determines the overall results.
The individual results and more detailed information of both cases can be found in the report that is available on the project website [7].

5.2 Feasibility of NZE level

The results presented in the previous paragraphs show that in the 'NZE' scenario for the Torhout case, where the whole roof surface is used for PV (3.4 kWp) and solar boiler panels (25 m²), it is not feasible to reduce the average annual energy consumption to zero. This is due to the relatively large surfaces of windows and garage doors, with a much higher thermal conductivity than the opaque façade parts. This makes it very hard to reduce energy demand for heating very significantly.
In the Wachtebeke case however, the NZE-level is achievable: covering the roof with PV panels leads to a yearly energy consumption cost of 44 €.

6. Conclusions

In terms of cost efficiency, striving for a very low energy consumption is not cost efficient, due to the high initial investment. Also the elevated maintenance and replacement cost for more sophisticated installations gives the advantage to less complex and less ambitious solutions.
Starting from the as built situation, achieving NZE level is possible using renewable energy techniques, on the condition that the energy demand can be reduced substantially and thus that wall openings are limited – which becomes clear from the comparison between Wachtebeke & Torhout.

In terms of environmental performance, higher levels of energy performance lead to lower environmental impacts. Whereas bringing more materials and installations to a renovation project inevitably leads to higher environmental impacts, this is easily compensated by the reduction of the energy use. The energy use dominates the environmental impact for standard and low energy renovations. The impact of the materials and installations gains importance when striving for the passive house or NZE level. This is related to the strong decrease in energy use, but also to the increase in amount of materials and installations needed to achieve these levels. From this point of view it would be interesting to investigate the environmental impact of different material applications for reaching NZE-level.

It can be concluded that there is still a trade-off to make between cost efficiency and the best option for the environment, within the chosen boundary conditions.

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