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Vertical Extension of Buildings as an Enabler of Energy Renovation

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Abstract

We report on the study of six similar buildings built in an area of Gothenburg, Sweden, in 1971, which are now in urgent need of renovation. However, the owner of the buildings - a municipal housing company did not achieve a financially viable renovation of the pilot project. This meant that renovation on a similar basis for the remaining five buildings would not be possible. For this reason the housing company chose to undertake a vertical extension, by adding two floors with apartments on top of the existing buildings. This has improved the economics and made renovation of the five buildings possible. The objectives of this study are therefore, to show how a vertical extension can make a renovation of these buildings financially viable. We argue that a vertical extension can be applied to other similar buildings from this era. If vertical extensions could make more renovations possible this would lead to a significant impact on final energy use and carbon emissions. This case study has been supported by a site visit, interviews with the housing company and the contractor, document analysis, energy simulation and global warming potential simulation. Four renovation concepts are compared in order to find the most appropriate: minimalist, code-compliant, low-energy and low-energy plus vertical extension renovation. The conclusion of this study is that vertical extensions provide enough incentive to preform extensive energy renovations, which could reduce final energy use by more than 50%.

Keywords - Energy renovation; Life cycle analysis; Densification; Vertical extension of buildings

1. Introduction

In order to achieve the national energy targets, the Swedish building regulations (BBR) have been continuously revised in order to reduce the energy consumed by the building stock [1, 2]. However, these regulations mostly affect new building projects and not the existing building stock. Therefore, if Sweden wants to reduce its energy consumption by 50% by 2050, according to the European directive on the energy performance of buildings (EPBD) [3], housing companies have to proactively perform more energy efficient renovations or reactively face the risk of stricter policy instruments.

Studies have shown that energy renovations are possible for a majority of the existing building stock and that there are many different renovation measures which can be applied. Kost et al. [4] analysed energy efficient renovations in Switzerland in order to find financially viable solutions, however they showed that many energy efficient renovations were close to being viable. Verbeeck and Hens [5] developed a global methodology to optimize low energy buildings, but none of the concepts studied appeared to be financially viable with current energy prices. Boverket (The Swedish National Board of Housing) [6] showed that in renovation projects energy-saving measures that exceeded the building code requirements struggle to reach financial viability. These studies show that energy efficient renovations are possible but they are not always profitable. One measure which has not been studied before is low-energy renovation combined with a vertical extension of the building.

2. Aim

In this paper we report on six similar buildings in Gothenburg, Sweden, owned and operated by a municipal housing company (i.e. a municipality-owned, public housing company) and built in 1971. The reason why these buildings were chosen for the study is because the housing company wanted to undertake major energy renovation. However, the first building to be renovated, the pilot project, was not financially viable. The measure taken to make the project viable was a vertical extension of two floors.

The purpose of this paper is to reveal how a vertical extension could enable low-energy renovation even though it is not financially viable on its own.

3. Method

Four steps were involved: First, data are gathered for the six buildings and then four different concepts were identified and simulated: minimalist, code-compliant, low-energy and low-energy plus vertical extension renovation. Secondly, we use a life cycle analysis, similar to the one used by the municipal housing company, to analyse the four different concepts. Thirdly, the results from the life cycle analysis are presented. Finally, a discussion of results, the possible use of vertical extension in other renovation projects and the effects that low energy plus vertical extension might bring.

Data gathering include three interviews, two with the project manager from the municipal housing company and one with the site manager from the contractor company. We also had access to the housing company’s project server with containing the documents for both the pilot project and the vertical extension project. Additionally, we simulated the energy use with the dynamic building energy simulation tool, *VIP Energy* [7]. Finally, the global warming potential for each concept were calculated using *Eco-Bat 4.0* [8].

4. Four Concepts

The original buildings

Building part	*U [W/(m²K)]*
Exterior Walls	0.31
Roof	0.14
Crawl Space	0.40
Base Walls	0.48
Windows	2.40

Table 1. U-Values in the original building

The six buildings are in urgent need of renovation and are typical of those found in Sweden's "million homes program". The structure is prefabricated concrete elements. Over the decades, the concrete elements have been damaged by carbonisation and now leak. Moreover, attached balconies have been acting as thermal bridges because they are a part of the concrete slabs that make up the floors. The U-values can be seen in table 1. Furthermore, the ventilation system and windows have not been improved since the buildings were constructed. However, heating and hot water comes from district heating, which in Gothenburg is based on 81% renewable energy.

Minimalist renovation

The first concept is the minimalist renovation, where the main purpose to establish a reference for the other concepts. Every renovation must meet the requirements stated in the building code, but only if the renovation is extensive [1]. Since the minimalist renovation is more or less a large maintenance overhaul, it cannot be considered extensive. This means that this concept does not have to fulfil the requirements in the building code.

Minimalist renovation also includes an overhaul of the living standards without improvement to the building's energy performance and its technical systems. This would allow for a rent increase as the living standards of the residents are improved. However, it does not bring the improvements that an energy renovation would bring, such as a more stable indoor climate and better air quality. Therefore, the U-values are the same as in the original buildings, see table 1. A modest rent increase of 8.7 €/m²a is assumed. The global warming potential of this concept is 15.0kg-eq CO_2/m^{2}a and the final energy use is 178kWh/m^{2}a.

Code-compliant renovation

Building part	*U [W/(m²K)]*
Exterior Walls	0.17
Roof	0.15
Crawl Space	0.74
Base Walls	0.20
Windows	1.70

Table 2. U-Values in the code-compliant concept

The aim of the code-compliant renovation concept has been to simulate a building that embodies the building code requirements for newly constructed buildings or large renovation projects. The code requires the final energy use to be 80 kWh/m²a or lower [2]. However, when this case study was performed in 2014, requirement was 90 kWh/m²a, which is why 90 kWh/m²a is used in this paper. The main energy-saving measures were additional insulation of the building envelope (see table 3) and heat recovery from the ventilation system. Living standards are assumed to be slightly better in this concept than in the minimalist renovation because of the better indoor climate. Accordingly, the rent increase after the renovation is estimated to be 14.1 €/m²a. The global warming potential of this concept is 9.3kg-eq CO_2/m^2a and the final energy use is $90kWh/m^2a$.

Low-energy renovation

Building part	*U [W/(m²K)]*
Exterior Walls	0.12
Roof	0.10
Crawl Space	0.10
Base Walls	0.30
Windows	0.9

Table 3. U-Values in the low-energy concept

This concept was chosen for the pilot project and was completed in 2009. Since the pilot project has been occupied for a few years, it has provided actual performance data and, therefore, made it possible to check the simulations. This concept includes several major improvements such as additional insulation to the building envelope, ventilation system with efficient heat recovery, a new radiator system, individual metering of hot water and free-standing balconies. Basically, everything except the concrete frame was replaced and improved, e.g. bathrooms, kitchens and technical systems. This low-energy concept brings additional improvements to living standards with even better indoor climate and better air quality than in the code-compliant renovation. The rent increase for this concept is 17.3 €/m²a. The global warming potential of this concept is 7.9kg-eq CO_2/m^2a and the final energy use is $57kWh/m^2a$.

Low-energy plus vertical extension

Building part	*U [W/(m²K)]*
Exterior Walls	0.12
Roof	0.10
Crawl Space	0.10
Base Walls	0.30
Windows	0.9

Table 4. U-Values in the vertical extension concept

This concept was chosen for the remaining five buildings and is similar in performance to the low-energy concept with the only difference being the additional two floors. The extended walls have the same U-value as the low-energy concept walls even though they are infill walls with steel instead of prefabricated concrete walls with added insulation. There are some economic benefits with this concept because the construction costs can be spread out across all apartments. The rent increase in the existing apartments is the same as in the low-energy concept, 17.3 €/m²a. However, the additional rent from the added apartments is 13.5 €/m²a. The global warming potential and the final energy use of this concept is also the same, 7.9kg-eq CO_2/m^2a and respectively $57kWh/m^2a$.

5. Life Cycle Analysis

The housing company is evaluating their projects' financial viability using a life cycle analysis and only if an investment meets or exceeds the cost of capital will the project be realized. In this paper a similar analysis will be used, consisting of five steps: lifespan, investment, income, net present value and profit.

Step 1 - Lifespan

To calculate the technical lifespan for the buildings the life and the investment cost for each measure was compared to the total investment cost (see equation 1). Where *l* is the life span, *i* is the investment cost, *n* is the number of measures and *T* is the whole renovation concept.

$$\frac{l_1 \times i_1 + l_2 \times i_2 + \cdots + l_n \times i_n}{i_T} = l_T \quad (1)$$

Step 2 - Investment

The investments for the low-energy and the vertical extension concepts were identified using the project documents. Using this information together with *Wikells* [9] and *REPAB* [10] it was possible to calculate the investment cost for the remaining two concepts. *Wikells* and *REPAB* are cost data, for investment, operation and maintenance, gathered from the construction industry in Sweden.

Step 3 - Income

The income in this analysis consists of rent changes, operational savings and current net operating income. The changes to the rent for the low-energy and vertical extension concepts and the rent from the additional apartments were identified. However, the rent for the minimalist and the code-compliant concepts were our best estimates.

The operation savings include reductions from both energy and maintenance. The maintenance savings were identified from the project documents. Using the energy simulation we calculated the energy savings for each concept.

The current net operating income, i.e. from the buildings before renovation, was identified from the project documents.

Step 4 - Net present value

The net present value (NPV) of the rent changes (RC), operational savings (OS) and current net operating income (CNOI) are shown in equation 2. Where *l* is the lifespan and *p* is the discount rate, i.e. the cost of capital.

$$NPV = \sum_{i=1}^{l} \frac{RC+OS+CNOI}{(1+p)^i} \quad (2)$$

Step 5 - Profit

Dividing the net present value by the total investment cost results in a quota produces its long-term profit of the renovation. If this is greater than 1 the investment is financially viable.

$$\frac{NPV}{i_T} > 1 \quad (3)$$

The return on investment can be calculated by multiplying the profit by the discount rate.

$$\frac{NPV}{i_T} \times p \quad (4)$$

6. Results

Step 1 - Lifespan

Using the project documents the lifespans of the technical systems, building envelope, plumbing and fittings were identified as 15, 40, 40 and 30 years respectively. The same lifespan was used for all concepts. The investment costs for the vertical extension concept are: technical systems 95.5 €/m_2, building envelope 198.3 €/m_2, plumbing 146.9 €/m_2 and furnishing 293.8 €/m_2. By using equation 1 the technical life span is determined as a little under 33 years.

$$\frac{15\times95.5+40\times198.3+40\times146.9+30\times293.8}{734.5} = 32.8 \qquad (1)$$

It is likely that the building will, in 30 years or so, need further renovation to meet the needs of the future.

Step 2 – Investment

		Min.	CC	L-E	L-E VE
Investment [€/m²]	Building envelope	59,5	168,6	218,1	198,3
	Plumbing	181,6	181,6	181,6	146,9
	Technical systems	4,0	87,6	95,5	95,5
	Fittings	363,1	363,1	363,1	293,8
	Total investment	**608,2**	**800,8**	**858,3**	**734,5**

Min=Minimalist, CC=Code-compliant, L-E=Low-energy, L-E+VE=Low-energy plus vertical extension

Table 5. Investments in Euros per m^2 of floor area

As seen in table 5 plumbing and fittings are a lion's share of total investment. The investment of the vertical extension is included in the building envelope of the L-EVE concept. The improvements to the roof and the foundation are a large part of the building envelope investment and are the same in both L-E and L-EVE. Therefore the L-E concept will be more expensive than the L-EVE because the latter has a larger floor area. Moreover, the plumbing investment is also lower for the L-EVE. Since removing old plumbing throughout is expensive and no old plumbing have to be removed in the additional floors. The same is true for fittings.

Step 3 - Rent changes, operation savings & current net operating income

		Min.	CC	L-E	L-E VE
Rent [€/m²a]	Rent increase in existing appartments	8,7	14,1	17,3	17,3
	Rent from added appartments	0,0	0,0	0,0	13,5
	Vacancy risk	1%	1%	1%	1%
	Rent changes	**8,6**	**13,9**	**17,1**	**30,5**
Operation [€/m²a]	Energy use [kWh/m^{2}a]	178	90	57	57
	Energy savings	0,0	7,3	10,1	6,8
	Mantenance savings	1,7	1,7	1,7	1,2
	Operation savings	**1,7**	**9,0**	**11,7**	**8,0**
	Current net operating income	**13,5**	**13,5**	**13,5**	**9,2**

Table 6. Rent changes, operation savings and current net operating income in Euro per m^2 of floor area.

As seen in table 6, in the L-EVE where apartments are added, there will be additional rent. However, energy savings are lower because of the additional floors. In the Min. concept no energy savings are taken into consideration. Even so, one could argue that even a minimalist renovation would bring a minor energy saving from reduced heating and losses from the hot water systems, lighting and ventilation. Savings are greater in the more complex concepts because more insulation is added and more energy-efficient technology is installed. Maintenance savings result from new plumbing and fittings.

Step 4 - Net present value

	Min.	CC	L-E	L-E VE
Net present value	**442,5**	**678,7**	**789,7**	**888,1**

Table 7. Net present value in Euro per m^2 of floor area

Rent changes, operational savings and current net operating income are summarized and the net present value is calculated and presented in table 7. Other inputs are the 33-year lifespan and 3.8% discount rate; no residual value is assumed.

Step 5 – Profit

		Min.	CC	L-E	L-E VE
Result [EUR/m²]	Result	-165,7	-122,1	-68,6	153,6
	Profit	73%	85%	92%	121%
	Return on capital	**2,76%**	**3,22%**	**3,50%**	**4,59%**

Table 8. Result in Euro per square meter of floor area, profit and return on capital in percent.

The results presented in table 8 show that only the low-energy plus vertical extension renovation leads to a financially viable investment. The results show that it is not the operational cost savings that make a renovation profitable; instead, it is the rent change (increase) which contributes the most in achieving an economically-viable renovation. Note that none of the concepts would be viable without the current net operation income, i.e. the operation income from the building before the renovation.

It is important to know that the studied buildings had a few contextual conditions that might not be found in other cases. First, there was a lot of wear and tear and a lack of maintenance, thus a minimalist renovation would have been rather expensive. Second, the authors have estimated the rent changes in the existing apartments in each of the concepts based on the project documents and the expected benefits. Third, there was little insulation and many thermal bridges in the original building so any added insulation would reduce heating costs considerably. Last, to be able to compare the concepts we had to include improvements which in many cases would not be reasonable to include in a minimalist renovation, such as attention to the roof, façade and foundations.

7. Discussion

Our study has addressed the matter of whether or not vertical extension could increase the financial viability of low-energy renovation. The results show that, in this specific case, a low-energy plus vertical extension renovation concept leads to a higher return on capital compared to the low-energy concept and two other concepts.

There is an argument for not taking current net operating income into consideration because it is not a direct benefit of renovation. However, current net operating income has a major impact on the results of the life cycle analysis and also enables more renovation concepts to be considered. Current net operating income can, however, create the illusion that minimalistic renovations are almost as attractive as more-extensive renovation concepts.

From the perspective of the housing company, the pilot project, similar to the low-energy concept, did not meet the cost of capital of 3.8%. Adopting the vertical extension concept makes the renovations financially viable and so the housing company can continue to renovate the remaining five buildings. Since renovation will lower final energy use by 68%, from 178 to 57kWh/m^2, it will contribute with a yearly energy saving of almost 6GWh, calculated without the additional apartments from the extension.

Considering that the studied buildings are typical of those from the "million homes program" it would be reasonable to assume that there are possibilities for similar renovation concepts elsewhere. Many of the buildings from the "program" have an oversized concrete structure, which might be able to support a lightweight extension made of timber or steel. Moreover, many buildings from that period are also in need of renovation after 40-50 years of occupancy.

From a national perspective, an energy saving of 6GWh would not make a significant contribution to the 2020 or 2050 targets. Even so, similar renovations would, on a larger scale, result in a significant energy saving. From an environmental perspective, the vertical extension concept would reduce the renovated buildings' annual global warming potential by almost 47% and annual final energy use by 68%.

Energy renovation and vertical extension can together improve our energy efficiency; densification also reduces the urban footprint. Both initiatives are being encouraged by policymakers [11], [12], [13]. The authors agree that, although low-energy plus vertical extension renovation might bring many benefits, it is not the optimal renovation concept for every situation.

8. Conclusion

In this paper, we have shown that a vertical extension can provide enough incentive to undertake an extensive renovation. In the buildings we studied, the housing company successfully reduced energy use by 65% and the investment value exceeds its cost of capital. We have argued that similar renovation projects could be undertaken for other buildings from the 1960s and 1970s. If so, it means that renovations based on low-energy plus vertical extensions would use less energy and increase the number of apartments without expanding the urban footprint.

However, this study is limited and the buildings studied might have preconditions that are uncommon. Further studies are required to determine if the vertical extension of buildings is an enabler for energy renovation.

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