Renovating the Housing Stock Built Before 1945: Exploring the Relations Between Energy Efficiency, Embodied Energy and Heritage Values

Paula Femenias, Liane Thuvander, Pär Johansson, Paula Wahlgren and Petra Eriksson

Abstract Swedish multi-family buildings constructed before 1945 constitute an important part of the national built heritage. However, the majority does not have a formal heritage protection. Part of this building stock has already been renovated, notably through earlier energy saving programmes where additional exterior insulation, new façades and windows were frequently installed with little consideration for the original architecture. Now, 40 years later, these buildings face new renovations. This provides opportunities to improve the energy efficiency, indoor climate and user comfort. At the same time, the original architectural and historical characters lost in previous renovations could be recreated. In this paper, an inter-disciplinary research team illustrates the challenges met in practice to reach a sustainable renovation based on three cases. The case buildings are so-called "Landshövdingehus", constructed in the 1930s and owned by a public housing company. The relations between building physics, energy efficiency, embodied energy, and the effect on heritage aspects in renovation are studied. The results demonstrate the potential to reach 30% calculated energy efficiency without investing in ventilation systems. When comparing embodied energy to savings in operational energy a short payback time is achieved. However, focusing on the replacement of windows, the cases illustrate difficulties to recreate heritage values at same time as achieving an air-tight and energy efficient construction. In order to improve the results from the heritage point of view, there is a need for quality assurance of the renovation and building permit process.

Keywords Multi-family buildings · Energy efficiency · Embodied energy
Heritage values · Value conflicts

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1 Introduction

Swedish public housing owners must conform to European, national and local directives to reduce the energy use in their existing stocks. Energy savings can be addressed through an overhaul of systems and installations but can also require improvements of the building envelope. To reach cost-efficiency, energy saving measures are often planned in relation to extended maintenance and renovation [1]. Energy saving renovations involve a number of conflicts between different objectives, stakeholders and value areas which need to be considered when choosing a renovation strategy: the conflict between architecture, heritage values and energy savings [2, 3], the landlord-tenant dilemma, i.e. the distribution of value and costs as a result of renovations [4], or the relation between the decreased operational energy and the embodied energy of the added building materials in a renovation project [5].

In this paper, we focus on renovation of Swedish multi-family buildings constructed before 1945. These buildings constitute an important part of the built heritage. However, the majority does not have a formal heritage protection. A share of this stock has already been renovated, notably through energy saving programmes in the 1970s and 1980s. These energy renovations usually involved additional exterior insulation with a new façade and new windows. The alterations were frequently applied without consideration of the original architecture. It also appears that many renovations were carried out to compensate for neglected maintenance and to reduce the need for future maintenance, for example, by replacing wooden façades with corrugated metal sheets. Now, after 40 years, these buildings face new renovations as part of their maintenance cycle. This provides the opportunity not only to improve the energy efficiency but also to recreate or restore original architectural and historical characters lost in previous renovations.

Based on three case buildings, the paper illustrates how renovation measures will affect moisture safety, energy efficiency, embodied energy, and heritage values. The research is carried out by an interdisciplinary team involving architects, building physicists and a building conservator. The research is still on-going and what is presented is work in progress. The overall objective of the project is to provide a basis for guidelines about energy renovation of this part of the housing stock. The end-users' perception is studied in the research project but not presented in this paper. The research aims at enriching the knowledge base about viable and sustainable renovation strategies for historic buildings by extending the discussions beyond a domination of building conservation and energy saving criteria [6].

2 Method

The overall method is a case study with rich data descriptions and what can be regarded as typical cases with potential for replication [7]. Studies have been carried out post-renovation (Case A and B) to compare results before and after renovations.

The cases are part of a systematic development carried out by the public housing company Bostads AB Poseidon in Gothenburg in search for renovation solutions to be used as reference or prototype for housing stocks constructed before World War II. These buildings need measures addressing energy saving and improved indoor climate, which also permit the transformation of existing attics to additional apartments and rentable space. There is a high interest in transforming attics into apartments due to a general housing shortage in Sweden.

We have studied three blocks built in the 1930s, case A–C. Case A recently went through a renovation of the building envelope with new windows and additional exterior insulation of walls and the roof. The exterior insulation method permits the creation of new apartments in the attic. This possibility is not explored in Case A due to the small size of the attics in that building, but can be used in other part of the housing company's stock. In Case B, only an interior insulation of the attic/roof was performed together with installation of new windows. Case C is proposed to be renovated using the same concept as in Case A and is used as a reference for the status of the buildings before renovation. More information is found in Table 1.

Table 1 Overview of Cases A to C

Building	A	B	C
Year of construction/ renovation/ re-renovation	1937/1970/2015–2016	1939/1976/2014	1938/1970
Number of apartments	36	12	30 + 30
Attic	Insulated on the outside with 100 mm phenolic foam insulation, mineral wool at the wall to roof connection	Insulated on the inside, loose fill insulation, careful sealing	Ventilated cold attic, new roofing and a non-insulated outer roof
Windows	U-value new windows 1.1 W/m^{2}K. U-value old windows in the range of 3 W/m^{2}K	U-value new windows 1.1 W/m^{2}K. U-value old windows in the range of 3 W/m^{2}K	U-value existing windows in the range of 3 W/m^{2}K
Façade	Added 70 mm mineral wool, 25 mm ventilated air space. New façade with wooden boards and battens. Plastered ground floor	Façade repainted, wooden panels on all three floors	Asbestos plates on wooden boards on the two upper floors, bottom floor plastered
Heated area (m^2)	2,674	755	4,090
Energy use (kWh/m^2)	Before renovation 154[a] After renovation 93 (calculated)	Before renovation 182[a] After renovation 130[b]	Today 169[a]

[a]From EPCs

[b]Based on the delivered heating energy. 24 kWh/m^2 was added for energy use for hot water production and property electricity to enable comparisons

An inventory of the case buildings was made using different methods. Energy figures before the renovations were collected from energy performance certificates (EPC) and calculated figures for the energy use after the renovation were provided by the housing company. Information about renovation measures with respect to thermal performance, airtightness (thermal comfort), heritage values and aesthetics have been studied through observations, drawings and documents and interviews with involved actors. Data on the materials used for the renovation were provided by the contractor. For the assessment of heritage values, we have focused on visual aspects of the exterior appearances and the historical authenticity with reference to generic elements of heritage valuation [2] and to the heritage preservation programme of the City of Gothenburg [8]. The embodied energy of building materials has been calculated for building A, defined as the total primary energy use for the extraction, processing, manufacturing, delivery of building material to the building site and construction. The input data is generic from databases such as Ökobilanzdaten im Baubereich. Comparisons have been made for a 50-year scenario, including maintenance, indicating the break-even between savings in operational energy and embodied energy of the renovation.

3 The Case Buildings

The case buildings, constructed between 1937 and 1939, are located in Gothenburg and of the type “Landshövdingehus”, a local recurrent housing type originally built for working class citizens, with one floor in brick or stone and two floors in wood. In the area of the case buildings, the influence by emerging functionalistic ideals of the 1930s is visible in few decorations and that they are constructed as lamella blocks in a strict parallel order breaching with the earlier typology of Landshövdingehus constructed around closed courtyards.

Although many buildings in the neighbourhood of the case buildings have façades altered by renovation, the area is identified with heritage values in the heritage preservation programme for the built environment [8]. The motivation for the heritage values is that the urban plan is a clear example of the functionalistic ideals and, in Gothenburg, the last large area built with “Landshövdingehus” (Fig. 1). Case A and B were specifically designed for families with many children and thus also has a value from a sociohistorical perspective.

In 1970, the façades of case Case A and C (Fig. 2) were covered in asbestos boards to reduce maintenance costs. No insulation was added. In the 2010s, renovations of Case A and B were initiated due to high energy use. In Case A, exterior insulation was added to the façades and the windows were replaced. Initially the housing company wanted to replace the asbestos façade with a new board material. After negotiations with the city planning office, a wooden façade was chosen instead, with the goal to reconstruct the appearance of the original façade. For the roof, a solution with exterior insulation was chosen. One advantage with this solution is that the tenants do not have to empty their attic storage during the renovation process.

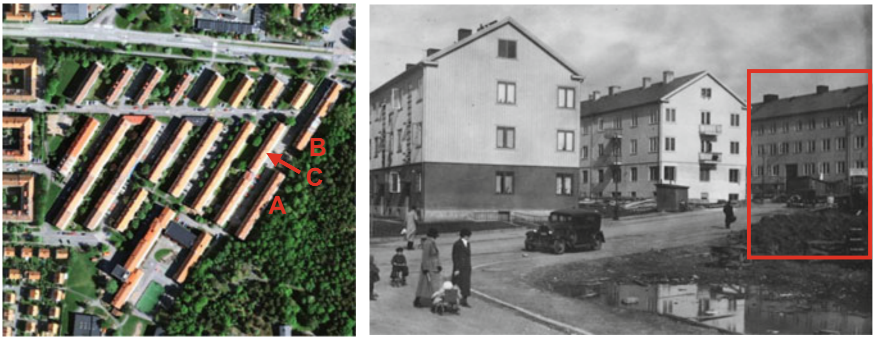

Fig. 1 The housing area today and in the late 1930s. Case B can be seen in the upper right part. Case C has not yet been built. Photo: Eniro (left), and Gothenburg city museum (right)

Fig. 2 Façade of Case A after the reconstruction of the wooden façade (left), Case B with unchanged façade (middle), and façade of Case C with the asbestos boards from 1970s (right)

In Case B, an alternative to the renovation method used in Case A was tested applying an internal insulation of the attic and replacing the windows. The status of the case buildings and the measures for the latest renovation are presented in Table 1.

4 Results and Discussion

Energy savings have mainly been achieved by insulating the thermal envelope. The heating and ventilation systems are unchanged, i.e. hot water radiators are connected to district heating and the ventilation is based on natural ventilation (stack effect and wind). After renovation, the indoor air temperature has been monitored in the different apartments (sensors placed on an inner wall in the living room).

In Case A (most recently renovated), the indoor temperatures are substantially higher than in Case B. As an example, 23 of February 2017, the outdoor temperature was 5 °C, and the indoor temperatures were ranging from 20 to 26 °C in Case A compared to 19–22 °C in Case B. However, overheating has decreased (in top floor) after insulating the attic in Case B. After the renovation in Case A, the energy use is expected to decrease from 154 to 93 kWh/m^2 (calculated). Additional savings are expected when the heating system is adjusted to the new indoor conditions.

4.1 Insulation, Windows and Outer Façade Measures

The largest renovation was made in Case A where the attic was insulated from the outside with 100 mm insulation (vapour open phenolic foam, $\lambda = 0.020$ W/(m K), system Clima Comfort, Monier) with an outer ventilated air gap under brick tiles, see Fig. 3. Walls were insulated with 70 mm mineral wool on the exterior.

The new windows are pivot windows with a U-value of 1.1 W/m^2K. The windows were, with respect to the original façade from the 1930s, placed in line with the outer wooden panel except for the ones in the basement (masonry walls). They were left in their original position because of the storage rooms in the basement and that moving the tenants' belongings for this operation was considered too complicated and costly. The new placement of the windows in the wooden walls proved to be difficult as it left an uninsulated air gap around the window causing problems with both conductive and convective heat losses. It is essential for energy, thermal comfort and moisture protection to have a good air barrier when renovating.

Fig. 3 Detail of the roof to wall connection and the wall design (left, building permit, 2015-04-09), Case A with recessed windows in the basement floor (middle) and new doors (right)

In Case A, one part of the building had an air barrier (wind barrier on the exterior) and one part lacked air barrier. In order to investigate how this affected the airtightness, one apartment of each type was tested (airtightness and air leakage search). The apartments had similar measured airtightness rates and penetrations were a large cause of air leakage (for example air inlets that were not properly connected). There were draught and cold surfaces around the windows (in total 8 examined windows). All windows except one had been changed and the original window was the only one without leakages. The fitting of new windows during renovation has often been proved problematic with respect to airtightness. Since there were leakages around several windows, the sealing was redone and extra sealing was applied using expanded polyurethane on the exterior and extra joint sealants on the inside.

The details in the original panel were more in proportion and thought through than the details on the new façades. The original panel is equipped with both window ledge and a decorative transition from panel to ground floor, while Case C only has window ledge. Almost all windows in the three buildings have been replaced and it is no longer possible to find original window settings and boards.

4.2 Operational and Embodied Energy

Case A has been used for a comparison of operational and embodied energy. To assess the impact of the embodied energy, the whole renovation process was studied, including raw material extraction and transportation, manufacture, transportation of building materials to the building site and construction work. Generic input data from sources like Ökobilanzdaten im Baubereich were used [9]. The operational energy was estimated using data from the EPC before renovation and calculated energy use data after renovation. The weight of material that was used or removed during the renovation were provided by the contractor.

The quantity of removed and added new materials reflects the main changes in the renovation. In Table 2, the top five materials (in terms of weight) that were removed or added are listed. The climate impact of the waste material only refers to

Table 2 The five most used components/materials in terms of weight during the renovation

Component	Material	Removed material (kg)	New material (kg)	Life span (year)
Roof tiles	Clay	38,600	35,640	30
Plaster	Plaster (gypsum)	22,500	22,500	30
Wood panels	Pine wood		16,360	30
Roofing frame timber	Pine wood		13,280	50
Windows	Glass, pine wood, aluminium	11,100	10,930	30

the transportation of the material (no production), and this is estimated to be less than 6% of the total embodied energy added during the renovation. Furthermore, the amount of embodied energy from manufacturing is strongly dependent on the choice of database [9]. In particular wood data is very different in the databases and, consequently, wood can be estimated to have a very large, or a minor, effect on embodied energy.

In terms of weight, roof tiles and plaster are important, but they have a relatively low impact on the embodied energy from the manufacturing process. On the contrary, insulation materials represent a small amount in terms of weight, but have a large impact in terms of embodied energy. As an example, insulation is 6% of the added material weight and 9% of the embodied energy. Roof tiles is 30% of the added material weight and 7% of the embodied energy. Windows, doors and balconies represent almost 25% of the embodied energy due to manufacturing of new materials.

The payback time (with respect to embodied and operational energy) of the studied renovation is estimated to 1–2 years using four different databases. Results from the Ökobilanzdaten im Baubereich database are shown in Fig. 4 (payback time 2 years).

4.3 Architectural and Heritage Values

In the early discussions for the building permit in Case A, the city planning office emphasised on a reconstruction of the original wooden façade with reference to the heritage protection programme and by indicating a quicker handling process. The wooden façade would be more expensive than the initial idea of using a board

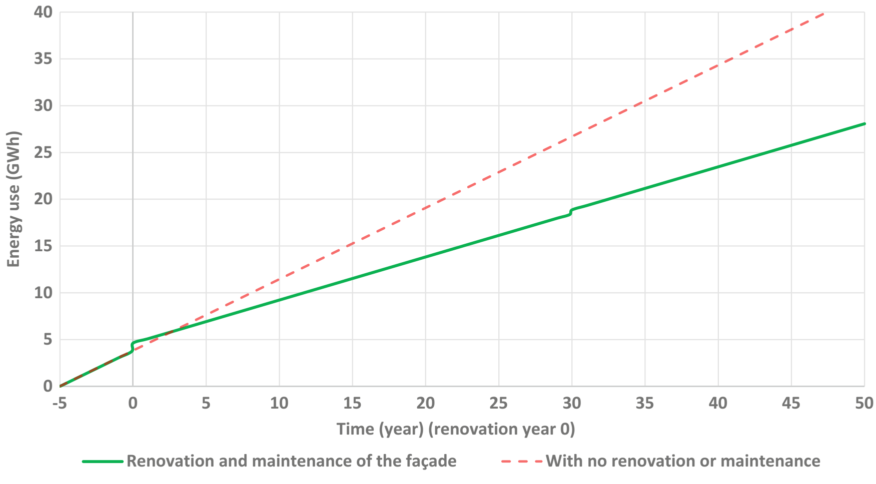

Fig. 4 Primary energy use for Case A over a 50-year scenario estimated with the Ökobilanzdaten im Baubereich database

material, but the property owner managed to get the tenants and the tenants association (responsible for rent negotiations in Sweden) approval for a small rent increase of approx. 25 €/month or just under 5% with reference to several value-additions for the tenants e.g. better indoor comfort due to new windows and new outdoor areas. The renovation process was halted for two years before an agreement with the tenants was reached.

In the design of the new façade no inventory of the original façade under the asbestos boards were carried out. The city museum was not approached and no building conservation officer was consulted. The design was made by an architect who searched inspiration from the surrounding area proposing a yellow wooden façade with laths covering the interstice between the wooden planks (as is found on for example Case B) and a grey coloured basement. The original façade revealed in the demolition showed a pale green colour and without any covering laths. However, according to the contractor, such a smooth surface would anyway have been difficult to recreate with contemporary material and production methods. The heritage preservation programme gives no detailed guidance regarding the façades, focusing instead on the importance of keeping the original urban plan. A heritage inventory carried out by the city museum in 1979, after the façade of Case A and C were covered in asbestos, proposes the original façades to be recreated, a wish that is now carried out.

The architect proposed the existing double casement vertically hinged windows to be recreated. These were also to be aligned with the new outer limit of the façade, not to create deep window sills, which is an important characteristic of local traditional housing. No detailed drawings were provided by the architect as the contractor took over the design as part of a design-build contract. The client, maybe out of concern for cost or future maintenance, instead choose pivot hanged windows with a false mullion to recreate the visual of a double casement window. The same kind of windows had earlier been chosen for the renovation of Case B. The choice of windows largely lowers the overall architectural impression of the buildings and is not true to the original heritage characteristics.

5 Conclusion

The renovation strategies in Case A and B demonstrate an interest in finding renovation solutions for public housing where heritage values are protected or even recreated. At the same time a substantially lower energy use is reached without investing in ventilation systems that usually also lead to necessary interior changes. The renovation strategies are also good choices with respect to the short payback when comparing embodied energy to savings in operational energy. While the strategy used in Case B has the advantage of being smaller and less resource intensive (with reference to material use), the thermal comfort is potentially better in Case A due to the insulated walls, which is also of importance.

However, in practice, there have been problems to reach the goals. In Case A, the calculated energy, has yet to be reached. There have been difficulties to achieve an air-tight construction. Partly, the higher energy use (compared to calculations) might also be explained by unnecessary high indoor temperatures. As for the windows, our studies illustrate problems to reach heritage and energy goals. Since the U-value of the window affect energy use, in Case B it might have been possible to improve the U-value without changing the whole window. Keeping the original windows would have been of interest both from a heritage perspective and from thermal comfort perspective. In Case A, additional insulation is added to the outside of the façade and the window location is adjusted for heritage and aesthetical reasons. There were substantial difficulties to achieve good airtightness around the windows (and prevent draught) in their new position, and to avoid large thermal bridges. The construction company would have preferred the original position of windows. Our results point to a need of adequate detailing in drawings, and instructions for the construction workers.

The housing company initiated Case A and B to test and evaluate renovation strategies for this part of their stock. The company considers the roof renovations having potential for replication in renovation of the remaining stock from the same construction period. An example of their learning process is an improved roof solution for Case C, where a more simple and cheaper roof solution than Case A is discussed.

However, the company still have some improvements to make regarding learning and innovation. The former energy strategist and a property engineer have left the housing company. This is problematic since documentation of the building process is somewhat sparse which makes renovation information dependent on staff knowledge. Therefore, processes for documentation during and after renovation projects need to be improved.

Finally, with respect to protecting and recreating heritage values in renovation, the cases point to the need for quality control in the building permit process. The final choice of windows should have been supervised by the city planning office that, when needed, can bring in building conservators as expert support. Detailed drawings of the windows should have been requested in order to assess the impact from a heritage point of view.

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