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Renovation of a Multi-family Building in Sweden – Analyses of Energy Savings, LCC, LCA and Co-benefits

Åke Blomsterberg[1], Rikard Nilsson[2]

[1]*Energy and Building Design, Architecture and the Built Environment, Lund University Box 118, SE-221 00 Lund, Sweden*

[1]ake.blomsterberg@ebd.lth.se

[2]*Construction management, Building and Environmental Technology, Lund University Box 118, SE-221 00 Lund, Sweden*

[2]rikard.nilsson@construction.lth.se

Abstract

To meet the energy and climate targets of the European Union the existing building stock must be very much improved. Within IEA EBC Annex 56 (Cost effective energy and carbon emissions optimization in building renovation) one of the main objectives was to provide best practice examples of renovations. One example is the demonstration of an energy retrofit of a typical multi-family building in Sweden, which needed a major renovation. The aims of this project were to determine the energy savings, life cycle costs, life cycle impact and co-benefits of a renovation. A substantial improvement of the standard of the building and a substantial reduction of the energy use were achieved. According to the owner of the building the energy saving measures are not profitable. A life cycle cost calculation according to the guidelines of IEA Annex 56 result in less poor profitability, using a lower cost of capital and a longer lifetime, which could be motivated from a societal perspective. However adding two floors with new apartments on top of the roof result in profitability the owner claims. A life cycle impact assessment from "cradle to grave" showed a reduction of greenhouse gas emissions. The use of primary energy showed a very small reduction. A better choice of materials used for the energy savings measures resulted in a reduction of primary energy. The main aim of the energy saving measures was to reduce the purchased energy and to improve the indoor environment.

Keywords; block of flats, energy retrofit, LCA, LCC, renovation

1. Introduction

In Sweden there is a substantial number of multi-family buildings built between 1965 -1975 i.e. the million homes program. Many of these buildings are now in need of major renovation and have a high use of energy. It is important that these renovations include major energy saving and efficiency improvements to ensure low operational and energy costs and low environmental impact during the remaining life cycle, which will be an important contribution to meeting the energy and climate targets of the European Union. It is important that the energy improvements of the buildings are realized at the same time as the buildings are being renovated in order to ensure that the measures can be carried out at a reasonable cost. Next major renovation might not occur for another 30-50 years. New methods for cost effective energy and carbon emissions optimized renovation of buildings are needed. Therefore IEA EBC Annex 56 (Cost effective energy and carbon emissions optimization in building renovation) was initiated.

Participating countries in the annex were Sweden, Switzerland, Italy, Austria, Denmark, the Netherlands, Spain, the Czech republic with the operating agent from Portugal. The objectives were to develop a new analysis and calculation methodology for cost effective renovation of existing buildings and simultaneous optimization of energy use and carbon emissions. The project will develop and offer methods, guidelines, recommendations and good examples on major renovations of mainly residential buildings. Co-benefits from energy retrofits such as reduced operating costs, improved comfort, increased property value etc. are to be evaluated. The target group is decision makers such as property owners/managers, architects, consulting engineers, clients, as well as researchers. The project will be finished in June 2016.

Good examples have been analysed and presented from the annex from Austria, Denmark, the Netherlands, Portugal, Sweden and Switzerland. To qualify as a good example the renovation must include a substantial reduction in energy use and environmental impact, and maintenance and standard improving measures. Often the starting point is a renovation due to need of maintenance. For Sweden three renovations of "million homes programs" buildings have been analysed and documented: Brogården in Alingsås, Backa röd in Gothenburg and Maratonvägen in Halmstad.

Some of the good examples were selected for more detailed analyses [1]. From Sweden Backa röd was selected and is presented in this paper.

2. Method

The aims of this project were to determine the energy savings, the life cycle costs, the life cycle impact and co-benefits of a major renovation. The energy use for different energy saving measures were calculated using a dynamic building energy simulation tool [2]. Life cycle impact (excluding transportation), life cycle costs (60 years, cost of capital 3 %, no inflation, no energy price increase), co-benefits and cost effectiveness (compared with the necessary maintenance renovation) were determined from cradle to grave using the methodology developed within IEA ECB Annex 56 [3]. The life cycle impact was estimated using Eco-Bat 4.0 [4].

3. Description of the Renovation of Backa röd

The good example on a renovation in Sweden is a demonstration project located in Gothenburg in the district of Backa röd, which consists of 1,574 apartments in high-rise buildings, low-rise buildings and low tower blocks built in the sixties and seventies during the 'million homes' program. The demonstration project involved one first building to be completely renovated. The owner wanted to gain experience for future major renovations. The building is a low tower block with 16 two bedroom apartments and 4 floors, built in 1971. The apartments have good floor plans, with generous and easily furnished rooms. However, the buildings needed to be renovated due to maintenance needs, as is the case for many 'million program homes'.

The buildings are typical for the sixties-seventies with a prefabricated concrete structure with sandwich facades panels, a triple layer wall. The facades were damaged by carbonation and were in need of renovation. The building was leaky, through the façade and between the apartments. Draught occurred from the infill walls at the balcony and cold floors were caused by thermal bridges from the balconies.

The buildings are heated by district heating. In each apartment there were radiators under the windows. The apartments were ventilated by mechanical exhaust ventilation without heat recovery.

The overall aim was to renovate and improve the standard of the building, to reduce the energy use and to improve the indoor climate.

The energy reduction was achieved by

- Additional insulation of the building envelope and new windows (see table 1)
- New balconies on freestanding supports to minimise thermal bridges
- Individual metering and invoicing of domestic hot water
- New radiator system with thermostatic valves.
- Installation of ventilation heat recovery.
- Installation of low energy lighting for fixed lighting.

Furthermore the renovation included:

- New water, sewage and electrical systems
- New bathrooms and kitchens
- New interior surface finish
- Safety doors for the apartments.
- Glazing of balconies

Table 1. U-values, W/(m²·K), before and after renovation

Element	U-value before renovation	U-value after renovation	Renovation measures
Exterior walls	0.31	0.12	Adding 195 mm of polystyrene
Roof	0.14	0.10	Adding 300 mm of loose fill insulation
Crawl space	0.40	0.10	Adding 500 mm of expanded clay
Base wall	0.48	0.30	Adding 100 mm of polystyrene
Windows average	2.40	0.90	New triple-pane low energy windows

4. Sustainability

Ecological/Environmental sustainability

The environmental impacts of the different materials needed for the energy renovation were calculated. "Total Primary Energy (CED)" in kWh/(m²·year), the "Non-renewable Primary Energy (NRE)" in kWh/(m²·year) and the "carbon emissions)" in kgCO_2-eq/(m²·year) were determined (see figure 1).

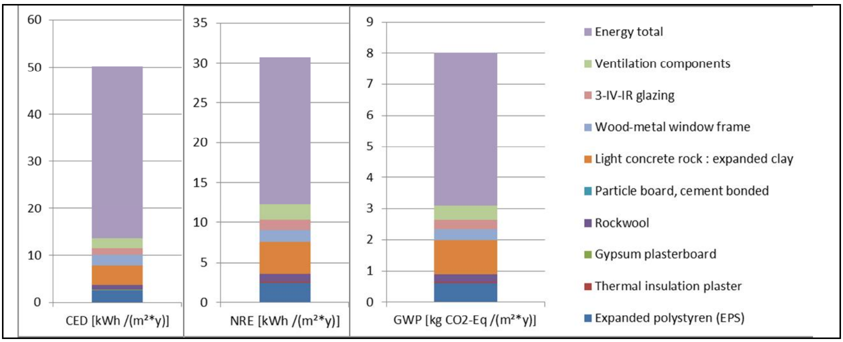

Fig. 1 Calculated "Total Primary Energy (CED)" in kWh/(m²·year), "Non-renewable Primary Energy (NRE)" in kWh/(m²·year) and the "carbon emissions" in kgCO_2-eq/(m²·year). m² = floor area.

The environmental impact of the materials used for the energy renovation during the lifetime is approximately 30-40 % of the total impact. The materials with the highest impact are the expanded polystyrene of the additional insulation of the façade, the expanded clay added to the crawlspace and the new windows. Improvement of the environmental impact is possible by modifying these materials (see 7 Life Cycle Assessment).

Economical sustainability

The actual costs have been divided by the housing company into refurbishment (1.55 million €) and energy efficiency measures (0.40 million €). The actual total costs are 1.97 million €. The investment costs consist of standard-raising measures (0.65 million €), operating cost reducing measures (0.19 million €). Costs which are paid directly are long due maintenance (0.90 million €) and energy measures with low profitability (0.21 million €).

The payback time of the energy savings is estimated to be 25 years. The housing company mainly focuses on the by the management required yield (profitability). Rent (before) was 75 €/m²/year including space heating and domestic hot water. Rent (after) was 102 €/m²/year incl. space heating excluding domestic hot water. A LCC-analysis with different assumptions is presented under 6. Life Cycle Costs.

Construction process

As for most of the energy saving measures new materials were added or replaced existing ones. For a building which mainly consisted of prefabricated elements, demolition should be fairly straightforward.

The renovation project was started in 2008 with a pilot study, that lasted five months. The first step was an evaluation using LCC analysis. Then followed the actual design work, which lasted six months, during which new LCC analyses were made. At the end of the design phase the design was approved at a board meeting of the owner. In April 2009, the actual construction work started and lasted for six months. After the scaffolding was erected, the entire building was covered by a tent. This ensured that most of the construction could be carried out during dry conditions avoiding moisture problems. The tenants were evacuated during the construction phase. The energy efficiency measures were developed in close cooperation between the consultants, the main contractor and the loose fill insulation contractor etc..

Building material

The recyclability of the chosen building material was not considered and not analysed in detail.

All construction products used for the renovation were products that meet BASTA's properties criteria. The aim of the BASTA system is to phase out substances with particularly hazardous properties from construction products. BASTA is a Swedish database with sustainable construction materials.

Special aspects of sustainability in the construction

The replacement of more short-living component layers without destroying the more long-living components is an aspect that has to be considered. During the construction or renovation phase it is recommended to integrate predetermined breaking points.

The construction of the façade shows a special aspect of sustainability regarding separability and dismantling. The new insulation elements were fixed on the existing building where the old exterior concrete hasn't been removed. This concrete can now be seen as a predetermined breaking point between the wall and the insulation. While removing the insulation the wall cannot be destroyed since the exterior concrete acts as a protective layer.

Sociocultural sustainability

According to a questionnaire before and after the renovation, the tenants perceive that

- Draughts from external walls and windows, and cold floors have been eliminated
- The room temperature is more comfortable, although it gets warm indoors at times in the summer.
- Unpleasant odours and noise levels have decreased

Only 4 out of 16 apartments were occupied by the same tenants after renovation. Some of the tenants preferred to stay in the apartments they were evacuated to during the renovation. A likely reason is the rent increase in the renovated building.

5. Energy use

The detailed monitoring of the building was started in 2010. The yearly energy savings thanks mainly to reduced energy losses and individual metering of domestic hot water was calculated to be 100 kWh/(m^2·year) (161-61) for space and domestic hot water heating, and facility electricity. The monitored reduction was 117 kWh/(m^2·year) (174-57).

After renovation the use of facility electricity has not increased in spite of more fans. The reason for this is the installation of energy efficient fans and energy efficient lighting in common spaces.

6. Life Cycle Costs

The owner made several life cycle cost calculations on their own. Their main goal was to determine cost efficient renovations with focus on lowering the annual costs. Therefore the focus on lowering carbon emissions and other environmental benefits was not of highest priority.

For their life cycle cost calculations the owner used the following requirements: cost of capital 6.25%, inflation rate 2.25%, life cycle cost period 30 years and yearly increase of energy cost of 2%. These requirements are different from the assumptions made here, according to the guidelines of IEA Annex 56 [3]. The cost calculations are based on a life cycle cost period of 60 years, inflation rate 0%, cost of capital of 3%, yearly increase of energy cost of 0%. Using these values could be motivated from a societal perspective.

The price for district heating varies over the year, however for the calculations a yearly average price (0.080 Euro/kWh) was used i.e. weighted according to the monthly variation in energy use.

The reference case includes air tightening and thin wall plastering of the façade, a new district heating substation, new radiators, and domestic hot water recirculation, which are for maintenance reasons, but only have a minor effect on the energy use. The façade renovation includes scaffolding, which is also needed for the realized renovation package.

The highest investment costs and but not the lowest annual costs occur for the realized renovation package, v3, which was a demonstration renovation to learn from. The annual cost increase is 7.7 €/m² of floor area (30 %) (see figure 2 and 3), from 25.5 to 33.2 €/m². Two alternative renovation packages were examined, one where the minimum requirements of the Swedish building code of 2012 for new construction are fulfilled (v1) and one which corresponds to the realized renovation package but excludes heat recovery on ventilation (v2). The last renovation package has similar annual costs to the reference case, 25.9 compared with 25.5 €/m².

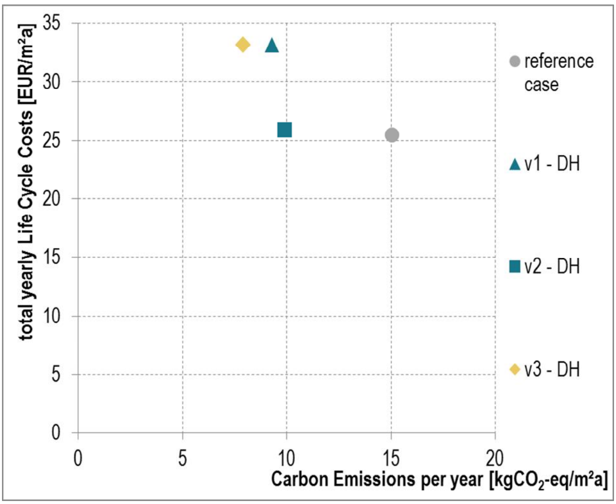

Fig. 2 Calculated total yearly life cycle costs vs. carbon emissions per year.

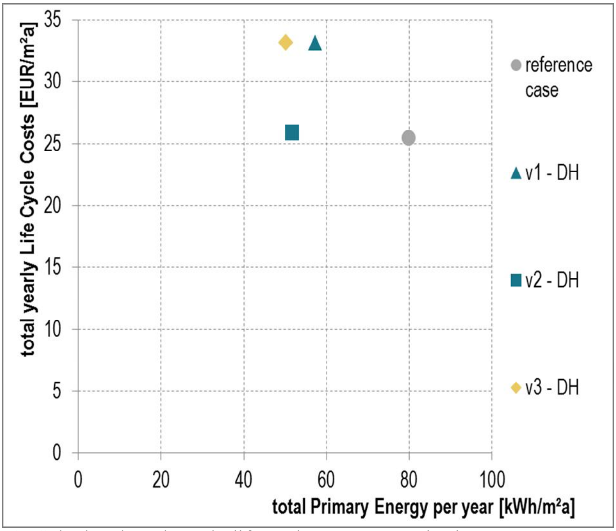

Fig. 3 Calculated total yearly life cycle costs vs. total primary energy per year

7. Life Cycle Assessment

The analysis included embodied energy of the materials used for renovation. Transportation was however not included. The only adaptation of the used tool was the inclusion of Swedish district heating, from Göteborg with 20% fossil fuel use. The used figures for energy use are a combination of measured and calculated results. The life span of the building after renovation was assumed to be 60 years.

All energy renovation packages reduce the final energy use, the total use of primary energy and the carbon emissions (see figure 2 and 3).

The realized renovation package reduces the final annual energy use by 65%, from 178 kWh/(m^2·year) to 57 kWh/m^2a. Half of the reduction is from building envelope energy saving measures and the remainder from BITS (building integrated technical systems) measures. At the same time the annual total carbon emissions are reduced by almost 50% (from 15 to 8 kgCO_2-eq/(m^2·year)), the annual total primary energy by 37% (from 80 to 50 kWh/(m^2·year)) and the annual total non-renewable primary energy is unchanged (31 kWh/(m^2·year)).

If e.g. thermal insulation materials, which are more environmentally friendly, had been used for the actually realized renovation package then the total use of primary energy would have been reduced by 41% and the use of non-renewable primary energy reduced by 10%.

The reference case and the executed renovation are based on district heating for space heating and domestic hot water, which applies to 91% of the multi-family building built been 1961 and 1975 in Sweden. 2% of the buildings use electricity for heating, 1% gas and 0.3% oil. The use of primary energy and the carbon emissions are much higher for those alternatives.

8. Improvements and co-benefits

Besides energy efficiency measures the renovation involved several other improvements. Examples are:

- New water and sewage systems installed instead of the old ones
- Hot water circulation installed
- New electrical installations installed instead of the old ones
- Bathrooms and kitchens renewed
- Change to parquet floor in living rooms and bedrooms
- New surface finish in apartments
- Safety doors for the apartments
- New extended glazed balconies, which also reduce the thermal bridges

Several of the energy efficiency measures also result in other benefits, co-benefits. Examples are:

- Draught, important aspect of thermal comfort, is almost eliminated thanks to the insulation of the entire building envelope and new windows that reduced air leakage.
- Thermal comfort is improved by the increased operative temperature thanks to the above mentioned improvement.
- Thermal comfort is improved by the improvement of the thermal insulation of the building envelope, the reduction of air leakage and the installation of mechanical supply, which to some extent pre-heats the air.
- External noise is reduced by the added thermal insulation and the improvement of air leakage.
- Indoor air quality is improved by the installation of balanced mechanical ventilation.
- Appearance of the exterior of the building is improved by the additional thermal insulation with thin plaster on the façade.
- The exposure to energy price fluctuations is improved by the substantial reduction in energy use.

9. Conclusions

The renovation was necessary due to wear and tear, which is true for many older buildings. The renovation resulted in a substantial improvement of the standard of the building, and a substantial reduction in energy use, while keeping a similar architectural appearance. The standard improvements included new installations, new bathrooms and kitchens, and new surface finish, which some of them resulted in an increased. The rent includes the heating costs. The energy saving measures included added thermal insulation to the entire building envelope, low energy windows, installation of ventilation heat recovery and individual metering of domestic hot water. The tenants have appreciated the improvements in thermal comfort, indoor air quality and noise climate.

According to the owner the energy efficiency measures have not been profitable, given the yield requirements of the owner (30 years perspective etc.). Even with a 60 year perspective the realized renovation package is not profitable. Other benefits, co-benefits, have to be taken into account, which are difficult to set a monetary value on.

Major energy renovations usually make sense only in buildings which need a major renovation, which was the case in this demonstration project and probably in many other buildings. The profitability of renovations increases for bigger multi-family buildings and if many buildings can be renovated at the same time.

The owner has therefore continued with similar energy renovations of five identical tower blocks in the same area. An additional feature is adding two floors with apartments on the roof. This way the profitability requirement of the owner is claimed to be met.

A life cycle impact assessment from “cradle to grave” showed a reduction in carbon emissions for the demonstration project, which was a pilot renovation to gain experience from for future renovations. However, an analysis of the use of primary energy shows a very small improvement. A better choice of renovation materials used for the energy renovation shows a reduction in primary energy. Hence it is important to choose the right materials.

The main aim of the energy saving measures was to reduce the energy paid for and to improve the indoor environment, which partly is a co-benefit of the energy saving measures.

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