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Life cycle environmental impact of refurbishment of social housing

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Abstract. The current focus on climate change mitigation is reflected in policy goals to reduce the energy use of buildings. However, buildings are not only responsible for a large share of energy use and corresponding GHG emissions, they moreover require a lot of resources, produce a lot of waste, and emit harmful substances. In this paper, an approach is developed to investigate the most preferred renovation strategies for social housing, considering various parameters such as efficiency of the current and future heating system, service life of the heating system and insulation level of the building envelope. Moreover the reduction in life cycle environmental impact due to the replacement of heating systems by systems with increased efficiency is studied. The results show that for non-insulated buildings an increase of the thermal resistance of the building envelope is more effective than replacing the heating system while for, even poorly, insulated buildings the efficiency of the heating system is more important. A holistic Life Cycle Assessment approach is preferred to assess renovation scenarios as focussing on energy reduction might lead to an increase of the life cycle environmental impact of the building. Although this paper focuses on social housing, the approach is broadly applicable.

1. Introduction

Buildings are responsible for a large share of energy use and GHG emissions in Flanders [1] [2], require a lot of resources, produce a lot of waste and emit harmful substances [2] [3]. Despite these insights policy currently focusses merely on the reduction of energy use in buildings. The current draft climate policy plan for Flanders aims for a compliance of all residential buildings with an Energy Performance Certificate (EPC) level A by 2050 [4], [5]. An EPC shows the energy score of the building compared to other buildings [6] and is calculated using a standardized method [7]. To reach this goal the energy use in residential buildings should decrease 76% compared to 2012 by 2050 [5] and therefore Nearly Zero Energy Building (NZEB) renovations are put forward [8] [4]. Social housing companies face an important challenge in renovating their existing housing stock to a level compliant with these policy goals [1] [4] [8] as they have limited budgets. Although operational energy use is causing an important impact on climate change [9], a narrow focus on energy reduction should be avoided. This paper therefore evaluates renovation scenarios using a Life Cycle Assessment (LCA) approach, considering multiple environmental impacts. The most preferred refurbishment strategies for social housing are investigated, considering various parameters such as efficiency of the current heating system, service life of the heating system and (increased) insulation level of the building envelope. Typically, LCA studies are static studies, meaning that the impact of the interventions of to date are included in the



assessment, but that future improvements during the service life of the building are not considered. In this paper, a dynamic approach is developed that takes into account future improvements such as expected improvements of heating system efficiency for every future replacement.

2. Description of the method

2.1. Estimation of the energy use

In a first step the energy use for spatial heating of the building is estimated based on the equivalent degree day method [10] [11](1). Ventilation losses and solar and internal gains are assumed to be constant for the various refurbishment strategies as data collection on these aspects is not yet finalised.

$$Q_t = \left(0,024 \sum_{q=1}^w \frac{S_q a_q}{R_q}\right) E q^\circ d \frac{1}{\eta} * L \quad (1)$$

Table 1. Parameters to estimate the energy use to compensate transmission losses over the service life of the building.

Q_t	Heating energy over the building service life (kWh)	
S_q	Surface of each element (m ²)	Input
a_q	Correction factor heat losses	Input [12]
R_q	Thermal resistance of each element (m ² K/W)	Input [12]
$E q^\circ d$	Equivalent degree days (K d)	1200 [13], [14]
η	Global system efficiency (%)	Input [15]
L	Building service life (years)	60

For the energy calculation (and related environmental impact assessment), a dynamic approach is used whereby a more efficient heating system is assumed each time the system is replaced. As future efficiencies are unknown, estimates are made based on the analysis of historic data. The estimated efficiency of the heating system installed in the year of the replacement ($\dot{\eta}_t$) is based on the efficiency in year 0 ($\dot{\eta}_0$) and the annual growth rate for efficiency ($g_{\dot{\eta}}$) (2). The latter is assumed to be 0,5%. Sensitivity analysis on this parameter is foreseen in a future step of the research.

$$\dot{\eta}_t = \dot{\eta}_0 * (1 + g_{\dot{\eta}})^t \quad (2)$$

2.2. Assessment of the environmental impact

The environmental impact of the materials used for the renovation measures and of the energy use for heating is assessed through a Life Cycle Assessment (LCA) [16] [17]. The Belgian LCA method for buildings and building elements [13] is used. This method considers seven impact categories in line with the European standard EN15804+A1:2013 [18] and ten additional impact categories in line with the Belgian legislation [19].

For the inventory of the data, the Ecoinvent database version 3.3 [20] is used. Scenarios for transport to the building site and installation, as well as scenarios for cleaning, maintenance, sorting, transport to the End Of Life (EOL) treatment and the EOL treatment itself are based on the Belgian LCA method [13]. The dismantling of materials is assumed to be manual and therefore no impact is included. In case the elements are still in a good condition, the existing element is maintained. In case the element is renovated, both the impact of the new element and the impact for the EOL treatment of the existing element (E_0) are taken into account. It is furthermore assumed that the service life of some components is lower than the service life of the building and hence require replacements during the building service life. More specifically, it is assumed that 10% the roof tiles and the entire internal roof finishing are replaced each 30 years. These are assumed to be replaced by identical materials (with the same environmental impact as to date). The estimated service life of the windows is assumed to be 30 years and these are replaced by better insulating windows. The service lives of elements are based on literature [21]. At the end of the service life of the building, here 60 years, the impact of the EOL treatment of all elements is included. The assumptions for the EOL treatment of the elements and systems are presented in Table 2.

Table 2. Overview of EOL treatment [13].

	On site Sorting on site	Fractions landfill	allocated to incineration	specific EoL recycling
Waste glass sheet (window)	70%	5%		95%
Wooden products (window)	40%		85%	15%
Ceramic roof tiles	75%	95%		5%
Fibre cement slabs	75%	100%		
Gypsum plasterboard	50%	80%		20%
System (metals)	100%	5%		95%

2.3. Assessment of the Environmental Life Cycle Cost

The national LCA method in Belgium includes the option to aggregate all impact categories in a single score by calculating an external environmental cost in euro, the E-LCC, presented in Table 3 [22]. This represents the costs to avoid or compensate the environmental impacts caused. To make straightforward decisions in case of contradictory indicators, the E-LCC is used to compare the renovation strategies.

Table 3. Overview central monetary values [22, table 3 and 4, p 12]

Environmental indicator	Unit	Monetary value (€/unit)	Environmental indicator	Unit	Monetary value (€/unit)
Global warming	kg CO2 eqv.	0.100	Ecotoxicity: freshwater	CTUe	3.70E-05
Depletion of the stratospheric ozone layer	kg CFC-11 eqv.	49.10	Water scarcity	m3 water eqv.	0.067
Acidification of land and water sources	kg SO2 eqv.	0.43	Land use: occupation: a. soil organic matter	kg C deficit	2.7E-06
Eutrophication kg	(PO4)3- eqv.	20	Land use: occupation: b. biodiversity		
Formation of tropospheric ozone photochemical oxidants	kg ethen eqv.	0.48	- urban: loss ES	m2.a	0.30
Abiotic depletion of nonfossil resources	kg Sb eqv.	1.56	- agricultural	m2.a	6.0E-03
Abiotic depletion of fossil resources	MJ, net caloric value	0	- forest: biodiversity	m2.a	2.2E-04
Human toxicity			Land use: transformation: a. soil organic matter	kg C deficit	2.7E-06
a. cancer effects	CTUh	665109	Land use: transformation: b. biodiversity		
b. non-cancer effects	CTUh	144081	- urban:	m2	n.a.
Particulate matter	kg PM2,5 eqv.	34	- agricultural	m2	n.a.
Ionising radiation,			- forest, excl. tropical	m2	n.a.
a. human health	kg U235 eqv.	9.7E-04	- tropical rainforest	m2	n.a.
b. ecosystems	CTUe (per kBq)	3.70E-05			

3. Results and discussion

3.1. Description of the case study building

The case study building is a terraced family house of two floors with three bedrooms for four people. The building is constructed in 1983. The external walls and roof are insulated with 6 cm of mineral wool insulation. Currently no ventilation system is installed. The present heat production system is a gas boiler with a production efficiency of 85%. The default values of the Flemish EPB standard [15] are assumed for the efficiency of the other system components (emission, regulation and distribution) which results in a total system efficiency of 69%. The surface area and composition of the building elements being renovated are presented in Table 4.

Table 4. Composition of building elements being renovated.

Element	Construction	U value (W/m ² K)
Floor on grade 86,85 m ²	- Concrete slab - Support layer - cement based screed - Ceramic tiles	2,89
External walls 83,20 m ²	- Gypsum plaster - Loadbearing brickwork - Mineral wool insulation (6 cm) - Brick veneer	0,45
Pitched roof 83,70 m ²	- Roof tiles - Wind and water barrier - Mineral wool between wooden beams (6 cm) - Gypsum board	0,55
Windows (27,88 m ²) and roof windows (3,15 m ²)	Wooden frame with double glazing	3,30

3.2. Description of the renovation scenarios

The renovation scenarios for the building envelope are presented in Table 5. For each scenario several thicknesses of the insulation material are considered. For the external walls the first scenario is adding external mineral wool insulation with a finishing of façade tiles on a wooden frame. In a second scenario external EPS insulation is added to the walls, finished with a mineral rendering. It is assumed that the service life of the external rendering is 30 years and that it is then replaced by an identical one.

Table 5. Description of renovation scenarios.

External wall					
Scenario stone wool ($\lambda 0,04$ W/mK)			Scenario EPS ($\lambda 0,03$ W/mK)		
Thickness (m)	U value (W/m ² K)	Environmental investment cost (euro/m ²)	Thickness (m)	U value (W/m ² K)	Environmental investment cost (euro/m ²)
0,06	0,67	2,04	0,06	0,50	1,83
0,07	0,57	2,09	0,08	0,38	1,94
0,085	0,47	2,14	0,10	0,30	2,05
0,09	0,44	2,20	0,12	0,25	2,17
0,10	0,40	2,25	0,14	0,21	2,28
0,12	0,33	2,35	0,16	0,19	2,39
0,18	0,22	2,67	0,18	0,17	2,51
Pitched roof					
Scenario stone wool ($\lambda 0,036$ W/mK)			Scenario PUR ($\lambda 0,024$ W/mK)		
Thickness (m)	U value (W/m ² K)	Environmental investment cost (euro/m ²)	Thickness (m)	U value (W/m ² K)	Environmental investment cost (euro/m ²)
0,06	0,60	2,69	0,06	0,40	3,17
0,08	0,45	2,77	0,08	0,30	3,65
0,10	0,36	2,85	0,10	0,24	4,13
0,12	0,30	2,94	0,12	0,20	4,61
0,18	0,20	3,19	0,16	0,15	5,56
Windows					
High efficiency double glazing - wooden frames U 1,5 W/m ² K	Environmental investment cost (euro/m ²)		Triple glazing - insulated wood-cork frames U 0,9 W/m ² K	Environmental investment cost (euro/m ²)	
	12,46			14,95	
Roof windows					
High efficiency double glazing - wooden frames U 2,45 W/m ² K	Environmental investment cost (euro/m ²)		Triple glazing - insulated wood-cork frames U 1,47 W/m ² K	Environmental investment cost (euro/m ²)	
	12,46			14,95	

Table 6. Description of the renovation scenarios studied in Figure 3

	Insulated	Not insulated
Current status	6 cm mineral wool wall insulation 6 cm mineral wool roof insulation Roof windows U 3,30 W/m ² K Windows U 3,30 W/m ² K Heating 69% efficiency, 30 year service life	No wall insulation No roof insulation Roof windows U 3,30 W/m ² K Windows U 3,30 W/m ² K Heating 69% efficiency, 30 year service life
Minimal investment	6 cm mineral wool wall insulation 6 cm mineral wool roof insulation Roof windows U 3,30 W/m ² K Windows U 3,30 W/m ² K Heating 78% efficiency, 30 year service life	No wall insulation No roof insulation Roof windows U 3,30 W/m ² K Windows U 3,30 W/m ² K Heating 78% efficiency, 30 year service life
Minimal energy use	18 cm EPS wall insulation 16 cm PUR roof insulation Roof windows U 1,47 W/m ² K Windows U 0,90 W/m ² K Heating 104% efficiency, 20 year service life	
Minimal E-LCC	6 cm mineral wool wall insulation 6 cm mineral wool roof insulation Roof windows U 3,30 W/m ² K Windows U 3,30 W/m ² K Heating 84% efficiency, 30 year service life	10 cm stone wool wall insulation 12 cm stone wool roof insulation Roof windows U 3,30 W/m ² K Windows U 3,30 W/m ² K Heating 84% efficiency, 30 year service life
NZEB 1		18 cm stone wool wall insulation 18 cm stone wool roof insulation roof windows U 2,45 W/m ² K windows U 1,50 W/m ² K Heating 84% efficiency, 30year service life
NZEB 2		12 cm EPS wall insulation 10 cm PUR roof insulation Roof windows U 2,45 W/m ² K windows U 1,50 W/m ² K Heating 84% efficiency, 30year service life

One of the current renovation measures in social housing is replacing the existing heating system by a better one, represented in Figure 3 as the scenario “min investment”. For the case study building this results in an E-LCC decrease of 4%, while for the non-insulated building the effect is higher, namely 7%, due to the higher original heating demand. The results show that (1) the effect of improving the heating system is lower when the building is better insulated and (2) that it is more interesting to improve the insulation level of non-insulated buildings than replacing the heating boiler.

The renovation scenario minimal energy use in Figure 3 leads to the lowest heating demand for the poorly insulated building. For this renovation scenario a reduction of the energy use of 64% is obtained, however, the E-LCC for this scenarios increases with 88% compared to the current status. Apparently the reduction of the impact for heating the building due to the extra insulation and more efficient heating boiler cannot compensate the additional impact for the new materials and the new boiler. On the other hand, for the non-insulated building a reduction of the energy use of 89% is shown for the scenario leading to the lowest energy use, which results in a reduction of the E-LCC with 19%. Striving for a minimal energy use is hence not the best approach for all buildings to reduce the environmental impact.

The renovation scenario resulting in the lowest E-LCC for the poorly insulated case study building results in a reduction of 7% of the E-LCC and a reduction of 15% of the energy use. This scenario only includes a replacement of the heating system. Further increasing the insulation of the building envelope does not result in a sufficient reduction of the heating demand to compensate for the additional impact of the new materials. For the non-insulated building a much higher (44%) reduction of the E-LCC is achieved for the scenario leading to the lowest E-LCC. The further energy reduction due to additional replacement of the windows is insufficient to compensate for the additional environmental investment costs.

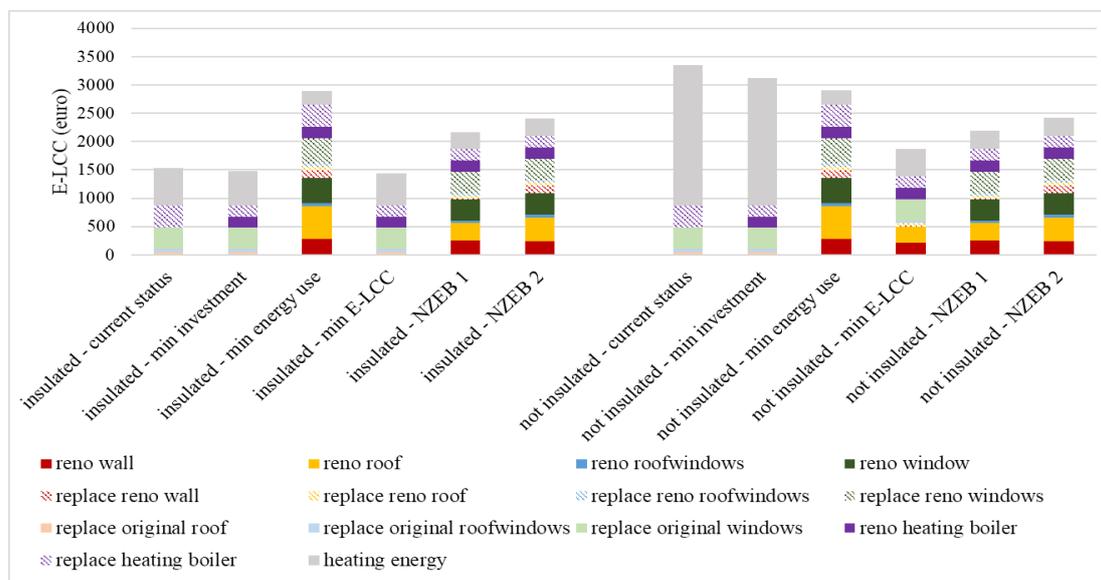


Figure 3. E-LCC for several renovation scenarios for the poorly insulated case study building and the hypothetical non insulated situation

3.4.3. E-LCC results of two NZEB scenarios. The requirements for NZEB renovation are based on U values for the building elements [8]. However, the environmental impact of buildings is not merely related to the impact of the energy use, but moreover the impact of the materials can be important. To gain insight in the E-LCC of NZEB buildings compared to the analysed renovation scenarios, two scenarios for NZEBs, with different materials, were defined. The results are presented in Figure 3 for both the poorly insulated case study and the hypothetical uninsulated building.

For the poorly insulated building the reduction in energy use of the two NZEB scenarios is similar, 54% and 53%. Although the E-LCC is increased for both scenarios the magnitude of the increase is slightly different due to the different impact of the insulation and finishing materials used in each scenario. For the scenario with mineral wool insulation the E-LCC has increased with 41%, while for the scenario with EPS and PUR insulation the E-LCC has increased with 56%. This can be explained by the difference in the impact of the production process of both the insulation and the finishing materials and in the difference in service life of the chosen finishing [21]: the rendering needs to be replaced once entirely during the service life of the building while the façade tiles need only one partial replacement. For the non-insulated building the NZEB renovation scenarios lead to a decrease in energy use of 87% and 86% and a decrease in the E-LCC of 35% and 27% respectively.

For the case study building, the NZEB renovation scenario leads to an increase of the E-LCC of the building compared to the current status, while for the non-insulated building the NZEB renovation scenarios lead to a decrease in the E-LCC, although other scenarios lead to an even further decrease.

Table 7. Overview of the effect on energy use and E-LCC of the various renovation scenarios.

Scenario	Insulated building		Non-insulated building	
	Energy use (kWh)	E-LCC (euro)	Energy use (kWh)	E-LCC (euro)
Current	100%	100%	100%	100%
Min. investment	-9%	-4%	-9%	-7%
Min. energy use	-64%	+88%	-89%	-19%
Min. E-LCC	-15%	-7%	-80%	-44%
NZEB 1	-54%	+41%	-87%	-35%
NZEB 2	-53%	+56%	-86%	-27%

The effect on the energy use and E-LCC of the various renovation scenarios is presented in Table 7. The policy goal to reduce the energy use with 76% seems not possible for the case study building. However as the case study building is already insulated, this goal is possibly to strict. Based on the current EPC score (241) for the case study building [23], only a reduction of 42% is needed to reduce the EPC score to 100. Based on the results presented in Table 7, a 42% reduction can be achieved although resulting in a higher E-LCC and thus leading to a higher environmental impact. If the case study building would not have been insulated, all energy renovation scenarios would lead to a lower E-LCC, however important differences in the magnitude of the reduction of the E-LCC are noticed.

4. Conclusions and further outlook

This paper studied whether a future increase of the efficiency of heating systems has an important impact on the estimation of the life cycle environmental impact of a building. Furthermore the most preferred renovation strategies for social housing are investigated.

Considering that replacements of heating boilers during the service life of a building will include a higher efficiency at each replacement, results in a decrease in the Environmental Life Cycle Cost (E-LCC) of 5,47% for a poorly insulated building and 8,99% for a non-insulated building. As improvements in the emission and distribution components of heating systems as well as coupling with other systems, such as for example heat pumps can be expected, it seems interesting to further study possible improvements in technology for heating in detail. Besides the effect of efficiency increase of heating systems, the effect of the service life of the system on the E-LCC of the building is studied. As a shorter service life of the heating boiler results in more replacements and the corresponding increase in E-LCC linked to the investment in new systems, it is preferred not to replace the heating system before the end of its technical life.

The most preferred renovation strategy for a non-insulated building proved to consist of improving the thermal resistance of the building envelope rather than replacing the boiler by a more efficient one. For poorly insulated buildings, the opposite was found: for these buildings it is more interesting to replace the heating boiler by a more efficient one.

The analysis of NZEB renovation scenarios as proposed by policy revealed that these lead to an increase in the E-LCC for the poorly insulated building, whereas for the non-insulated building this scenario leads to a reduction of the E-LCC compared to the current status of the building. However renovation scenarios with a lower insulation level lead to an even lower E-LCC. Striving for a minimal energy use results in a higher E-LCC for the poorly insulated building because the E-LCC of the additional materials to insulate the building envelope cannot be compensated by the reduction of the E-LCC for energy. It seems therefore more efficient to focus in the E-LCC of renovation scenarios rather than on the reduction of the energy use.

As the impact on global warming is linked to the amount of energy from natural gas needed for heating the building it seems interesting to study the effects of a shift to renewable energy. Therefore estimations on the energy use needed to prepare sanitary hot water and the electricity use should be included in future research to assess the effect of renewable technologies such as solar collectors or PV panels.

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