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Renovation of buildings from before 1945: status assessment and energy efficiency measures

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Abstract

This paper presents inventories of building components and renovation measures in buildings from before 1945. External inventories with focus on durability, moisture performance and energy performance were made on 602 properties by building physicists, architects and building antiquarians. In addition to these, results from in-depth inventories were collected from 94 properties. The in-depth inventories also included cultural historical values and the interior status of buildings. The collected data showed that there is a lack of knowledge about the status of the building at the property owner. To suggest the most optimum energy efficiency and renovation strategy more information is needed.

Keywords: retrofitting; energy efficiency; building stock inventory; vacuum insulation panels; hydrofobic surface treatment

1. Introduction

The majority of the buildings in Sweden were constructed more than 40 years ago. They were typically designed for a service life of at least 100 years. During this time there is a need for several major and minor retrofits and also for continuous maintenance of the building envelope due to degradation by natural aging, incidental damages, or because of outdated building techniques. To optimize the timing and selection of retrofitting measures, reliable information about the state of the existing construction and materials in the building is crucial. This information is needed by the architect, designer, contractor and building owner so that they can plan both small and large retrofitting

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measures. However, this information is often incomplete or not readily available because there is no praxis to systematically document and to keep record of the changes made in a building. Instead, decisions on renovations are based on in-situ inspections and due to incomplete information, they may differ depending on by whom and when inspections are performed. In many cases the available information about the technical status of the building is only relying on the knowledge and experience of the facility manager. The Swedish National Board of Housing, Building and Planning (Boverket) concluded that out of 1 800 investigated buildings, 40% had technical documentations that could not be used [1]. The most common cause for renovation is that there is an acute need, or that different components have reached their end of service life [2]. In these cases, the time for planning and implementing the retrofitting measures is limited. Therefore, the optimal solution might not be chosen, neither from service life perspective, nor from life cycle cost perspective. Thus, more knowledge is needed as a basis for decision support.

Due to a lack of general decision support tools for systematic in-situ service life assessment, it is not possible to properly plan when, why and where renovation measures have to be put in action. According to the BETSI study [3], 29% of the buildings in Sweden have mold growth in the building envelope (foundation, attic, exterior walls). To repair all failures, investments of 230 to 330 billion SEK (€ 24-35 billion) are needed. There are many examples of problems resulting from a lack of knowledge about how heat, moisture and air are transported and stored in building constructions, especially after renovations. There is a delicate interaction between temperature and relative humidity in structures. A reduction of the temperature in a construction can result in a high relative humidity (with subsequent performance problems) or increased air movements, which also can cause problems. An energy efficiency measure may also enhance thermal bridges and cause surface contamination due to increased air movement. By implementing preventive actions at the right time, by having efficient renovation strategies, funds can be used more efficiently leading to better performing buildings and more satisfied users.

2. Overall aim of project and previous outcomes

The aim of this study is to evaluate the long-term effects of energy-related renovations carried out during the period 1975 and onwards in the pre-1945 housing stock focusing on a selection of building typologies. Many property managers are taking actions to decrease the energy use and prolong the service life of their buildings. Therefore it is of greatest importance to provide guidelines and good examples of successful retrofitting measures from Sweden and elsewhere. In this part of the study, the aim is to evaluate the technical status of the thermal envelope (U-values, thermal bridges, air tightness) in relation to cultural values. This is done by using existing data from a combination of field inspections (e.g. mold and algae growth, thermography, crack width and moisture measurements) and databases of building stock data for the City of Gothenburg, Sweden. Three databases were used to find relevant buildings; the database of energy performance certificates (EPCs), the national property register (PR) and geodata from the City of Gothenburg. The project uses data provided from a large infrastructure project in Gothenburg where a railway tunnel will be built under the central parts of the city. There are ongoing building inventories, monitoring and documentation that are performed before, during and after the construction. The detailed investigations and monitoring programs are enforced by Trafikverket (Swedish transport administration) for buildings in proximity to the excavations. The durability assessment in the project is based on ocular inspections of building envelopes (crack width, thermography, moisture content, etc.). The development of the research methodology and three case study buildings were presented by Johansson et al. [4]. Based on the situation and building typologies found in Gothenburg, and the problems related to durability found in this stock, Johansson and Wahlgren [5] showed how different critical details were solved in the past and identified possible case studies. In this paper the aim is to present what knowledge can be derived from the work done so far by investigating common renovation measures.

3. Performance indicators/criteria

In research the last years focus has been on energy efficiency with little attention to the long term performance and durability in other aspects such as indoor environmental quality, thermal comfort and moisture safety. The users of the building have demands on a good and healthy indoor environment, but also the society demands that the building shall perform according to certain standards. These are often given in building codes, where for example the allowed energy use for heating is defined together with other performance criteria. Some performances are easily followed up and validated by using measurements of, for example, the energy use and indoor temperature, which are compared to the performance criteria. Other performances, such as moisture performance, of the building envelope, are more difficult to control and follow up because of the lack of adequate performance criteria as well as of appropriate control techniques. For these cases, performance failures are discovered first when there is a visible damage to the construction or when there are complaints from the users (unpleasant smell, damp air, etc.). At that stage it is too late to implement preventive actions to avoid costly repair work.

Recently, much progress has been made in the development of computational tools and performance criteria for risk assessment of building envelopes, in particular moisture risk assessment. For example, the mold growth index [6] is a relatively new criterion that indicates elevated moisture contents in ventilated constructions (cold attics, crawl spaces, etc.). However, practical methods for evaluation of expected service life are still lacking. A practical method should be able to predict the expected service life based on the current status of the building envelope, even when the history of the building is unknown. For example, such methods should tell if a solid brick wall would risk losing structural integrity if additional insulation was to be applied on the inside, how much insulation can be added to an attic floor without risk for mold growth or when the façade has to be repaired.

Most of the available methods for performing risk assessment concerns the structural integrity of the building. Of these, non-destructive methods are of large practical interest and in particular those that can be used on a large variety of building materials. One example of a risk assessment method for masonry buildings was developed by Mensinga et al. [7]. The method requires knowledge of the building and the specific materials in the construction. Material data is obtained by frost dilatometry which is a methodology for identification of the frost resistance of bricks. This data is used to support the decision on which retrofitting measures is suitable for a specific building, for instance repairing brick and mortar or installing hydrophobic surface treatment on the exterior in connection to a renovation measure.

4. Retrofitting with respect to decreased energy use and improved indoor environment

There are several different approaches to decrease energy use and improve the indoor environment (both thermal and air quality). Examples are; additional insulation (wall, attic, foundation, including decrease of thermal bridges), change of windows or adding window panes, change or upgrading of building services, increased airtightness and decreased water penetration. The latter can seriously damage the durability of the structure, indoor air quality and also energy use. It can occur through façades, roofs, foundation (rain water and ground water), joints and the areas around penetrations are in particular vulnerable. When estimating the proper renovation strategies, there are many building physical functions (for example rain or wind barrier) that need to be fulfilled in a building and that have to be taken into account. These functional requirements have been structured in Table 1. The different categories are labelled E (energy) or I (indoor air quality) for the reason to renovate. For decision making, other aspects also need to be included; such as building antiquarian aspects, daylight, regulations, social and economic aspects.

Table 1. Building physical aspects of the thermal envelope and building components that they affect. The different categories are labelled E (energy) or I (indoor air quality) for the reason to renovate.

Building component Function	Wall	Roof	Foundation	Windows	Building services incl. penetrations
Rain barrier	E, I	E, I	E, I	E, I	(E), I
Wind barrier	E, I	E, I	E, I	E, I	(E), I
Air barrier	E, I	E, I	E, I	E, I	E, I
Interior moisture protection (vapor content and leakages)	(E), I	(E), I	(E), I	(E), I	E, I
Heat/cold protection (insulation, thermal bridges)	E, (I)	E, (I)	E, (I)	E, (I)	E, I

Within the project, several case studies and large inventories have been made. These are presented in Johansson et al. [4], Johansson and Wahlgren [5], and Lång and Sandgren [8]. The latter focused on brick buildings from 1870-1930 and they have found that, for these houses, the following measures were the most common; adding insulation, changing windows and converting attic spaces into apartments.

The total project inventory has currently covered 640 buildings, on 602 properties, of which all were built 1945 or earlier. This data set has been compared to the inventory and status assessment by Trafikverket (Swedish transport administration), previously mentioned, resulting in 94 properties that were included in both data sets. The results of the inventory for a number of parameters are presented in Fig. 1.

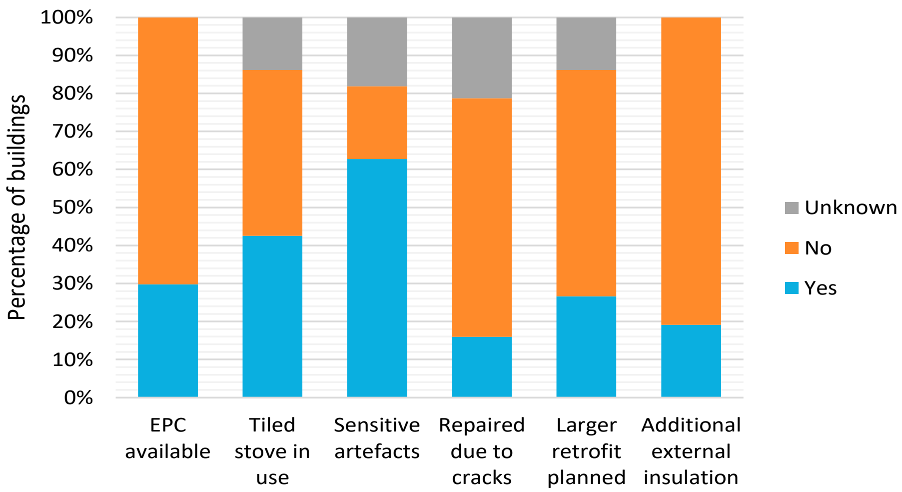

Fig. 1. Information on the 94 properties in the inventories presented in [5] and by Trafikverket.

The sensitive and vulnerable artefacts can for example be tiled stoves, stucco, ornamentation, windows, paintings, ceramic tiles and sculptures in the building. It is also interesting to note how many of the buildings that have a tiled stove in use. As a consequence, the measured energy use in the EPC might be difficult to interpret since the extent of the use of the stove is not always known. The degree of renovation in the buildings has been evaluated in [5] using EPCs and value year (as a measure of the degree of renovation). The share of buildings with additional insulation was determined by site visits. A small share of the buildings have been repaired due to cracks on the interior or exterior surfaces. Larger retrofit was planned for 25 of the buildings and common measures were; converting attic space into apartments, converting common or commercial premises to apartments, change of ventilation system and change of windows.

There will be further in-depth investigations to determine the reasons for retrofitting and renovation (structural problems, moisture problems etc.), especially in the cases where information is lacking. To provide proper advice on renovations of buildings from 1945 and earlier, it is important to know the chain of action within the housing companies, in particular when non-technical aspects such as building antiquarian aspects shall be taken into account. In the following, three common renovation measures (attic space converted into apartments, additional exterior thermal insulation and hydrophobic surface treatment) are described as case studies.

4.1. Attic space converted into apartments

Five brick buildings from 1907 to 1932 were studied in detail [8]. The buildings have homogenous load-bearing exterior walls made of brick and floor slabs made of timber. The foundation walls are commonly constructed with a combination of bricks and dry stone walls or only bricks. The attics are cold and ventilated and are currently used as storage space. However, the construction of the roof provides the opportunity to convert the space into apartments, as long as issues concerning, for example, load-bearing structure, moisture conditions (in particular wooden beams in connection to the brick wall), room height, accessibility and building services (space and noise) can be solved.

Investigations were made on the thermal (U-value) and moisture performance of a converted attic, using numerical hygrothermal (heat and moisture) simulations. The simulations show that the wooden beams that enter the building envelope (homogenous brick wall) are subjected to a high relative humidity and high mold growth index. The source of moisture is both rain from the outside and vapor from the inside. The wooden beam needs to be protected (an example is shown in section 4.3) or changed to a more moisture proof material (non- organic). According to analysis of the energy use and U-value, a conversion of the attic into apartments and insulation on at least one of the exterior walls can in combination lead to a substantially more energy efficient building. In addition, converting cold attics into attic apartments can finance other measures such as changing the outer roof.

4.2. Exterior thermal insulation

A common energy efficiency measure is to add thermal insulation to the walls, either on the interior or exterior. In the study by Johansson and Wahlgren [5], results from site visits and inspections in the 640 buildings were presented. At the inspections, the year of construction was confirmed, the degree of renovation (e.g. the amount of additional insulation and state of the windows) was investigated and durability problems were noted. The investigated buildings were 2 to 7 floors high with different ownership of the building, i.e. housing cooperative or rental apartments. Buildings with rental apartments were in general either totally renovated or not renovated at all. Buildings in bad condition were often rental apartments. Buildings owned by a housing cooperative were in general renovated continuously and there was less contrast between bad and good examples.

The majority (53%) of the 640 investigated buildings had no visible additional thermal insulation on the façades. In cases where there was no air gap in the façade and exterior insulation had been added, the façade was more often damaged than façades with an air gap. Furthermore, the additional insulation was more often wet when there was no air gap in the façade. A large part of the buildings had only partial insulation, i.e. the ground floor had another type of construction and materials than the ones above, and was therefore left without additional insulation. The thickness of the additional insulation in the exterior walls ranged from 20 to 220 mm where 90-100 mm was the most common thickness.

Until today, buildings are mainly insulated with mineral wool and expanded polystyrene (EPS). In the old building stock, cultural heritage restrictions limit the wall thicknesses. By using highly efficient insulation materials (super insulation materials), the thickness of the wall can be kept at a minimum and thereby increase the possibilities to preserve the aesthetics of the building. Previous studies have shown that the energy use can be reduced by 20-30 % in a building by adding a layer of vacuum insulation panels (VIPs) on the exterior of the façade [9]. Renovations based on highly efficient insulation materials will be further studied.

4.3. Hydrophobic surface treatment

It is advantageous to insulate the exterior of the wall with regard to moisture safety. However, this is not permitted (or desired) in many cultural and historical buildings. They must therefore be insulated from the interior. This poses challenges because rentable area of the building is lost, and the heat, moisture and air transports in the wall are changed dramatically, which might lead to moisture damages [10]. An example, where the challenges were underestimated, is the renovation of old Vasa hospital (currently Ekocentrum) in Gothenburg built in 1888. The building is a plastered brick building where mineral wool was installed on the interior. After a few years, mold growth was discovered between the insulation and the brick wall. Moisture coming from the outside is often causing these types of problems. Therefore, one solution can be to make the exterior surface water repellant by using a hydrophobic surface treatment [11].

Lauby [12] studied a warehouse brick building completed in 1964 in Gothenburg. She investigated whether it was possible to retrofit the building by using VIPs on the interior in combination with hydrophobic treatment. Using a 20 mm thick VIP encapsulated on both sides in 10 mm polystyrene, the theoretical U-value was reduced from 0.58 $W/(m^2{\cdot}K)$ to 0.16 $W/(m^2{\cdot}K)$. By using hygrothermal simulations she found that the main challenge would be to take care of the rain load on the façade to reach a satisfactory hygrothermal performance. A hydrophobic surface treatment was modeled. The treatment makes the surface more water repellent while allowing for vapor transfer trough the layer. The results showed that the moisture content in the wall was reduced significantly, resulting in a decreased risk for freeze and thaw damages in the façade. The risk for microbiological growth was also reduced.

5. Conclusions

There are no databases that describe which types of renovation that have been made for individual buildings. This makes it difficult to separate buildings with, for example, more cosmetic or aesthetic renovations from buildings with energy efficiency measures included in the renovations. Generally, there is a lack of information on the status of the building at building owner level which makes it difficult to propose typical renovation strategies. To make the renovation design and implementation process more in line with the needs and demands of the users, a support tool is needed for owners and for societal decisions. There are no general tools available today for assessing the building envelope which gives a case-to-case evaluation often based on the knowledge of individuals. In order to investigate what type of renovations that have been made, it is necessary to visit the buildings. A practical methodology for evaluating and prioritizing the renovation need in buildings would save time and money.

By converting attics into apartments, it is possible to increase the energy efficiency of the building. Care has to be taken, so that the thermal envelope is intact without creating new thermal bridges and special attention is needed at locations where, for example, the wooden beam end meet the brick wall. Super insulation materials in combination with hydrophobic surface treatment can be one way to create new solutions for energy efficiency measures.

The final outcome of this project is to present guidelines to property owners as a support for planning up-coming renovations in the housing stock built before 1945.

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