COSTS, BENEFITS & ENVIRONMENTAL IMPACT OF ACHIEVING NZE-LEVEL IN RENOVATION: A CASE STUDY

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ABSTRACT

The ERACOBUILD One Stop Shop project [1] aims to create a volume market for holistic, deep renovation of houses. Within the research project, several renovation cases are analysed with life cycle costing (LCC) and life cycle assessment (LCA) methodologies in order to document the cost effectiveness and the environmental impact of different renovation scenarios and verify the feasibility of obtaining a Nearly Zero Energy (NZE) level in renovation.
In this paper one Belgian case study is presented in detail where the renovation "as built" (achieving passive house standard) is compared to several other renovation scenarios with varying levels of insulation and choice of installations: "standard", "low energy" as well as renovation towards the ambitious "NZE-level". The results of the cost and environmental assessment of the different scenarios provide insights in the financial and environmental implications of different renovation strategies and hereby support the discussion on the deep renovation of houses.

1. INTRODUCTION

As for the whole building market, also the ambitions in the renovation of single houses evolve to an increasing energy performance. The ERACOBUILD One Stop Shop project [1] aims to create a volume market for holistic, deep renovation of houses and investigates how potential clients can be motivated to perform an integral and deep energetic retrofit. In general, the motivation and reason for renovating a house is 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 availability of budget and the return on investment, or cost efficiency, form important decision criteria in many projects. From a broader perspective, taking into consideration societal issues, also the environmental impact of retrofit measures gains importance in the decision process.

Within the One Stop Shop project, the cost effectiveness and environmental impact of several existing renovation projects with a 'low energy' or 'passive house' ambition level are analysed as case studies.
First, the costs and environmental impacts of the 'as built' project are documented for a period of 30 or 60 years and compared to those of renovations with lower energy ambitions. For this comparison, different levels of ambitions are defined. A 'Standard Renovation' is considered to be an integral retrofit, where only minimalistic measures are implemented. A variation to the Standard Renovation is the K40-renovation, where the integral renovation results in an energy performance that meets (or approaches) the current requirements for newly built houses in Flanders.
Secondly, the feasibility to obtain a Nearly Zero Energy building by applying additional measures to the *as built* situation is discussed. More specifically the cost effectiveness and environmental implications of this step are determined. In this project, 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 into 'getting as near to zero as possible within the project's site boundary' for the projects under study.
Finally, the robustness of the results in different circumstances and assumptions is verified (such as energy cost escalation rates and requirements on buildings at the end of the study period).

2. RENOVATION CASE STUDY

Renovation of social houses to passive house standard

FIGURE 1 – 5 SOCIAL HOUSES BEFORE AND DURING RENOVATION TOWARDS PASSIVE HOUSE STANDARD

In a social housing neighbourhood in Wachtebeke, a block of 5 terraced houses was selected by the VMSW (Flemish Agency for Social Housing) for a pilot project on renovation towards passive house standard. The houses have a North-South orientation and a floor surface of about 120m² each. The middle house was selected for the case.
Besides some general improvements in terms of floor plans and organisation, the most radical changes relate to improvements of the insulation levesl for the roof, façades and ground floor, and the implementation of installations required to achieve the passive house standard. The roof is replaced and the attic floor insulated with 36 cm of mineral wool. The façade's facing bricks are demolished and replaced with an External Thermal Composite System (ETICS) with 30cm of EPS insulation and a plaster finish. The new windows contain triple glazing. The crawl space underneath the ground floor is filled with 40 cm of EPS pearls and the thermal bridges at the floor and foundation are solved by excavation and placement of cellular glass and XPS insulation. Finally, installations for heating, ventilation (mechanical with heat recovery) and production of hot water are combined in one heat pump based system, a "compact unit". This compact unit is combined with a thermal solar boiler, with panels on the south facing roof. A more detailed description of the project's context and technical measures is available in a separate project leaflet [1].

Considered alternative scenarios

In addition to the *as built* Passive House (PH) renovation, the following theoretical concepts for renovation with a different energy demand were considered, while keeping the building's lay-out:

- Standard renovation (SR): "typical" renovation measures as taken in identical houses in the neighbourhood;
- Standard K40-renovation (K40): "typical" renovation measures with the goal to achieve a general insulation level of K40, as is required for Flemish new buildings anno 2012;
- Low Energy renovation (LE): renovation similar to the *as built* (PH), but with limited thicknesses of insulation and less attention for air tightness;
- Nearly Zero Energy renovation (NZE): renovation similar to the *as built* (PH), but with the addition of renewable energy production. More specifically, an additional thermal panel and several PV panels were added on the south facing roof.

A detailed overview of the renovation measures considered for the different alternatives is available in Table 1. In first instance, all these variants are heated with electricity, because no gas connection is available at the site. Additionally a (hypothetical) scenario with a condensing gas boiler for heating and hot water is considered for all variants, to study the effect of the energy carrier used.

	SR Standard	K40	LE Low Energy	PH *(as built)* Passive House	NZE - Nearly Zero Energy
Facades	No action (keep existing 6 cm mineral wool)		Demolition outer wall		
			Add 20 cm EPS + putty	Add 30 cm EPS + putty	
Insulation Attic floor	Add 14 cm mineral wool (keep existing 10 cm mineral wool)		Add 30 cm mineral wool	Add 36 cm mineral wool	
Insulation Ground floor	Add 4 cm PU-foam sprayed + tile covering				
	-	Add 40 cm EPS grains in crawl space	-	Add 40 cm EPS grains in crawl space	
Windows & doors	low-e glass (1.1)		low-e glass (1.1) (South)	triple glazing	
			triple glazing (North)		
Heating & hot water *	Electrical convectors & boiler		Heat pump		
Solar energy	-	-	2 thermal panels		3 thermal panels
			2 PV-panels	-	16 PV-panels***
Ventilation	Natural (A)		Mechanical (D) + heat recovery		
Air tightness	12	7	4	11	11
Thermal bridges	Unsolved**		Partly solved	No thermal bridges	

* For the gas alternatives, a condensing boiler is combined with radiators or hot water batteries to heat the ventilation inlet air.
** The influence of thermal bridges present in the building is being accounted for in the energy performance calculation (penalty).
*** The solution to attain the 'NZE'-level consists of installing the amount of PV-panels that fits on the south side of the roof.

TABLE 1 – OVERVIEW OF CONSIDERED ALTERNATIVE RENOVATION SCENARIOS

3. COST EFFICIENCY

Methodological approach

To assess the cost efficiency of the different renovation scenarios, the relevant **life cycle costs** over a period of 30 years are determined and discounted to the values of 2012 using a real discount rate of 1.96%. The viewpoint of an individual investor is taken as basis for analysis.

The **investment costs** are based on the real costs for the *as built* situation, and complemented by cost data from similar projects and reference books, and include all relevant works to the envelope and the technical systems.

Energy consumption is determined using the Flemish EPB-software. 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. In the calculations, the energy required for cooling was not considered, on the condition that no real overheating risk is present. The same energy consumption figures are used for the cost as for the environmental analysis.

For the economic analysis, a unit cost of 0.2 €/kWh electricity, 0.08 €/kWh natural gas and 0.055 €/kWh oil is assumed, together with a yearly increase of prices of 2.25%.
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 is regarded separately, so their influence can be considered apart from the rest of the analysis. The subsidy mechanisms available in Flanders on April 1st 2012 are taken into consideration.

Investment cost

The costs for each of the scenarios is shown in FIGURE 2. No financial incentives are included at this point. It is clear that the investment becomes bigger when a higher energy efficiency is strived for.

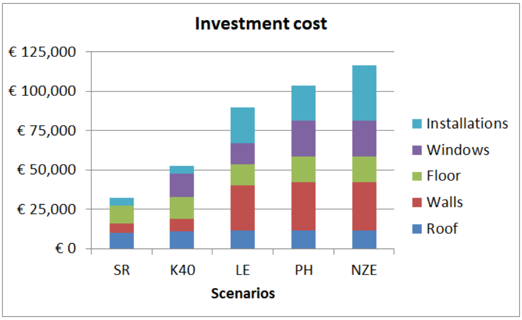

FIGURE 2 – OVERVIEW OF INVESTMENT COST FOR DIFFERENT RENOVATION SCENARIOS

Life cycle costs

Without financial incentives, the K40-scenario is the most cost efficient (Figure 3). The higher investment and maintenance cost of the LE and NZE scenario do not outweigh the extra energy cost savings. The total NPV of the PH (*as built*) scenario is similar to that of the K40 alternative.
When the financial grants are included (FIGURE 4), the net present value of the life cycle costs decreases with increasing energy performances. This makes the NZE scenario the most cost beneficial. In both cases, the minimal standard renovation (SR) is the least efficient in terms of investment versus life cycle cost.

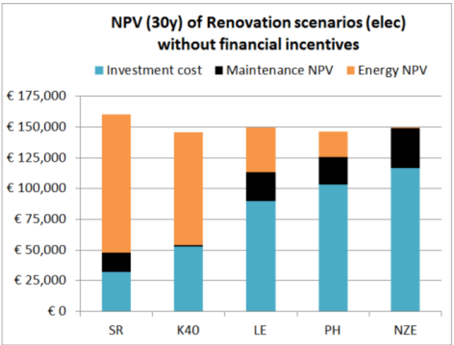

FIGURE 3 – LIFE CYCLE COST OF RENOVATION SCENARIOS (WITHOUT FINANCIAL INCENTIVES)

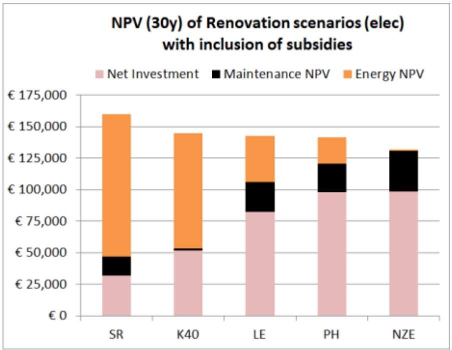

FIGURE 4 – LIFE CYCLE COST OF RENOVATION SCENARIOS WITH FINANCIAL INCENTIVES

If natural gas would be present, FIGURE 5 shows the results without financial incentives. The K40 remains the most interesting scenario. The costs for gas are much lower than those for electrical heating, which makes investing in additional energy saving measures less interesting. When taking into account subsidies (see FIGURE 6) the form of the figure changes, but the NZE and PH alternatives do not become more interesting than the K40- or SR-scenarios.

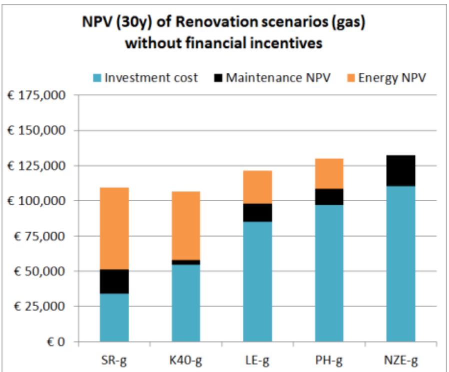

FIGURE 5 – LIFE CYCLE COST OF RENOVATION SCENARIOS WITH NATURAL GAS AS ENERGY CARRIER FOR HEATING (WITHOUT FINANCIAL INCENTIVES)

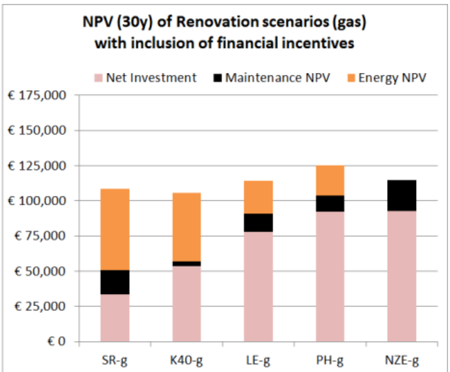

FIGURE 6 – LIFE CYCLE COST OF RENOVATION SCENARIOS WITH NATURAL GAS AS ENERGY CARRIER FOR HEATING (WITH FINANCIAL INCENTIVES)

Robustness of results

The results presented above are valid within the circumstances defined (energy prices and escalation rates, no assumptions beyond the 30 year horizon). To test the robustness of the results, different aspects were considered additionally.

A sensitivity analysis is executed, using different annual energy price escalation rates (1% (low), 2.25% (normal), 3% (high) and 5% (very high)). The results show that at lower rates, the K40-option remains the most interesting one, and also the SR-option is interesting. At higher escalation rates, the NZE and PH scenarios are the most cost efficient and the NPV of the SR and K40 scenario increase significantly.
At the end of the analysis period (2042), additional considerations can be made that influence the results.

- Assuming that measures like insulation and technical systems with a remaining part of their service life still have a value at the end of the analysis period, a residual value can be calculated, using linear depreciation and discounting. This Present Value can be considered as a 'negative cost' in the NPV calculation.
- At that time in the future, it will be required to upgrade the building to the NZE-level. The costs to do this were determined based on today's costs, and discounted to present value. These costs can be added to the other life cycle costs to determine the total NPV.

Both approaches are summarized in the table below and result in similar conclusions: the PH and NZE scenarios become more interesting, since they have more 'value' at the end of the analysis period, and require less effort to upgrade to very severe energy standards in force in the year 2042.

	SR	***K40***	***LE***	***PH***	***NZE***
Residual Value (PV)	3,909	2,486	8,711	10,575	13,551
Total NPV incl ResidVal	156,779	143,310	141,245	136,000	136,261
Upgrade cost (PV)	44,554	43,056	24,670	21,247	13,937
Total NPV incl Upgrade	205,242	188,852	174,626	167,821	163,750

TABLE 2 – OVERVIEW OF RESIDUAL VALUE AND UPGRADE COSTS IN THE YEAR 2042 FOR THE DIFFERENT RENOVATION SCENARIOS AND THE INFLUENCE ON THE TOTAL NPV AND COST EFFICIENCY.

4. ENVIRONMENTAL IMPACT

Methodological approach

The environmental impact of the different renovation approaches is analyzed using life cycle analyses (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.

Impact of materials and installations
The global environmental impact of the **materials** increases with increasing levels of insulation (going from SR to NZE: + 107%). In this specific renovation case, the decision to demolish part of the façade in order to install an ETICS has a significant effect on the environment as it leads to a large amount of additional building materials for the renovation. The global environmental impact of the materials increases 51 % going from K40 to LE (FIGURE 7). The differences in amount of materials in the highly insulated alternatives (LE, PH and NZE) are reflected in smaller differences in terms of environmental impact of the materials (going from LE to PH/NZE: +11%).
In this case, the result of an increasing environmental impact when going from SR over LE to NZE is also reflected in the results for all 17 individual environmental indicators. This can be explained by the fact that the considered renovation scenarios mainly vary in terms of the amount of materials that is considered and not in type of materials. Other cases, where different types of materials are considered for the different renovation strategies, show that the consideration of the individual indicators can lead to important nuances and differences.
The global environmental impact of the **installations** increases from SR to LE due to the installation of the compact unit and the solar panels. The impact of the installations is slightly smaller again for the PH renovation because no solar panels are used in that scenario. Finally, the environmental impact of the installations increases significantly for the NZE renovation because of the large amount of photovoltaic panels considered. The relative importance of the installations starts to grow for the LE and PH scenarios but becomes substantial when trying to reach the NZE level.

It should be noted as well, that the impact of the ventilation system was not included in this study, which suggests that the impact of the installations presented here are underestimated for the LE, PH and NZEB scenarios.

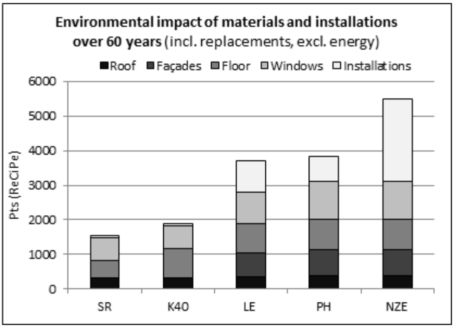

FIGURE 7 – ENVIRONMENTAL IMPACT OF MATERIALS AND INSTALLATIONS OVER LIFE CYCLE FOR DIFFERENT RENOVATION SCENARIOS

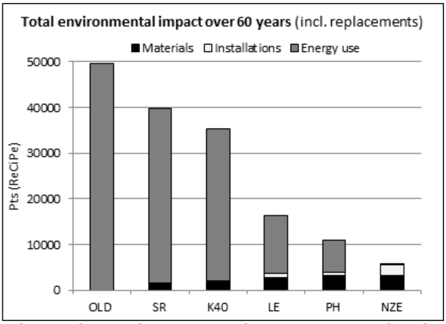

FIGURE 8 – TOTAL ENVIRONMENTAL IMPACT OF DIFFERENT RENOVATION SCENARIOS OVER THEIR LIFE CYCLE

Impact of energy

The decreasing heating demand for concepts with higher energy performance leads to a decrease of the global environmental impact of the **energy use** (from K40 to PH: - 79%). The environmental impact of the energy use for the NZE scenario approaches zero because the project produces the energy that it needs for consumption: the environmental benefits from the energy production through the PV-panels are included in the global score.

A consideration of the **total environmental impact** over the building's life cycle (Figure 8) illustrates that the impact of the energy use (heating, ventilation and aid energy) is very high compared to that of the materials and installations. As a consequence, the total environmental impact decreases for renovation concepts with increasing energy performance (going from SR to NZE) (FIGURE 8).

Finally, the **energy carrier** - and thus consideration of a condensing gas boiler for heating and hot water - has a considerable effect on the global environmental impact related to the energy use (FIGURE 9). In the standard renovation scenarios (SR and K40), the impact of the energy use is significantly lower when using a gas boiler compared to electrical convectors. The differences related to the energy carrier become smaller for alternatives with increasing energy performance (LE, PH and NZE) and the trend reverses: alternatives using gas have a higher impact than those using electricity for the compact unit. In addition, the electricity produced by the PV-panels can be used for feeding the compact unit, whereas, the use of a gas boiler requires a connection to the gas network.

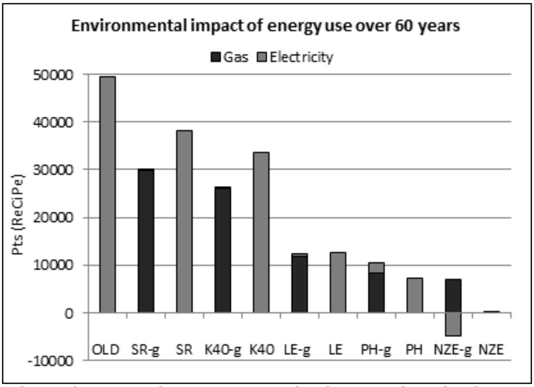

FIGURE 9 – ENVIRONMENTAL IMPACT OF ENERGY USE OVER LIFE CYCLE FOR RENOVATION SCENARIOS WITH NATURAL GAS COMPARED TO ELECTRICITY AS ENERGY CARRIER FOR HEATING

5. GENERAL DISCUSSION

Other case studies

Within the One Stop Shop project, another Flemish renovation case (Torhout) was studied according to a similar approach. The results of the Torhout case lead to similar findings for both the cost and environmental analysis, which enforces the general trend from other research [8, 9]. In the Torhout case, the 'Standard Renovation' scenario (with K48-E83 as performance) is the most cost efficient over a period of 30 years, even when financial incentives are included. The investment costs are higher than the total present value of the energy costs over 30 years and thus dominate the total result.
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. In terms of total environmental impact, the Torhout 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 [4].

Feasibility of NZE level

In the Wachtebeke case, the NZE-level is achievable: covering the whole roof with PV panels leads to a yearly energy consumption cost of 44 €. In the Torhout case, on the contrary, adding a very large solar boiler installation (25 m²) and a PV installation (3.4 kWp) are not sufficient to annihilate the energy consumption cost. This is related to the lay-out of the façades in Torhout (with large openings for doors and windows), which makes it harder to reduce the energy demand for heating.

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 that wall openings are limited). The subsidies for production of renewable energy (electricity via PV) make it more interesting to go to NZE instead of PH or LE.

Also the inclusion of residual values or the ‘upgrade step’ towards NZE at the end of the analysis period stimulates striving for very ambitious renovation.

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.

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