Energy Renovation of Social Housing: Finding a Balance Between Increasing Insulation and Improving Heating System Efficiency

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Abstract. As the budget of social housing companies is limited, reducing the energy use of their housing stock to be compliant with current standards and actions plans is an important challenge. Currently social housing companies in Flanders often prefer replacing the heating system to insulating the building envelope due to the lower investment cost and easy implementation. However, the investment in better heating systems has to be repeated several times during the service life of the building. This paper provides insights in the investment cost and life cycle cost of both renovation strategies. Moreover an environmental life cycle assessment provides insights in the environmental impact of the renovation strategies. The analysis reveals that it is recommended to replace heating boilers not earlier than at the end of their technical service life, both from an environmental and economic perspective. Sensitivity analyses show that changes in the estimated remaining building service life and increasing discount rate lead to changes in the life cycle costs but have no influence on the ranking of the renovation scenarios. Changes in the energy price, insulation level and original building type lead to changes in the costs and ranking of the renovation scenarios.

1. Introduction

As the budget of social housing companies is limited, reducing the energy use and environmental impact of their housing stock to be compliant with current standards and actions plans in Flanders [1,2,3,4] is an important challenge. This can be achieved among other measures by investing in 1) thermal insulation of the building envelope and/or 2) more efficient boilers in the heating systems. To date social housing companies often prefer to replace the boiler due to the lower investment cost and easy implementation. In contradiction to building insulation, the investment in better heating systems has to be repeated several times during the life span of the building as the service life of the system is shorter. This paper aims at providing insight in the Investment Cost (IC) and Life Cycle Cost (LCC) of both mentioned renovation strategies and a combination of them, including the necessary replacements. An Environmental Life Cycle Assessment (E-LCA) is moreover added to provide insights in the environmental impact of the renovation strategies.
2. Description of the method

2.1. Calculation method of the life cycle financial and environmental cost

A Financial Life Cycle Cost (F-LCC) [5] is calculated to gain insight in the financial impacts of renovation. The F-LCC includes the investment cost of the materials used for the renovation measures including their installation and the Sum of the Present Values (SPV) of the cost for heating to compensate the transmission losses through the building envelope over the remaining building service life. Ventilation losses and solar and internal gains are considered to be constant in this paper as the data collection on these aspects is not yet finalised. The SPV of the heating cost is estimated using formula (1). The F-LCC of the replacements of the boiler are estimated based on formula (3).

\[ \sum_{t=1}^{n} PV[H\bar{C}_t] = \left(0.024 \sum_{q=1}^{w} \frac{s_q \cdot a_q}{R_q} \right) \cdot \delta_{eq} \cdot \frac{1}{\eta_c} \sum_{t=1}^{n} PV[p_t] \]  

with

\[ \sum_{t=1}^{n} PV[p_t] = \frac{1}{1+g_e}(\frac{1+g_e}{1+d})^{n-1} \]  

\[ I_n = I_0 \cdot \left(\frac{1+g_m}{1+d}\right)^l \cdot \left(\frac{1+g_m}{1+d}\right)^{l-1} \]  

Table 1. Assumptions of the parameters

| Parameter | Description | Unit | Value |
|-----------|-------------|------|-------|
| HC_t      | Heating Cost in year t (euro) | | |
| Sq        | Surface of each element (m²) | Input | |
| a_q       | Correction factor heat losses | Input [6] | |
| Rq        | Thermal resistance of element (m²K/W) | Input [6] | |
| °deq      | Equivalent degree days (K d) | input | 1200 [7,8] |
| η         | Global system efficiency (%) | | 1200 [7,8] |
| c         | Lower calorific value (kWh/m³) | input | 11.51 [9] |
| p         | Price natural gas (€/m³, incl VAT) | | 0.05 [9] |
| t         | Year | | |
| d         | Nominal discount rate (%) | | 2 |
| g_e       | Nominal growth rate energy prices (%) | | 3 |
| n         | Building service life (years) | | 60 |
| l         | Replacement cost boiler over service life of building (euro) | | |
| I_0       | Investment cost boiler (euro) | | 1500 |
| g_m       | Nominal growth rate investment and installation cost of heating system (%) | | 2.5 |
| l         | Service life of the heating system | | 20 |

The environmental impact of the renovation scenarios is assessed through a Life Cycle Assessment (E-LCA) [10,11]. More specifically, the Belgian LCA method for buildings and building elements [7] is used. In this approach seven impact categories, the “CEN” categories, in line with the European standard [12] and 10 additional impact categories considered in Belgian legislation [13], the “CEN+” categories, are considered. An aggregated single-score indicator is calculated based on monetary valuation of the environmental impact, expressing the E-LCA in euro, further referred to as E-LCC. This cost represents the costs to avoid or compensate the environmental impacts caused and is often referred to as external environmental cost. The monetization approach is described in an annex of the Belgian LCA method [14]. For the calculation of the E-LCC, a growth rate and a discount rate of 0 % is assumed. As it is the aim of this paper to get insights in both financial and environmental consequences of renovation scenarios, the F-LCC and E-LCC are studied separately, although they can be added up since both are expressed in euro.

2.2. Description of the case study and the renovation scenarios

The case study is a two storey terraced building considered to be representative for a large fraction of the social housing stock. In the front and back facade respectively three and four windows, each 1 m x 1.5 m, and one door, 1m x 2.2m, are provided, consisting of aluminium frames and double glazing.
with thermal interruption and a corresponding U value of 2.5 W/m²K. The floor of 56 m² is composed of a 15 cm concrete slab, 5cm cement based screed and ceramic tiles and has a U value of 2.89 W/m²K. The external walls (65.70 m²) are non-insulated cavity walls consisting of a brick veneer, loadbearing brickwork and an internal finishing in gypsum plaster with a total U value of 1.87 W/m²K. The flat roof consists of a 15 cm concrete roof slab with light weight concrete sloping layer and a bitumen roof covering with a total U value of 2.99 W/m²K. The production efficiency of the existing gas boiler is assumed 85 %, while for the efficiency of other system components (distribution network, emission and control system) the default values of the Flemish EPB standard [15] are assumed. The (remaining) reference service life of the building is assumed 60 years.

The renovation scenarios for the building envelope, with their investment and environmental cost are presented in Table 2. For the heating system the existing boiler is assumed to be (1) recent and is hence not renewed or 2) to be old and is replaced at year 0 by a new boiler with an efficiency of 97 %. For the first scenario, the boiler efficiency of 85 % is kept constant for the whole life cycle of the building. In both scenarios replacement of the boiler is included at year 20 and year 40, other system components are assumed to be preserved. All interventions are implied at one moment in time, stepwise renovation scenarios are not considered.

**Table 2. Overview of renovation scenarios for the building envelope**

| Thickness (m) | Financial cost (€/m²) | Environmental cost (€/m²) | U value (W/m²K) | Composition (excl. insulation) | Financial costs (€/m²) | Environmental cost (€/m²) |
|---------------|-----------------------|--------------------------|-----------------|--------------------------------|-----------------------|--------------------------|
| Floor on grade (F) |
| 0.05 |
| 0.10 |
| 0.20 |
| External wall (E) |
| 0.06 |
| 0.08 |
| 0.10 |
| 0.12 |
| 0.14 |
| Flat roof (R) |
| 0.06 |
| 0.08 |
| 0.10 |
| 0.12 |
| 0.14 |
| 0.16 |
| 0.18 |
| 0.20 |
| Windows (W) |
| U value (W/m²K) | Financial cost (€/m²) | Environmental cost (€/m²) |
| 1.5 | 542 | 43.60 |
| 0.9 | 650 | 52.80 |
3. Results and discussion

3.1. Financial impact of the renovation scenarios

In Figure 1 the IC and F-LCC for the various renovation scenarios are presented. The black dot and corresponding line on the graph represent the F-LCC of the existing building. Renovation scenarios focusing on the renovation of a single element are presented in red markers: insulating the floor (F), external walls (E) or roof (R), replace the windows (W) or replace the boiler of the heating system (H). Renovation scenarios of two elements are indicated in green and blue markers. Renovation scenarios of three elements in yellow and orange. Renovation scenarios of four elements in purple and finally renovation scenarios of all five elements are indicated in grey markers. As shown in Figure 1 the majority of the renovation scenarios lead to a lower F-LCC than the un-renovated building. However, not all renovation scenarios are equally interesting.

The dashed line in Figure 2, the Pareto-front, indicates how step by step an additional investment is leading to a maximal reduction of the F-LCC. All points to the right and above the line represent renovation scenarios that are less interesting as they have higher IC and F-LCC than the renovation scenarios on the Pareto-front. In this example the first point on the Pareto-front is insulating the cavity wall (red diamond). In case more budget is available only considering roof insulation (red triangles) is the best option. If an investment budget of 3 300 euro is available, a combination of cavity insulation and roof insulation (blue dots) leads to a lower F-LCC, more specific the scenario with 6 cm cavity wall insulation and 14 cm roof insulation lead to the lowest F-LCC. The renovation scenarios combining cavity insulation and roof insulation with a replacement of the boiler (orange triangles) request a larger investment (from 5 100 euro) and lead to a lower F-LCC. However, as the reduction of the F-LCC per additional investment is rather small (<1,5 %) they can be evaluated as less interesting.
Figure 2. Financial Investment and Life Cycle Cost of renovation strategies on Pareto Front

3.2. Financial investment cost to reduce life cycle environmental cost

To get insight in the effect of the financial investment in renovation on the environmental impact of the building, the E-LCA and Financial IC for the various renovation scenarios are presented in Figure 3. Again a combination of 6 cm wall insulation and 14 cm roof insulation is identified as the preferred option. The scenario combining wall and roof insulation with replacing the existing boiler leads to a higher E-LCA due to the high environmental impact of the boiler. Renovation scenarios where three, four or five elements are renovated lead to higher E-LCA because the impacts are not compensated by the reduced environmental cost for heating.

Figure 3. Financial Investment and Environmental Life Cycle Cost of the various renovation strategies
3.3. Sensitivity analyses of the parameters
To gain insight in the influence of various parameters on the analytical outcomes, sensitivity analyses were performed. The parameters building service life, energy price, discount rate, insulation level of the original building and building type were investigated.

3.3.1. Effect of the building service life. In case the remaining reference service life of the building is shorter, i.e. 30 years, more renovation scenarios lead to a higher F-LCC and E-LCC than the un-renovated dwelling. This is because the period to benefit from decreased heating costs is shorter and the latter cannot compensate the investment costs. The renovation scenario with 6 cm cavity wall insulation and 10 cm roof insulation is now the preferred scenario both regarding F-LCC and E-LCC. For a lifespan of 40 years, the scenario with 6 cm cavity wall insulation and 12 cm roof insulation is the preferred scenario. This means that the service life of the building has an influence on the costs of renovation scenarios but only minor on their ranking as a combination of wall and roof insulation is still preferred.

3.3.2. Effect of current energy price. In case the (financial) energy price is increased with 50 %, to 0.075 euro per kWh, the F-LCC increases importantly for all scenarios. Although the ranking of the renovation scenarios remains similar, the scenarios with a combination of wall and roof insulation with additional replacement of the boiler and the scenario with supplementary floor insulation become more interesting, as shown in Figure 4.

3.3.3. Effect of discount rate. In the original assumptions the financial discount rate was smaller than the growth rate for energy and construction prices. Due to changes in the economy the discount rate might increase and become larger than the growth rate for energy and construction prices. To investigate the effect of this change, a nominal discount rate of 4 % for the whole period is considered. Although the F-LCC of all scenarios is decreasing importantly, the ranking of the scenarios remains unchanged.

3.3.4. Effect of insulation level of the original building. To check whether the conclusions are also valid if the original building is better insulated, the following insulation thicknesses before improving renovating are assumed: 8 cm roof insulation, 6 cm wall insulation and 4 cm floor insulation. In this case the original insulation level is in line with the Flemish EPB regulation of 2006 [16]. The existing windows are compliant with the regulation 2006 and are therefore retained. In case the original building is better insulated, only replacing the boiler leads to a lower F-LCC than the current building state. Due to the environmental impact of the boiler and the materials used to insulate the building, all renovation scenarios lead to higher E-LCC.
3.3.5. **Effect of the building type.** As a last sensitivity analysis the renovation scenarios are analysed for a semi-detached and free standing building. For the terraced and the semi-detached building, the same renovation scenarios are on the Pareto front, following the same ranking. As shown in Figure 5, the inclination of the graph is identical for these two types, whereas the length is different. This is because the surface of the external wall is higher for semi-detached buildings, and therefore the effect of insulating the external wall is higher. For the freestanding building the first scenario on the Pareto front is replacing the boiler. As the thermal compactness (more building envelope per heated volume) of the freestanding buildings is lower compared to the terraced and semi-detached building, the investment of replacing the boiler by a more efficient one is not only smaller than investing in roof and wall insulation, moreover it has a bigger effect on the decrease of the (larger) energy use. For terraced, semi-detached and freestanding buildings a combination of 6 cm cavity wall insulation with 14 cm roof insulation remains the preferred option both regarding F-LCC and E-LCC. A combination of this scenario with replacement of the boiler leads to a further reduction of the F-LCC with 3 %, 4 % and 5 % respectively, while the E-LCC increases for all three building types.

![Figure 5. Financial Investment and Life Cycle Cost of renovation strategies on Pareto Front for terraced, semi-detached and free standing buildings](image)

4. **Conclusions and further outlook**

The insight of this paper may support social housing companies in the decision making process on the renovation of their housing stock. For the existing insulation levels cavity insulation combined with roof insulation proved to be the preferred renovation scenario from both an environmental and financial perspective. An additional investment to replace the existing boiler by a more efficient one at the moment of the intervention does not result in a significantly lower life cycle financial cost in relation to the additional investment that is required. This requires moreover a significantly higher environmental life cycle cost compared to wall and roof insulation. For these reasons replacing the boiler before the end of its service life can be regarded as unnecessary.

Sensitivity analyses clarified the influence of various parameters on the results. Decreasing the estimated remaining building service life influences both the F-LCC and E-LCC of the renovation scenarios, but does not change the ranking of the renovation scenarios. A higher energy price leads to significantly higher F-LCC for all scenarios. Consequently increasing insulation and replacing the boiler become more interesting, even additional floor insulation combined with wall and roof insulation and a replacement of the boiler seems to further reduce the F-LCC. A higher nominal discount rate (4 %) results in a lower F-LCC but does not change the ranking of the scenarios. In case the existing building...
is already insulated, even with minor insulation thicknesses, increasing the insulation level of the building leads to a higher F-LCC and E-LCC and are hence not recommended. Replacing the boiler has in this case a positive effect on the F-LCC. For semi-detached buildings the ranking of the scenarios remains identical, whereas for freestanding buildings replacement of the boiler becomes more interesting.

In a next step of the research reducing ventilation losses, controlling solar gains and considering different internal heat gains will be assessed. As the efficiency of heating systems has been increasing over the past years, the effect of those replacements on the energy use will be investigated along with potential changes in the energy source, for example conversion to renewable energy.

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