Improving the Energy Performance of Existing Buildings: Search for Opportunities for Social Housing Companies

Els Van de moortel¹, Karen Allacker¹, Frank De Troyer¹,
Luc Stijnen², Erik Schoofs³

¹KU Leuven, Leuven, Belgium

²Zonnige Kempen, Westerlo, Belgium

³Molse Bouwmaatschappij, Mol, Belgium

Abstract

Policy regulations increasingly require further energy reduction of the existing housing stock. For social housing companies, it is an important challenge to find a balance between the necessary investment in energy reduction and the available budget. To estimate the effect of renovation measures over the service life of buildings, a dynamic Financial Life Cycle Assessment is used. The assessment considers investment costs and life cycle costs of increased insulation levels and increased efficiency of heating systems when these are replaced throughout the building service life. In this paper the financially most interesting renovation scenarios to reach the policy goals in Flanders are selected to support social housing companies in their decision making process.

Introduction

To mitigate the impact of the building sector on climate change various initiatives emerged to reduce the energy use of buildings. In Flanders the energy score of a building is expressed in an Energy Performance Certificate (EPC) (Flemish Energy Agency, 2017). According to the Flemish Energy Agency EPCs “are meant to raise the awareness on energy efficient buildings and show the energy score of the building compared to other buildings” (energiesparen.be, sd). The current draft climate policy plan for Flanders aims for a compliance of all residential buildings with an EPC level A by 2050 (Flemish Energy Agency, 2018), (Flemish Government, 2018). To reach this goal the energy use in residential buildings should decrease with 76% by 2050 compared to 2012 (Flemish Government, 2018). Nearly Zero Energy Building (NZEB) renovations are put forward to achieve this.

Figure 1: Overview of EPC scores of total Flemish housing stock and social housing stock 2050 (Flemish Energy Agency, 2018), (Statistics VMSW, 2016).

An overview of EPC levels (A+ to F) for all residential buildings in Flanders and for social housing in Flanders is presented in Figure 1. Apparently there are less level F buildings in the social housing stock and more buildings with level B, C or D compared to the total housing stock in Flanders. Nevertheless the social housing companies have to do an extra effort to renovate the existing housing stock as only 4% of the social houses have an EPC level A (Statistics VMSW, 2016).

Figure 2 shows the rental income from the housing stock and of the outstanding debt of social housing companies due to investments made. Due to rapidly increasing investments in their building stock and a slower increase in the rental income, there is an important financial constraint for social housing companies in Flanders to invest in renovation (VMSW, 2017), (Mallants, 2017).

Figure 2: Outstanding debt for and income from the housing stock for social housing in Flanders (Mallants, 2017, p 34).

The current focus on small investments (quick-wins) and on awareness raising programs for change of behaviour of tenants (Santangelo & Tondelli, 2017) does not lead to a sufficient energy reduction to reach the current policy goals. More profound renovation scenarios such as 1) increasing the thermal resistance through better insulation of the building envelop, 2) increasing the efficiency by replacing the heating system or 3) a combination of both seem to have a better effect on decreasing the energy use (Agliardi et al, 2018), (Guardigli, et al, 2018). Although this approach of deep renovation requests higher investment costs, it might reduce the cost for energy needed to heat the building during the service life of the building and as such lead to a lower life cycle cost. This principle is illustrated in Figure 3 where the Sum of the Present Value (SPV) of investment and energy cost is shown over a reference service life of the building, here

20 years. As suggested in Figure 3, a renovation scenario where only minimal thermal insulation is included requires a small investment cost in year 0 but leads to a limited reduction in the energy use needed for spatial heating, represented by the red line on the graph. The renovation scenario with a larger investment in thermal insulation in year 0 and with a corresponding lower energy use, represented by the green line on the graph, leads to a lower SPV of investment and energy cost at the end of the service life of the building. This is because the initial investment cost in insulation is compensated by the reduced heating cost (Van de moortel et al., 2018).

Figure 3: SPV investment cost and heating cost (LCC) until year t (Van de moortel et al., 2018).

For social housing companies, it is an important challenge to find a balance between the necessary investment in energy reduction measures and the available budget.

A second issue approached in this paper is how improvements of technology occurring during the service life of the building, for example increased efficiency of heating systems, can be integrated in the long term estimations on energy use and Life Cycle Cost (LCC). In LCC studies, generally the costs for replacements of systems or materials during the service life of the building are included by repeating the, preferably discounted, investment cost when the system is replaced (Islam et al, 2015). The effect of the better efficiency of the new system is often disregarded and hence only investment costs are considered but not the reduced energy use. This approach hence does not take into account technological improvements and is further referred to as a static approach. In reality the efficiency of the new system will be better than the efficiency of the old system, resulting in a lower energy use for heating. The effect of including the increased efficiency when replacing the heating system in the PV of heating costs is shown in Figure 4. As the growth rate for energy prices is estimated higher than the discount rate, the yearly heating costs are increasing. This is represented by the upward inclination of the graph. When the heating system is replaced by a new system with a better efficiency (at the end of period 1), less energy is needed to provide the heating demand. This is represented by the shift in the graph at point A. The SPV of heating costs over the total service life of the building is the sum of the SPV of period 1 and period 2 and is represented by the coloured surface on the graph.

Figure 4: PV of heating costs considering system efficiency increase when replacing the heating system.

Previous research (Pehnt, 2006) recommends a dynamic approach to take progress of technology into account. In this paper the dynamic approach assumes a better efficiency of the heating system when it is replaced during the service life of the building. It is examined whether this dynamic approach has an important effect on the estimation of the energy use for heating over the service life of the building and on the LCC.

Method

To get insight in the effects of several renovation scenarios on both the energy reduction for heating and the financial consequences for the social housing company the gross energy use for heating and the LCC is calculated for a selection of renovation scenarios. In this paper only the energy use needed to compensate transmission losses is studied. Ventilation losses and sanitary hot water production are not taken into account as data gathering of these aspects is not completed yet.

The LCC of various renovation scenarios are estimated by adding the investment cost (C_i) at year 0 for insulating the building and replacing the heating system to the sum of the present values (SPV) of future replacement cost for materials and/or installations (C_R) and to the SPV of heating costs (HC) up to a given year (1). As the insulation of the building envelope is assumed to happen in year 0 and no other renovations of the building envelope are assumed until the end of the service life of the building, no replacements costs for insulation of the building envelope are included.

$$LCC = C_i + \sum_{t=1}^L PV [C_{R_t}] + \sum_{t=1}^L PV [HC_t] \quad (1)$$

The SPV of the costs for heating the building to compensate transmission losses are estimated based on the equivalent degree days method (2). The parameters used in this formula are explained in Table 4 in Nomenclature section.

$$\sum_{t=1}^L PV [HC_t] = \left(0,024 \sum_{q=1}^w \frac{S_q a_q}{R_q} \right)^{\circ deq} \frac{1}{\eta} \sum_{t=1}^L PV [p_t]$$

With

$$\sum_{t=1}^L PV[p_t] = p_0 \left(\frac{1+g_e}{1+d} \right)^L \frac{\left(\frac{1+g_e}{1+d} \right)^L - 1}{\left(\frac{1+g_e}{1+d} \right) - 1} \quad (2)$$

The SPV of replacement costs of the heating system (C_R) during the service life of the building are based on the investment cost of the heating system in year 0 (C_{I_0}) and the growth rate for construction costs (g_m). The number of replacements is based on the ratio of the building service life (L) and the service life of the heating system (l) minus 1 to exclude the first installation (3).

$$\sum_{t=1}^L PV [C_R] = C_{I_0} * \left(\frac{(1+g_m)}{(1+d)} \right)^l * \frac{\left(\left(\frac{(1+g_m)}{(1+d)} \right)^l \right)^{\left(\frac{L}{l} - 1 \right)}}{\left(\frac{(1+g_m)}{(1+d)} \right)^l - 1} \quad (3)$$

The estimated improved efficiency of the heating system in the year of the replacement ($\dot{\eta}_t$) is based on the efficiency in year 0 ($\dot{\eta}_0$) and the growth rate for efficiency ($g_{\dot{\eta}}$) (4).

$$\dot{\eta}_t = \dot{\eta}_0 * (1 + g_{\dot{\eta}})^t \quad (4)$$

In this paper the yearly growth rate of system efficiency is assumed to be 0,5% as a first estimation. The assumption is based on the improvement of the current boilers installed in the case study building compared to the original boilers installed. Currently condensing boiler are already reusing most of the heat of the exhaust, therefore important further efficiency increase of those systems is rather unlikely. Replacement of the condensing boiler by other systems, such as for example heat pumps, is more likely to happen as well as improvement of the efficiency of other system components, such as heat release, transport and storage. As the aim of this paper is to find out whether including the efficiency increase at the moment of replacement has an influence on gross energy use and the LCC, a general assumption for improvement of the total system of 0,5% is assumed. In case the improvement of the energy efficiency can indeed affect the results, further research is needed to better estimate the growth rate for the efficiency increase.

The investment costs are based on the Belgian Aspen database for construction v. 2015. Organisational costs for the tenant and social housing companies are not included. A general average for Flanders of 1200 equivalent degree days is estimated based on a general assumption for internal and solar gains (Allacker, 2010) (Allacker et al, 2012). The thermal resistance of the elements, including the correction factor, is based on (NBN, 2008). The price of natural gas is assumed to be 0,05 euro per kWh (VREG). A service life of 60 years is assumed for the building. The assumed inflation is 2% (statbel, 2019), the nominal yearly discount rate (d) is assumed 2% (NBB, 2019), the nominal yearly growth rate for energy prices (g_e) 3% (Allacker, 2010), and the nominal yearly growth rate for construction costs (g_m) 2,5% (ABEX, 2019).

Results of the case study

To get insight in the effect of including the increased efficiency of the heating system when it is replaced in estimations on the gross energy use and LCC this dynamic approach is compared with the static approach where the efficiency of the system is kept constant for the total service life of the building for a specific case study building and a selection of renovation scenarios.

Description of the case study

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 stone wool insulation. Currently no ventilation system is installed. The present heat production system is a condensing gas boiler with an efficiency of 85%. The default values of the Flemish EPB standard (Flemish Government, 2017) are assumed for heat release and transport. Currently no storage is included in the system. These assumptions result in a total system efficiency of 69%. The surface and composition of the building elements is presented in Table 1. The current EPC score for the case study building is 240 kWh per m² per year, while the actual average use of natural gas used for heating and the production of SHW for this building type is about 85 kWh per m² per year (Zonnige Kempen, 2018). The estimated energy use for heating based on the equivalent degree day method used in this paper is about 77% of the actual gas use. This underestimation is possibly due to the fact that neither the energy use to compensate ventilation losses nor the energy needed for the production of SHW are included in the method so far.

Table 1: Composition of building elements.

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

Figure 5: Case study building – ground floor.

Figure 6: Case study building – first floor.

Description of the renovation scenarios

The renovation scenarios for the building envelope with their investment costs are presented in Table 2. For each scenario several thicknesses of the insulation material are included. For the external walls the first scenario adds external stone wool insulation with an external finishing in façade tiles on a wooden frame. The cost of this external finishing is estimated to be 77,29 euro /m². A second scenario for the renovation of the external walls is adding external Expanded Polystyrene (EPS) insulation panels, finished with a mineral rendering. The cost of the mineral rendering is estimated to be 49,53 euro /m². For renovating the floor a scenario with in situ polyurethane (PUR) foam insulation and a scenario with EPS boards are included. For both scenarios replacement of the tiles and screed (95,24 euro/m²) are included in case of 5 cm insulation and additional replacement of the concrete floor slab (203,39 euro/m²) is included for higher insulation thicknesses. Due to the limited ceiling height on the ground level, it is necessary to include demolition

of the existing floor slab, additional excavation of the ground and a new floor slab for the scenarios with more than 5 cm insulation. The two scenarios assumed for roof insulation are stone wool insulation between the existing wooden structure or adding PUR insulation boards on top of the existing structure. The finishing for both scenarios is assumed to be clay roof tiles at a cost of 120,21 euro/m².

Table 2: Description of renovation scenarios of the building envelope.

External wall			
Scenario stone wool ($\lambda 0,04$ W/mK)		Scenario EPS ($\lambda 0,03$ W/mK)	
Thickness (m)	Cost (€/m ²)	Thickness (m)	Cost (€/m ²)
0,06	10,41	0,06	20,39
0,07	10,88	0,08	25,26
0,085	12,75	0,10	29,96
0,09	13,35	0,12	34,52
0,10	14,37	0,14	39,04
0,12	17,06	0,16	43,48
0,18	21,62	0,18	47,84
Floor on grade			
Scenario PUR ($\lambda 0,024$ W/mK)		Scenario EPS ($\lambda 0,04$ W/mK)	
Thickness (m)	Cost (€/m ²)	Thickness (m)	Cost (€/m ²)
0.05	11,00	0.05	7,55
0.10	18,00	0.10	12,17
0.20	32,00	0.20	21,41
Pitched roof			
Scenario stone wool ($\lambda 0,036$ W/mK)		Scenario PUR ($\lambda 0,024$ W/mK)	
Thickness (m)	Cost (€/m ²)	Thickness (m)	Cost (€/m ²)
0,06	19,36	0,06	35,70
0,08	24,02	0,08	47,13
0,10	29,37	0,10	56,04
0,12	34,32	0,12	62,77
0,18	48,10	0,16	81,11
Windows			
High efficiency double glazing with insulated frames		Passive windows	
U window (W/m ² K)	1,5	U window (W/m ² K)	0,9
Cost (€/m ²)	450	Cost (€/m ²)	600
Roof windows			
High efficiency double glazing with insulated frames		Passive windows	
U window (W/m ² K)	2,45	U window (W/m ² K)	1,47
Cost (€/m ²)	428	Cost (€/m ²)	634

Besides improving the thermal insulation of the building envelope, replacing the heating system is another frequently used renovation scenario in social housing. To analyse the effect of replacing the heating system in year 0 two scenarios are included with an assumed efficiency of 78% or 84%. To investigate the influence of the service life of the heating system a service life of 20 and 30 years is assumed. In total there are six scenarios for the heating system, presented in Table 3.

Table 3: Description of the renovation scenarios of the heating system.

Renovation scenario	Efficiency (%)	Service life (years)
1 keep existing system	69	20
2 keep existing system	69	30
3 replace existing system	78	20
4 replace existing system	78	30
5 replace existing system	84	20
6 replace existing system	84	30

Gross energy demand and LCC for renovation of the case study building

The gross energy use for all combinations of renovation scenarios is calculated based on the dynamic approach. This means that for all renovation scenarios, both the scenarios where only the insulation is improved in year 0 and the scenarios where the heating system is replaced in year 0, a replacement of the heating system is included after 20 or 30 years and a better efficiency is assumed for the new heating system. To get insight in the effect of using the dynamic approach compared to the static approach, the gross energy use over the building service life is shown per net yearly energy use in Figure 7.

Figure 7: Gross energy use over building service life per net yearly energy use for dynamic and static approach.

The blue lines represent the results for the dynamic approach while the red lines represent the static approach. There are six blue lines on the graph corresponding with renovation scenarios for three types of heating systems (efficiency of 69%, 78% and 84%) and two options for the service life of the heating systems (20 years and 30

years). As a change in the service life does not affect the result when the efficiency increase is excluded, only three red lines are on the graph, representing each one type of heating system.

Figure 7 shows that including the efficiency increase when the heating system is replaced (i.e. dynamic approach) results in a lower gross energy use over the building service life.

In case of uninsulated houses (with a higher net energy use) the spread between the lines on the graph is rather wide. This means that changing to a boiler with a better efficiency has an important effect on the gross energy use. The spread between the graphs is higher for the static approach. For well insulated houses, the efficiency of the heating system is not affecting the gross energy demand a lot, neither is the consideration of the efficiency increase when replacing the heating system.

The renovation scenario that is leading to the highest reduction in energy use is a combination of 20 cm PUR floor insulation, 18 cm EPS wall insulation, 16 cm PUR roof insulation, passive windows and roof windows and replacement of the heating system by one with an efficiency of 84% in year 0 for both the dynamic and the static approach. In the dynamic approach a system replacement rate of 20 years leads to lower gross energy use over the service life of the building than the scenario with a replacement rate of 30 years. Although there is a difference in the amount of gross energy, the selection of the renovation scenarios is identical for the static and dynamic approach.

As it is important for social housing companies to find a balance between energy savings and financial costs, additionally the LCC for all combinations of renovation scenarios is calculated. For these results a Pareto front of the LCC and investment cost is drawn to get insight in the most cost efficient combinations of renovation scenarios.

Figure 8: Pareto front: LCC per increasing investment.

The first renovation scenarios on the Pareto front are insulating the external wall with 6 until 12 cm mineral wool insulation. The second series of renovation scenarios on the Pareto front are replacing the heating system, followed by a combination of wall insulation and replacing the heating system. From an investment of 3 000 euro onwards, the decrease of the LCC is less important. The scenario with an investment over 3 000 euro on the Pareto front is a combination of wall and roof insulation and replacing the heating system. This means

that all other combinations of renovation scenarios require higher investment costs and lead to higher LCC. All scenarios on the Pareto front exclude adding floor insulation and replacing the windows this means that those renovation scenarios are not financially interesting as the investment cost cannot be compensated by the reduction of the heating costs.

To examine whether the dynamic approach leads to different decisions than when a static approach would have been used, the LCC was recalculated excluding the replacement of the heating system by a better one. The efficiency of the heating system is hence kept constant for the total service life of the building. The orange line in Figure 9 shows the Pareto front of the LCC per increasing investment for this static approach. Although the LCC is increased for each scenario, mostly the same renovation scenarios are on the Pareto front. The static and dynamic approach hence lead to similar results in the selection of renovation scenarios.

For comparison the LCC of the renovation scenarios of each element separately and the combination of renovation scenarios leading to a NZEB renovation required by policy are presented in Figure 9. Only replacing the heating system is on the Pareto front. For the renovation scenarios where one element of the building envelope is insulated, the scenarios with roof or wall insulation require a rather small investment, but lead to a higher LCC than the renovation scenarios on the Pareto front. Replacing the windows or adding floor insulation require significantly higher investments and lead to a higher LCC than the renovation scenarios on the Pareto front. The NZEB renovation scenario proposed by policy requires a rather high investment and leads to a rather high LCC. Therefore this scenario seems not to be financially efficient.

Figure 9: LCC per increasing investment including efficiency increase of the heating system.

The scenario with the lowest LCC leads to a 33% reduction of the heating demand compared to the current situation, which is lower than the reduction of 76% required by the policy goals (Flemish Government, 2018). The NZEB renovation scenario that is proposed by policy to achieve this goal leads to a reduction of 71%. The renovation scenario leading to the lowest gross energy use, a combination of 20 cm PUR floor insulation, 18 cm EPS wall insulation, 16 cm PUR roof insulation, passive windows and roof windows and replacement of the heating system by one with an efficiency of 84% and a

system replacement rate of 20 years leads to a higher reduction of the energy use than requested in the policy goals. It is therefore investigated what is needed to meet the policy goals for energy reduction and what this means from a LCC perspective. In Figure 10, the gross energy use, calculated with the dynamic approach, is compared to the LCC, considering the full building service life.

Figure 10: Pareto front of gross energy use per increasing LCC.

The blue line in Figure 10 is the Pareto front where the decreasing gross energy use is shown per increasing LCC. This is a selection of the most interesting renovation scenarios to reduce the gross energy use in the financially most efficient way. The gross energy use for the current situation is indicated by the black dot on the graph. In this scenarios no initial investment is assumed, the LCC is based on the operational energy use over the building service life and replacement of the technical installation by one with a higher efficiency after 30 years. To reach the general policy goal of a reduction of 76%, the gross energy use has to decrease until 934 kWh/m² over the service life of the building or 15,6 kWh/m² per year, represented by the red line on the graph. The first scenarios on the Pareto front that complies with this goal is a combination of 20 cm PUR floor insulation, 12 cm EPS wall insulation, 12 cm stone wool roof insulation, passive windows and replacement of the heating system by one with an efficiency of 84% and a system service life of 30 years. The required investment cost would be 42 984 euro and the LCC 53 715 euro. As the gross energy use for this scenario is close to the requirement of a maximum yearly energy use for heating of 15 kWh/m² by the Passive House standard, the green line on the graph, a reduction of 76% seems to be a very strict demand in this specific case.

As the case study already has 6 cm roof and wall insulation to date, the EPC score of about 240 kWh/m² is slightly better than the average for Flanders. To reach the EPC level A as proposed by policy, the gross energy demand has to be reduced by 42% to reach an EPC score of 100 kWh/m² corresponding with level A, indicated by the orange line on the graph. The first scenarios on the Pareto front that complies with this goal is a combination of adding 20 cm EPS floor insulation, 8 cm stone wool wall insulation and 12 cm stone wool roof insulation, without replacing the heating system. The investment cost for this scenarios would be 21 598 euro and the LCC 47 865 euro.

Further outlook

In this paper the policy goals for energy reduction are used as a guideline. As not only the energy use of the building, but moreover the materials used for insulating and renovating the building can affect the environmental impact (Allacker et al, 2012), an Environmental Life Cycle Assessment will be carried out in further research to get insight in the total environmental burdens and benefits of renovation. By doing so more insight will be gained in the environmental impact of the proposed renovation scenarios.

As the renovation scenarios leading to the lowest LCC seem to be insufficient to lower the energy use according to the required level, additional funding, extra loans or stepwise renovation could be considered in further research. Moreover the effect of more rapidly increasing energy prices would be interesting to study.

Conclusion

In this paper the effect of several renovation scenarios for social housing is studied. The aim is to get insight in the financial effect of an increased insulation level of the building envelope, a more efficient heating system and a combination of both considering the full service life of the building. Therefore the gross energy use and the LCC are estimated.

To include the influence of technological improvement during the service life of the building a dynamic approach is used. The dynamic approach assumes a better efficiency of the heating system when it is replaced during the building service life. It is examined whether this dynamic approach has an important effect on the estimation of the energy use for heating and on the LCC.

Looking at the gross energy use over the service life of the building, the dynamic approach clearly leads to a different gross energy use for heating the building compared to a static approach, especially for uninsulated or poorly insulated houses. The selection of the renovation scenarios leading to the lowest gross energy use is however identical whether the efficiency increase of the heating system is considered or not.

Although including the efficiency increase of the system in the assessment decreases the LCC, it has no effect on the selection of the renovation scenarios leading to the lowest LCC. From a financial point of view, the dynamic approach seems not to be relevant to select a certain renovation scenario. However, it can possibly affect the accuracy of the estimations of the reduction of the costs related to energy savings through renovation and hence lead to more correct estimations of financial benefits.

As the energy reduction related to the renovation scenarios leading to the lowest LCC is not compliant with policy goals, the required energy reduction is compared with the LCC of several renovation scenarios. By doing so the financially most efficient renovation scenario compliant with the policy goals can be selected.

Based on the average EPC score for housing in Flanders it is proposed by policy to reduce the energy use in buildings with 76%. In case this decrease is only achieved

by decreasing the energy used for heating, which is the approach taken in this paper, this requirement results in an energy demand for heating close to the Passive House Standard for this specific case study. As the EPC score of the case study building seems to be slightly better than the Flemish average, a decrease of 42% of the energy needed for heating the building should be sufficient to reach the EPC level A by 2050.

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Nomenclature

Table 4: Parameters of formula (1) to estimate SPV for heating cost.

HC_t	Heating Cost in year t (euro)
S_q	Surface of the element (m^2)
a_q	correction factor for transmission
R_q	Thermal resistance (m^2K/W)
$^{\circ}deg_q$	Equivalent degree days ($^{\circ}K.days$)
η	Global system efficiency (%)
p_t	Price natural gas in year t ($€/kWh$, incl VAT)
p_0	Price natural gas in year 0 ($€/kWh$, incl VAT)
d	Discount rate (%)
g_e	Growth rate energy prices (%)
g_m	Growth rate construction cost (%)
L	Service Life of the building (years)

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