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Recreation of cultural historical values in buildings from before 1945: Inventory with focus on building physics performance

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Abstract. *The housing stock in Sweden is getting more attention for national energy saving measures. This study is part of a larger multi-disciplinary research project in which building physicists, architects and building antiquarians work together to develop a holistic retrofitting approach. The first part of the project concerns inventories of building components in buildings from before 1945 in need of a second major renovation. The focus of the inventories is on energy performance, moisture resistance, long-term durability and thermal comfort. The inventories are used to investigate alternative and improved solutions for re-renovation to recreate e.g. architectural details and cultural historical values in balance with contemporary demands for function and aesthetics. In this study, different databases with information on energy use, year of construction, value year and geographical data were combined. It became evident that there is a large variation in quality of data and that different data sources have different information. For instance, among the investigated buildings, many were reported as being built in 1929. This was in most cases (71%) incorrect. We found that the year of renovation is often missing and the calculation of value year is not consistent or is lacking. Comparing the energy use for buildings with different year of construction may give the impression that older buildings have better energy performance. This is not correct. When looking into the value year, it becomes evident that the older buildings have been more renovated and there is no such correlation. The inventories also showed that it is usually the exterior wall facing the courtyard, or southern facing façades, which has additional insulation, and that great care has to be taken when changing façades and windows to balance cultural historical values.*

Introduction

The goal to radically reduce the CO_2 emissions in the European Union by 80-95% in 2050 compared to in 1990 urge for measures for increased energy efficiency. Around 40% of the final energy use in the EU is used in buildings. Therefore, existing buildings that undergo major renovation should be upgraded so that they meet minimum energy performance requirements [1]. In Sweden, national energy saving measures were implemented after the oil crises of the 1970s and 1980s. Often these measures were detrimental to cultural and historical values. The contemporary debate has, like then, a one-sided focus on energy savings and barriers to implementation. However, many aspects need to be taken into account when renovating and, as a result, this study has a multi-disciplinary methodology in which building physicists, architects and building antiquarians work together to develop a holistic retrofitting approach. The aim of this study is to identify and develop measures that can be implemented to recreate and preserve qualities that were lost in former renovations and prevent this situation to reoccur.

The Suez crisis in 1956 showed the vulnerability of relying on foreign oil for heating and a national fuel investigation suggested to shift towards using electric energy originating from nuclear power. Meanwhile, projects where energy efficiency measures, such as additional insulation and triple glazing, were implemented were given government subsidize and additional mortgage, starting in 1956 and throughout the 1960s. In the 1970s and 1980s, the energy efficiency measures were targeted to reduce the use of oil for heating. The goal in Sweden was to reduce the energy use by 25% during a 10 year period 1978-1988 [2]. At that time around 30% of the Swedish buildings were considered too valuable from a cultural historical, aesthetic and architectural perspective to be subject for renovation of the building envelope. Today, this number is more uncertain but at least 31% of the multi-family buildings should not be subject to these measures while 28% are considered to be dubious and the remaining 41% are considered to have no hinder [3].

The most common measures in the 1970s and 1980s were to add insulation to the building envelope (walls, attic floor), change of windows to triple glazing (approximate U-value 1.9 W/m^{2}K), installation of system for heating regulation and changing heating distribution system. Elmroth and Anderlind [4] investigated 160 multi-family buildings before and after implementing the energy efficiency measures. Out of these buildings 57 were built before 1940. The buildings were chosen based on that they could receive public funding for the measures, with measures being implemented in 1983 and 1984. They found that the expected energy savings were reached in most cases. The measured energy use reduction was based on measurements in the different buildings during the winter months of 1982-1986. For instance, the expected energy savings for installing triple glazing in multi-family buildings was 10% while the measured savings were 9%. Other so called retrofit packages (at least three measures) were expected to reduce the energy use by 16% while 14% was measured. Change of windows was not only decided based on the energy savings, but also because the window frame in many newer buildings (newer than 1960) had rot damages. In addition, an evaluation by Antell and Paues [5] showed that the measures concerning adding insulation to the walls and triple glazing in most cases had large negative aesthetic influence. They found that the architecture of the buildings was simplified, made bulkier and was depreciated while the cultural historical values were destroyed.

The first part of this research project concerns inventories of buildings and building components in buildings from before 1945. The development of the research methodology and three case study buildings were presented by Johansson et al. [6]. The present study is based on the situation and building typologies found in Gothenburg, Sweden, and the problems related to durability found in this stock. The aim of this first study is to give examples on how different critical details have been solved in the past and identify possible case studies for the next step of the project. By careful investigation of the case studies in combination with numerical hygrothermal (heat and moisture) modelling of the critical details, recommendations can be given that fulfil modern requirements on energy efficiency and thermal comfort while preserving or recreating the cultural historical and architectural values in the buildings from before 1945.

Methodology for building stock characterization and inventory

The focus of the building inventories is on energy performance, moisture resistance, long-term durability and thermal comfort. The inventories are performed to investigate alternative and improved solutions for re-renovation to recreate e.g. architectural details and cultural historical values in balance with contemporary demands for function and aesthetics.

The first step has been to use databases of the energy performance certificates (EPCs), the national property register (PR) and geodata from the City planning office of Gothenburg. The databases have been combined to investigate how the energy use of the buildings has evolved based on the time of construction, time of renovation and the building typology. The EPC database contains data on the measured energy use, type of energy sources, and year of construction, for properties and individual buildings. The property register contains information on the building coordinates, ownership, year of construction, the so called value year (Eq. 1), and in some cases a year of renovation. The value year is calculated based on the economic extent of the renovation (see Table 1), improvement of standard, and is related to the expected remaining service life of a building. Only costs for larger renovation measures or extensions of a building can result in a change of the value year which is calculated by

$$\frac{\textit{Value year} - \textit{Construction year}}{\textit{Renovation year} - \textit{Construction year}} = \frac{\text{Renovation cost}}{\text{Cost of new building}}. \quad (1)$$

Table 1. Prerequisites for changing the value year [7].

Renovation cost of new building cost	Definition of value year
< 20%	No change of value year
20-70%	Changed according to Eq. 1
> 70%	Value year same as renovation year

The investigation of energy use in the buildings is done with respect to the actual year of construction, to the year of renovation and to the extent of renovation, expressed as the value year. There is very little information easily accessible about the renovations (type, extent, renovation year) so the basis for the inventory is visual inspection in combination with field measurements of for example the insulation thickness. The status inventory with respect to technical aspects can be made more or less complex. Normally, the technical status inventory includes the building envelope, the interior of the building, and the building services. Regarding the building envelope, an inventory can include checking the rain and wind protection, the insulation, air leakages, durability of materials, and contain information about the whole building. A more advanced inventory also take into account the building antiquarian aspect in the technical status inventory. A method to perform risk analysis and status determination, including building antiquarian aspects is being developed by Arfvidsson et al. [8]. Until this method is ready to use, a more traditional technical inventory method that focuses on the building envelope is used in the project.

The study includes 640 buildings distributed on 602 registered properties. The 640 buildings were inspected and the year of construction was validated using information from the City planning office of Gothenburg [9, 10], real-estate agencies, literature and information found on webpages. Best practice for investigating the year of construction was to make a quick assessment (using for example the property register in combination with information from the building owners' webpages), performing site visits and interviews on site and follow up with the official documentation from the City planning office of Gothenburg.

During the inventory, following information about the buildings were gathered:

- Façades; state, materials and insulation.
- Windows; materials, types and number of glass panes.
- Number of floors (including attic floors) used for apartments.
- Interesting buildings for further evaluation and inspections have been marked and the reason is explained in the comment field of the database.

Characterization of buildings from before 1945

Gothenburg is the second largest city of Sweden with around 550,000 inhabitants and in total 150,804 buildings in the property register. There are 2,217 residential multi-family buildings built before 1945 in Gothenburg whereof 2,124 buildings have a valid EPC. The above described inventory includes 640 buildings, which means that almost 30% of the buildings of interest have been investigated. The spatial distribution is presented in Figure 1. The buildings from before 1945 are spread all over the central part of Gothenburg with a slight concentration in the south west.

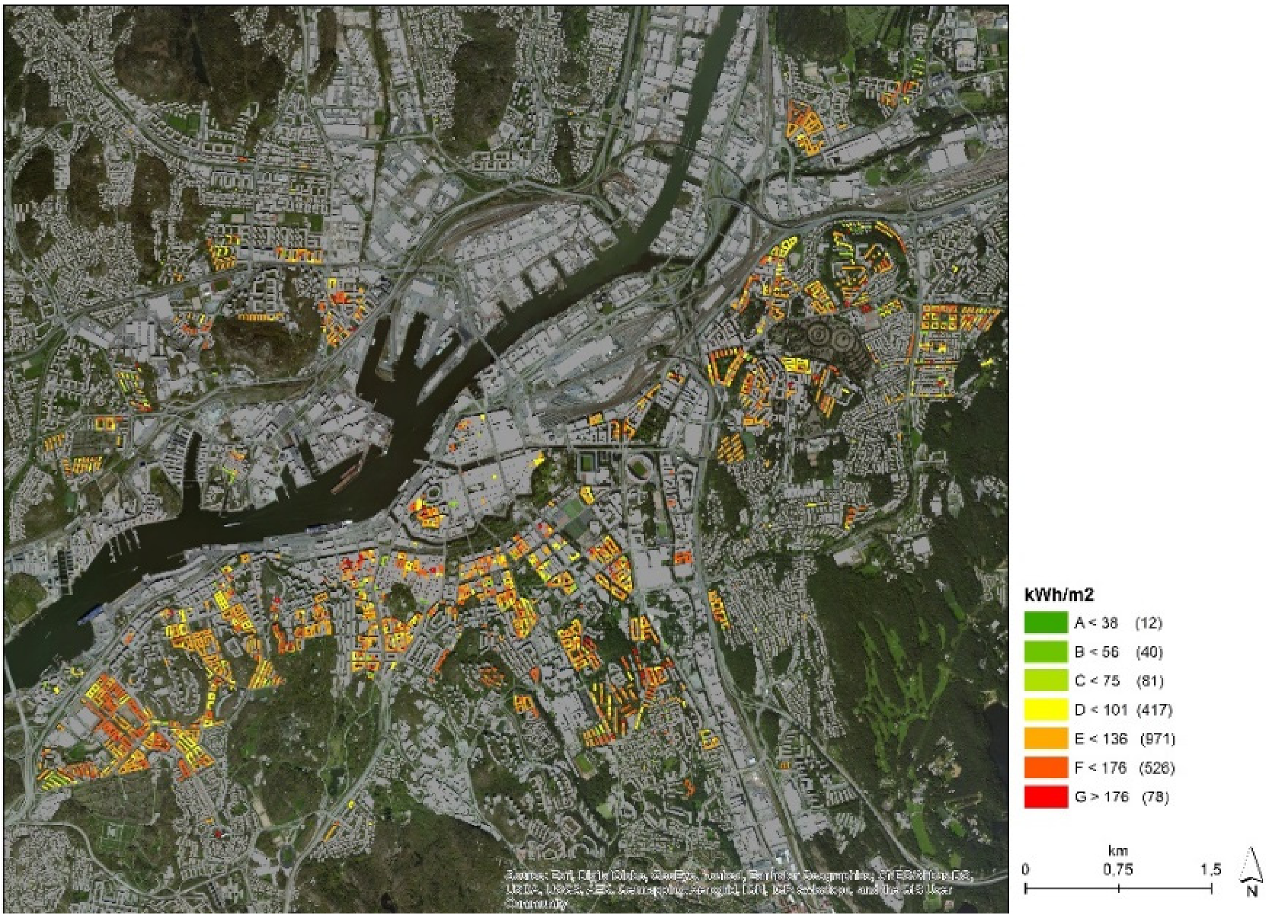

Figure 1. Spatial distribution of the 2,124 buildings in central Gothenburg from before 1945 (left). Number of buildings in each category in parentheses with the color scale based on their energy use for heating and domestic hot water [6] (right).

The color scale in Figure 1 is based on the measured energy use for heating (corrected to the reference year), domestic hot water and facility electricity. In Figure 1, the facility electricity (2-10 kWh/m^2) has been omitted and therefore only the summation of the energy use for heating (corrected to the reference year) and domestic hot water are presented. There are very few buildings of class A (<38 kWh/m^2), only 12 buildings, and the majority are buildings of class E (101-135 kWh/m^2) and F (136-175 kWh/m^2). For comparison, the building regulations for new multi-family buildings in the region of Gothenburg demand an energy use of maximum 75 kWh/m^2. This number also includes facility electricity. Consequently, from an energy performance perspective, there is a large potential for improvement when renovating the building stock built before 1945.

Many of the buildings from before 1945 in Sweden have already been renovated. During the period of 1975-2002, approximately 50% of the Swedish multi-family buildings from before 1945 were renovated. A large portion of renovations were made during 1975-1990 with some kind of energy subsidy, and are currently in large need of maintenance and renovation [11]. The buildings have different construction and load-bearing materials. The number of buildings with concrete, brick, aerated concrete and wood as load-bearing materials in buildings based on the year of construction is presented in Figure 2.

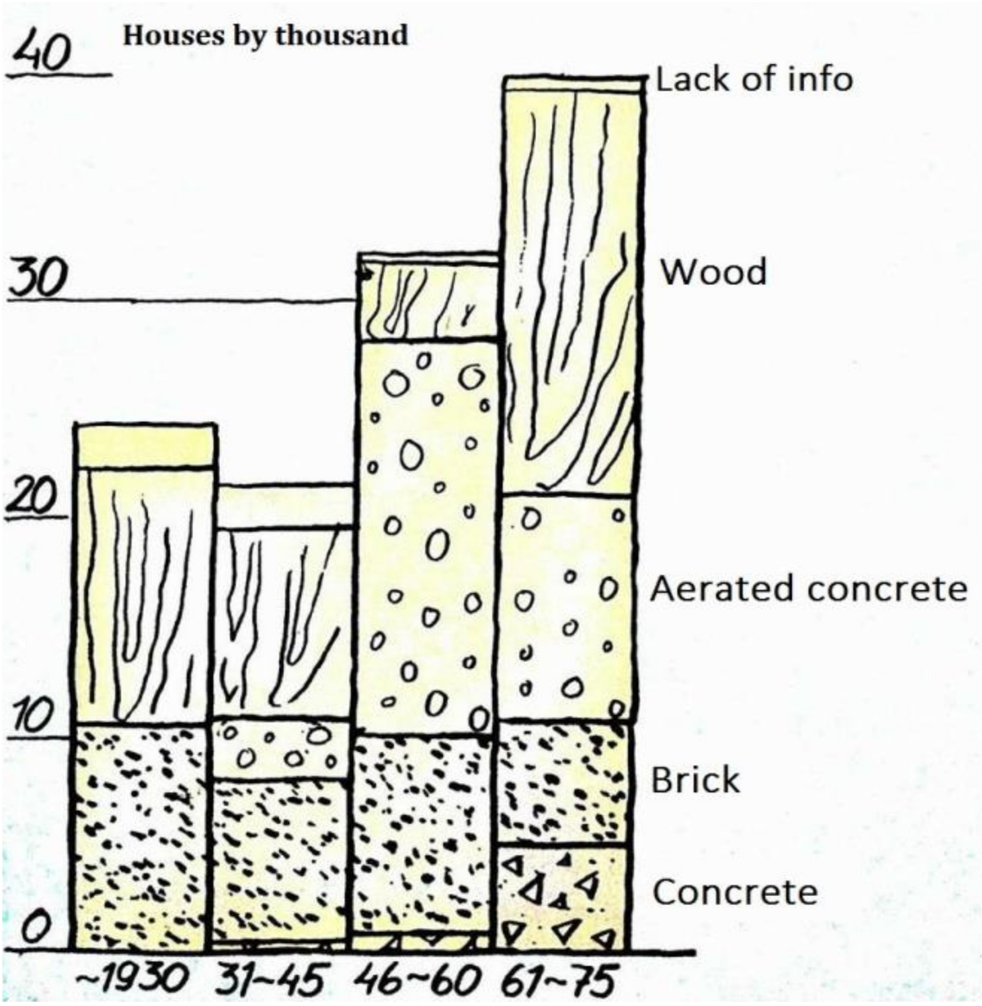

Figure 2. Load-bearing material in buildings in Sweden based on the year of construction [12].

The most common load-bearing materials in buildings from before 1945 is wood and/or brick, while concrete and aerated concrete was used to a small extent. Before 1950 brick was a common load-bearing material, but after this period brick is mostly used for cladding on the façade. Wood was used as homogeneous wall material in old buildings and started to be used in light-framed walls with insulation, combined with load bearing concrete structures, in the 1960s [12].

The multi-family buildings before 1945 contained mostly flats with 2 rooms and a kitchen. The buildings were of different number of floors, commonly 1-5 floors with a slight overweight to 1-2 floor, but after 1945 it was more common with 3-floor buildings [12].

Energy use and degree of renovation

To investigate the evolution of energy use in the building stock, the energy use for different year of construction, together with the energy use for different value year (Eq. 1) is studied. As previously mentioned, a value year is a measure of the extent of renovation and if there is a large difference between value year and year of construction, there has either been major renovations in the building or the renovations are made recently. However, there is no information on whether the renovation includes measures to improve energy efficiency or if only for example interior finishes or building services were affected. Figure 3 presents the energy use for 508 out of the 602 properties that were included in the inspections based on the construction year. These buildings are the ones that could be matched to both the EPC database and the property register. Here, the summation of the energy use for heating (corrected to the reference year), domestic hot water and facility electricity are presented.

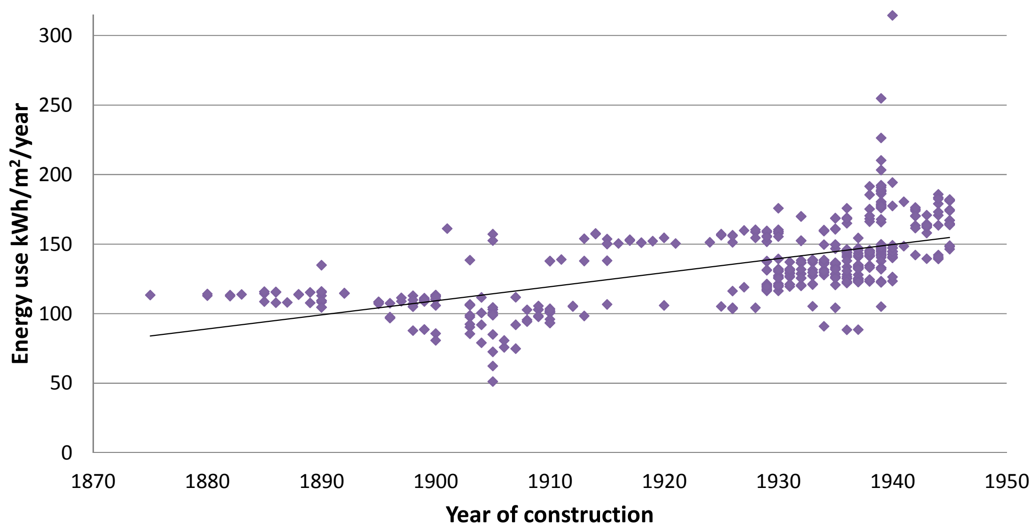

Figure 3. Energy use in buildings constructed before 1945, as a function of the year of construction.

As seen in Figure 3, the buildings from the late 1800s actually have lower energy use than the buildings from 1930-1940. This does not mean that the buildings were constructed in a more energy efficiency way in the late 1800s compared to the newer buildings, but these buildings have been renovated to a larger extent. This is shown in Figure 4 where the energy use is presented based on the value year (Eq. 1).

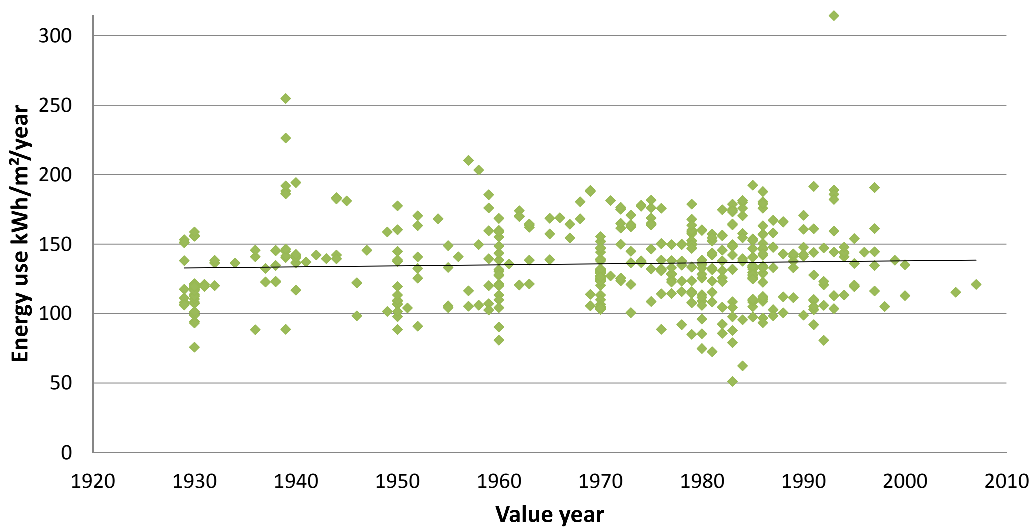

Figure 4. Energy use in buildings constructed before 1945, as a function of the value year.

When the value year is used, there is a more constant energy use, i.e. almost the same energy use irrespective of value year. This implies that the older buildings have been renovated to a larger extent or more recently, and there are also some buildings that have been renovated to an extent where the value of the building becomes representative of buildings from 2000 and onward. Out of the 508 buildings in this dataset, there are 38 buildings that have the same value year as year of construction, i.e. no renovation at all have been reported, and there are five buildings that lack information on value year. The buildings that lack information on value year are all built before 1925. The buildings that have not been renovated are from 1929 to 1945, which is in the end of the investigated period. The non-renovated buildings are fairly evenly distributed over time from 1929 and onwards. Out of the 508 buildings, 228 has a specified renovation year. When the energy use as a function of the renovation year is investigated, the buildings that are more recently renovated have slightly lower energy use.

Results of the building inventory

In order to investigate the 640 buildings, two people visited the buildings during the summer of 2016. From the on-site inventories (640 buildings) it was possible to ascertain the year of construction, investigate the degree of renovation (for example the amount of additional insulation, new windows) and to some extent investigate durability. The investigated buildings were 2 to 7 floors high. The above factors were also set in relation to ownership of the building, i.e. housing cooperative or rental apartments. Following was found.

Validation of year of construction. When looking into the databases and visiting the buildings it became evident that many times the construction year 1929 was not the correct year of construction. This is due to an error when the registration of construction year started in the property register. In total, the number of buildings with the construction year 1929 was 548 in the database of 2,217 buildings. Out of the 640 investigated buildings, 135 had 1929 as year of construction while in fact only 39 were actually built in 1929. This means 71% of the buildings with construction year 1929 had the wrong information in the property register. Buildings with construction year 1929 are usually older than that, but there are cases were the building is in fact newer.

Ownership. Buildings with rental apartments are in general either totally renovated or not renovated at all. Buildings in bad condition are often rental apartments. Buildings owned by a housing cooperative are in general renovated continuously and there is less contrast between bad and good examples.

Insulation and durability. In order to see if the buildings had been renovated or not, the value year (Eq. 1) was investigated. If the value year is different from the year of construction, the building has been renovated, see Table 1. As shown in Figure 5 the majority of the investigated buildings have been renovated, according to this definition. For each year of construction the percentage of renovated and non-renovated properties are shown. This information is combined with the number of properties from each year. Years that have buildings where 100% of the properties are non-renovated, i.e. the same value year and year of construction, only have one building in the data set from that year. Figure 5 also shows that there is a large number of buildings from 1929-1939 (10 years) included in the inventory that covers the range 1875-1945 (70 years), approximately 54%.

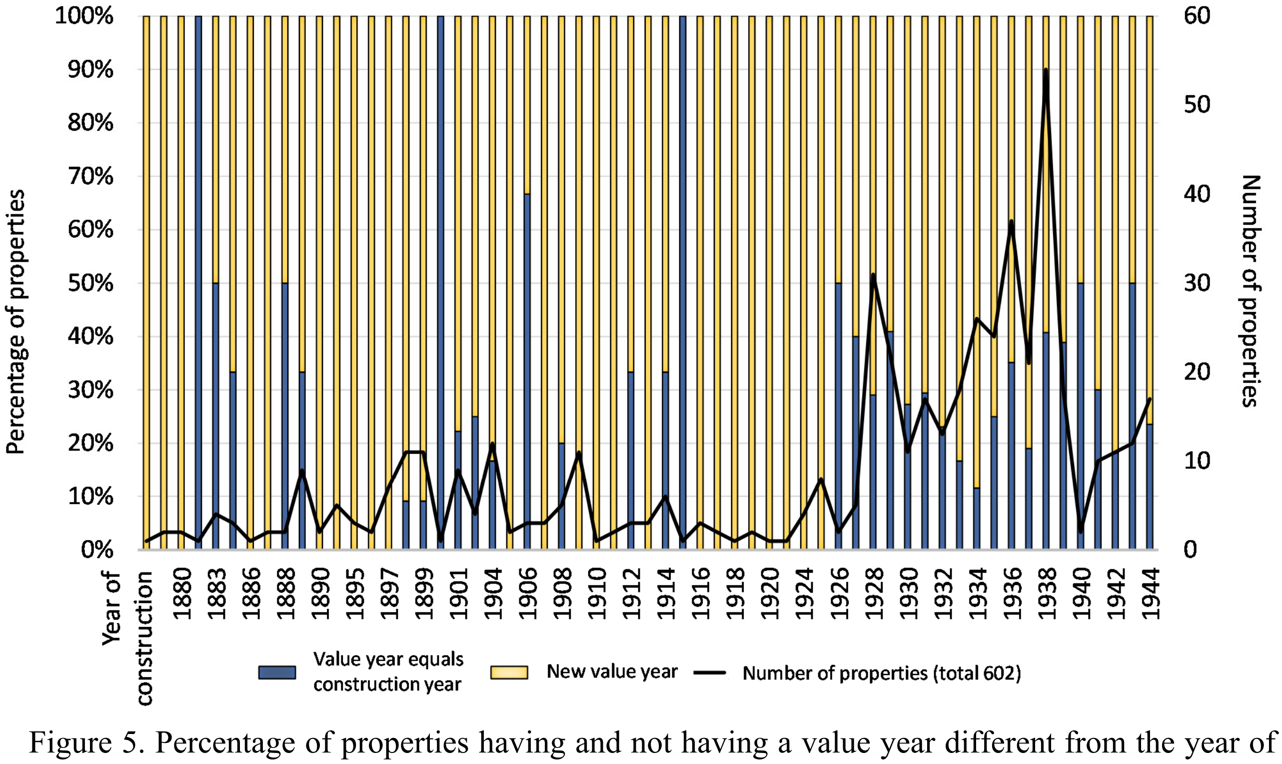

Figure 5. Percentage of properties having and not having a value year different from the year of construction as function of year of construction (columns) and number of properties per year (line).

Since the value year does not give an indication on whether the renovation included additional insulation, or new and more energy efficient windows, this information has been gathered by visiting and inspecting the buildings. In Figure 6, the information on additional insulation thickness in walls is showed. A majority of the buildings did not have any visible additional wall insulation. Furthermore, many building walls were only partly insulated. This means that not all external walls of the buildings were insulated or that the walls are not insulated over the whole building height. In many cases, the ground floor has another type of construction and materials than the ones above, and is therefore left without additional insulation. The thickness of the additional insulation in exterior walls ranges from 20 mm to 220 mm, as shown in Figure 6.

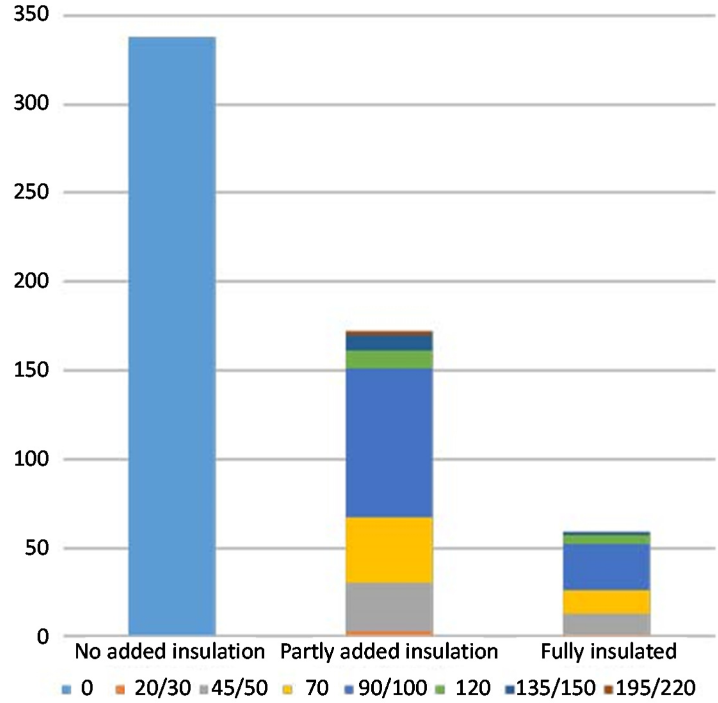

Figure 6. Number of properties with visible additional wall insulation. Results from inspections in 640 buildings. Partly insulated means that only the ground floor or the upper floors are insulated. Fully insulated means that all floors are insulated.

When only one side of a building has additional insulation, it is usually the exterior wall facing the courtyard, or the southern façade. The reason for insulating the wall facing the courtyard is that this does not change the appearance of the wall toward the street and the main entrance of the building, which are often protected.

The façades facing south are overrepresented when it comes to additional insulation. This is in particular common when there are few windows in the south façade. This is probably due to the fact that Gothenburg has a large amount of driving rain with predominant direction from south/south-west. Driving rain often cause water leakage into the façades [13]. Furthermore, solar radiation can cause deterioration of the façade material, both due to UV-radiation and thermally induced stresses and the southern facades are very exposed in this respect. An example of two renovated façades facing south is shown in Figure 7.

The inventory showed that great care has to be taken when adding insulation to exterior walls. In cases where there is no air gap in the façade and exterior insulation has been added, the façade is more often damaged than façades with an air gap. Furthermore, the additional insulation is more often wet when there is no air gap in the façade.

Figure 7. Often the south façade is renovated. Examples of two different strategies where cementitious boards (left) and a metal cladding (right) were chosen on the south facade.

Façades that have insulation or a new rain barrier all the way to the ground, see Figure 8, are almost always damaged, with the exception of façades of concrete, brick or very thick plaster.

Figure 8. Example of two façades with additional insulation, seen from below.

Concerning the rain barrier, wooden boards has been a common material in Swedish exterior walls. Due to durability and maintenance reasons, these are sometimes exchanged to other types of rain barriers, such as metal claddings, cementitious boards or plastic. In the inventory, façades with metal cladding were generally in good condition. However, in many cases there are problems with aesthetics but successful examples can also be found. New board materials and new wooden façades also have problems with the aesthetics. For the appearance of the façade it is preferable to use the original board width and profiles. In general, the best appearances are the ones stripped back to original design, the ones with a new exterior envelope and where original, imitations or similar looking materials have been used, see Figure 9. Attention to the detailing is very important to preserve the appearance.

Figure 9. Good example showing recreation of values on a building from the 1890s with initially one family on each floor and now containing 19 apartments (housing cooperative).

Windows. A majority of the buildings in the inventory had 3 pane windows (approximately 60%) and the rest were 2 pane windows. Consequently, all buildings had been renovated to an extent where 1 pane windows had been replaced. Most windows had a wooden frame, in some cases there was an aluminum cover (in particular newer windows). PVC covers were rarely used. However, to visually separate aluminum from PVC in window frames are sometimes very difficult. Wood is easier to distinguish. When changing from a wooden frame appearance to aluminum or PVC the façade loses a lot of character. In general, the best results are when the original windows, imitations or similar looking windows are used.

Conclusions

The initial stages of the project on recreation of cultural and historical values in buildings from before 1945 has mainly focused on energy use in buildings and inventories of buildings.

When setting up the database on energy use, combined with year of construction, value year and geographical data, it became evident that there is a large variation in the quality of the data and that different data sources have different information. All parameters included in the database have been subject to further investigation. The year of construction is not always correct, in particular for older buildings where the year 1929 is wrongly overrepresented for 71% of the buildings. The year of renovation is often missing and the calculation of value year is not consistent or is sometimes lacking.

The energy performance of a building is in some cases not representing one specific building but is calculated from the energy use of a whole property consisting of several buildings. In this case, a building with additional insulation can have the same energy performance as a building with less insulation. There is no databases that describe the type of renovation for buildings, which makes it difficult to separate the buildings with, for example, more cosmetic or aesthetic renovations from building with energy efficiency measures included in the renovations.

In order to investigate what type of renovations that have been made, it is necessary to visit the buildings. In order to cover a large number of buildings, the buildings were only inspected on the outside, why information on interior insulation or changing of ventilation or heating systems have not yet been investigated.

The inventories also showed that usually it is the exterior wall facing the courtyard, or southern facing façades, that have additional insulation, and that great care has to be taken when changing façades and windows. In cases when there is no exterior air gap in the façade, there is a larger degree of damage and of wet insulation.

Comparing year of construction with energy use may give the impression that the older the building, the better it was built with respect to energy efficiency. This is not correct. When looking into the value year, it becomes evident that the older buildings have been renovated and that there is no such correlation to be seen.

The next steps of the project is to choose a number of details to study more in detail, with respect to aesthetics, thermal performance, durability, and in the case of windows, daylight. The final outcome 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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