Renovation of an office building with prefabricated wooden element - Case Hedensbyn

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Abstract. There is a major need of cost-effective renovation that leads to lower energy consumption and better environment. This article shows the results from a pilot case of a newly developed prefabricated building system. It is an industrially prefabricated insulated wooden element adapted to renovation and upgrading of building envelopes. The renovated building is a one-story office building located in Skellefteå in the north of Sweden. Energy performance, thermal bridges, risk of moisture problems, LCA, applicability of the renovation method and assembly time were evaluated during the planning and execution of the renovation. Results from this case show that the elements were very light and easy for one person to handle at the building site. There is a great potential to reduce assembly time with improved joints and element sizes adapted to the building as well as improved batch packaging from the factory. With 100 mm insulation, the renovation gives a certain energy savings, and LCA calculations show that the reduction of climate impact due to reduced heating energy used during a service life 50 years corresponds to the climate impact of the renovation measures. The risk of microbial growth can be regarded as small.

Keywords: Façade renovation, Building envelope, Prefabricated wood element, Energy efficiency, Thermal bridge, Insulation, Climate impact, Retrofitting

1 Introduction

Worldwide primary energy demand has never stopped increasing during the last decades [1]. The EU Commission has recently stated that one of its highest priority tasks is to address global warming, especially focusing on reducing greenhouse gases. The Commission states that the building sector must decrease its use of energy to reduce CO_2 emissions. In addition, the 2016 Energy Efficiency Directive update established a set of binding measures to help the EU reach its 30% energy efficiency target by 2030 [2].

In this active context, Sweden has decided to take a step forward by completely phasing out net greenhouse gas emissions to the atmosphere by 2045 [3]. In order to meet these targets, many different activities must strive towards the same goal. One major part is the residential and service sectors, which accounts for about 40% of total energy use in Sweden [4]. Reducing the environmental impact and energy consumption of buildings cannot be solely achieved by regulating new buildings; it will also require renovation of existing buildings.

Moisture issues and thermal bridges have to be considered during energy renovation in order to avoid damage after renovation. A recent report [5] highlighted that 751 000 Swedish buildings were exposed to moisture damage to the point of affecting the indoor environment. Because of this, it is important to assess whether there is a risk of moisture in the construction after renovation, and if so, to take preventive actions at an early stage.

The effects of thermal bridges on the overall thermal performance of a well-insulated and energy-efficient building can be significant. A thermal bridge is a part where the thermal conductivity is greater than in other parts of the structure. This can occur, for example, around windows, between floors and walls, in corners, around studs or where there is insufficient insulation. Thermal bridges are a major problem in terms of energy losses as they contribute to increased heat flow out of the building envelope, but they can also create moisture related problems in the wall.

A façade renovation affects the performance of external walls in terms not only of energy performance and life-cycle cost, but also building performance, physical behavior, durability and aesthetic appearance. It is difficult to develop one single system for prefabricated renovation since buildings in need of renovation have been built in different eras with different cultural-historic aspects, with different technologies and materials. Even local climates give rise to varying renovation needs. Economic conditions, ownership of the estates, building regulations and construction methods differ between countries and have been investigated in numerous international projects. Some studies have focused on wooden facades, for example [6] and [7].

A common way to renovate façades is to use a contractor on site that removes the outer layers of old façades and builds the new ones on site. The aim in this project was to develop a concept for industrially prefabricated insulated elements for renovation and upgrading of building envelopes. The project with participants from Sweden, Finland and Norway focused on increased prefabrication of building envelopes and solutions based on wood. The prefabricated elements have been described in [8], the energy savings in [9], concept and cost in [10]. This study is about a real case and gives information on the applicability of the new system for renovation and an environmental assessment, and may be used for improvements of the renovation system.

The hypothesis in the project was that a fast installation process and a short period of disturbance to the tenants are advantages of prefabricated solutions. Important for the quality of the job are the indoor production of the wood element in dry conditions and reduced moisture exposure on building due to rationalized work on site. Wood was chosen, as it is a renewable and sustainable material with low climate impact.

1.1 Objective

The aim of this paper is to evaluate renovation with a newly developed renovation concept with prefabricated wall elements. A pilot renovation of an office building in Skellefteå, Sweden, "Case Hedensbyn", was performed to verify the functionality. Evaluation was based on both simulations and measurements during planning and execution stages.

2 Building and materials

2.1 Case Hedensbyn - the building

"Case Hedensbyn" is an office building in need of façade refurbishment located in Skellefteå, in the Northeast of Sweden. It was built in 1976 and is owned by Skellefteå Industrihus AB. The tenant is a company with focus on mobile communication.

The building is one story high and connected to a larger machine hall. It was built with a timber frame and had a yellow brick facade (see Fig.1). Some bricks had started to fall down, and the façade had been complemented with red profiled steel sheet on the north side of the building (see Fig.2). The original wall was built of 13 mm gypsum board, 0.15 mm polyethylene foil, 140 mm mineral wool of glass fiber and 145 mm wooden wall studs, 12 mm bitumen-impregnated fiberboard, 10 mm ventilated air gap, 65 mm facade bricks or 0.7 mm profiled aluminum sheets above/between windows.

Fig. 1. Photo of the building before renovation, west and south wall.

Fig. 2. Photo of the building before renovation, north and west wall.

2.2 Prefabricated insulated wood elements for renovation

In "Case Hedensbyn", a new system of small, modular prefabricated wood elements for renovation of façades was used (patented Termowood As; EP1963593, NO 323561). The prefabricated elements consist of two outer parallel multilayer solid wood panels with insulation and wooden connection rods between the wood panels. The elements are available with 50–250 mm insulation, depending on the requirements to upgrade the insulation in the building. Elements are produced with a width of 200 mm, thickness of 94–330 mm and length up to 6 m (but normally up to 3 m). Thickness of the solid wood panels is 22–40 mm. The elements can be combined by assembling segments together horizontally or vertically using a tongue and groove connection with a polyethylene sealing strip in the groove to ensure airtightness.

2.3 Condition of the building envelope

Drawings and documents were studied and the building was inspected to find out if it was suitable for renovation with prefabricated wall elements and to check the status of the existing envelope. The attachment of wood elements to the wood studs of the building was studied and there was a concern that the wall would have an irregular surface after the existing brick facade was pulled down. For use of elements on existing walls, the size, attachment and tolerances of the elements are important for the installation of new elements directly to the existing wall. This also requires no moisture damage or mold growth in the existing wall. If the old façade contains a ventilated air gap, the façade cladding must be removed down to the wind barrier and the condition of the existing façade should then be inspected. Damaged materials should be replaced with new materials before attachment of the elements.

The investigation of the building indicated that it was possible to attach the elements to the existing structure, and the work continued with the involvement of an architect and a contractor. The windows were changed some years ago, and it was decided to keep them as they were.

The thickness of the new wall elements had to be adapted to existing roof-overhang and base structure, and therefore the elements had only 100 mm additional insulation. Standard width was 200 mm, but also 98 mm wide elements were used to adapt to windows. The element length was generally 2.05 m, and elements were installed in two layers to get the full wall height. There were also shorter elements to be installed over (1.77 m) and under (0.81 m) windows. The thickness of the solid wood panels in the new wall elements was 22 mm. The elements were fixed to a sill that was screwed to the existing building at the bottom, middle and top of the wall. The new façade cladding was decided to be a mixture of a traditional 22 mm softwood façade and a newly developed wooden façade with milled pattern (patent Sweden nr 1451222-2 - Cross-laminated wood facade element).

The facade was built with a ventilated air gap behind cladding, and façade boards were fixed to double battening of horizontal 28- x 70-mm and vertical 12- x 48-mm battens. For a cross-section of the lower bottom part of the wall, see Fig. 3.

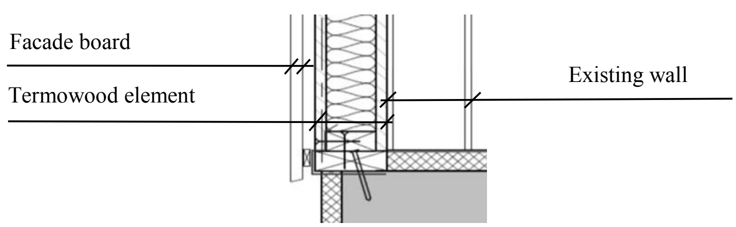

Fig. 3. Wall section of renovation with Termowood elements and facade boards.

3 Procedure of evaluation

Several actions have to take place in planning an actual renovation to secure the execution at a later stage. For "Case Hedensbyn", the renovation process was divided into three main steps: Planning stage, Execution stage and After completed renovation. Each step consists of several activities (see Fig.4). The first two stages are presented in this paper.

Planning stage. At this stage, the renovation was planned and the property owner, the builder and the material supplier were to agree on the terms. They had to evaluate if the building was suitable for prefabricated wall elements, which involved examining the existing building envelope using various methods. Calculations were made of energy savings, energy flow, heat losses due to thermal bridges and moisture transfer. In addition, many decisions had to be made: design, insulation thickness, connections, change of windows, roof connection and design and color of new facade cladding.

Execution stage. The applicability of the renovation methods was analyzed by in terms of the assembly time at the building site and LCA calculations. Documentation was also made with photos and a film. To assess the degree of satisfaction with the renovation concept, there were discussions with the builder and building owner during the renovation and after.

After completed renovation. Thermal bridges were evaluated by thermography images and moisture measurements with sensors in the new wall elements, and follow-up costs were assessed.

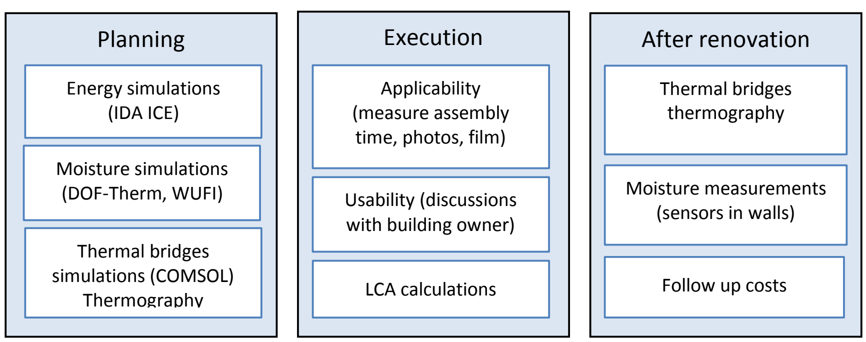

Fig. 4 Steps of evaluation and activities with methods in brackets

3.1 Energy simulations

The software IDA ICE was used for calculation of energy savings. The height of the building was 4.2 m, and the connected building was considered in the calculations. Two-glass windows with 2.5 W/m·K thermal conductivity were assumed and placed in the wall according to the plan drawing. The climate data of the city of Umeå (small difference in climate between Skellefteå and Umeå) were used. The thermal bridges were assumed to give low losses, and indoor temperature was 21°C.

3.2 Thermal bridges

Thermal bridges were simulated in 1D, 2D and 3D with COMSOL software. A climate data file for Oulu, Finland was used (small distance to Skellefteå and Umeå).
Thermography with a FLIRT620 camera was done to investigate thermal bridges in the existing building envelope. The thermography was done in May 2017 and carried out at night for the outdoor temperature to be as low as possible. An independent temperature gauge was used to calibrate the temperature of the camera. The temperature was measured on the outside of the building and used in the measurements. The camera was angled to the wall to avoid reflections from the body-heat radiation. Images were taken at windows, in the middle of the wall and at ground level. There was also thermography from the inside of the building, this time at ceiling beams, floor tiles, corners and middle walls.

3.3 Moisture simulations and measurements

The DOF-THERM software was used to evaluate moisture transport under stationary conditions. WUFI® software was used to evaluate moisture conditions under nonstationary conditions with coupled heat and moisture transfer in the building components.

HygroTrac sensors S-900-1 from General Electric were installed during the execution stage for measurement of moisture content (MC), relative humidity (RH) and temperature (T) in positions that are believed to have the greatest risk of moisture damage. Measurements are planned to continue during several years after competed renovation.

3.4 LCA

The LCA calculation was made with EPD data [11] and general data. Stages were according to EN 15804 [12]. The refurbishment stage b5 included removal of waste material from demolition of the old façade (brick façade, sheets, *etc*.), production of new materials and transport of materials. Maintenance of the new façade was also calculated. The functional unit was one office building with an area of 229 m^2 over a lifetime of 50 years. The LCA was used to compare the climate impact of the renovation and the climate impact resulting from a reduction in energy use during the renovation's service life. The LCA also gives indications of possible improvements that could further reduce the climate impact of the renovation system.

4 Results

4.1 Energy savings and thermal bridges

The energy saving was 9 kWh/m² per year when simulating the new façade element in IDA ICE [13]. The existing building had simulated annual energy consumption for heating the building of 258 kWh/m², and the renovated building with 100 mm additional insulation got an annual energy consumption of 249 kWh/m². The energy saving is only from the extra insulation; existing insulation in the roof structure and windows and doors with high U values was retained.

The major thermal bridges are usually located at connections. In this case, it was important to study the surface thermal bridges caused by the timber frame and assess how much energy could be saved by reducing these thermal bridges. Thermographic pictures taken before the renovation are shown in Fig. 5.

Simulation results of thermal bridges showed that the temperature difference between points on the inside of the wall at the position of studs and positions between studs (no thermal bridge) was reduced with added insulation (see Fig. 5)**.** In January (coldest winter month), the reduction was from 1.4°C to 0.6°C, and in July (warmest summer month) the reduction was only from 0.2°C to 0.1°C. The average for the year after refurbishment was 0.41°C. From this, the energy losses were calculated, and the calculated energy saving on average was 3.5 kWh/m^2 of wall surface in a year as a result of reduced thermal bridges at the studs.

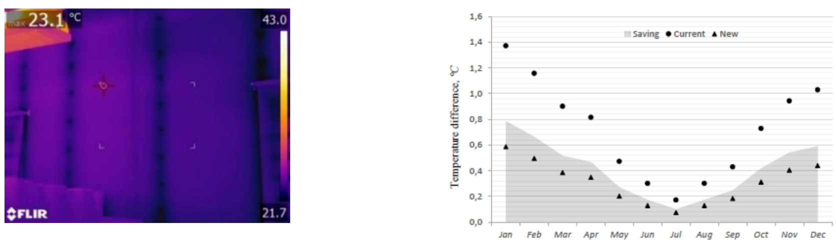

Fig. 5. Thermographic pictures show cold spots along the timber frame (studs). To the right, temperature difference calculated.

4.2 Moisture simulations and measurements

The DOF-THERM software calculations showed that for January, with outdoor temperature -12°C and indoor +20°C, there is risk of condensation on the outer wooden panels, and therefore a vapor proof barrier in the wall is important.

WUFI simulations of the walls with elements with 22 mm wood panels and 100 mm insulation showed that the outer wood panel in the northern wall will reach RH just over 80% during the winter months and the insulation closest to the outer panel will get RH 80–90% [13].

4.3 LCA

The LCA calculations show the climate impact of the renovation compared with the reduced climate impact of the energy savings according to IDA ICE simulations in 4.1. Energy for heating of the building comes from a district heating plant (biofuel). The results show that the reduced climate impact of energy savings over the lifetime of 50 years for a wall element with 100 mm insulation corresponds to the climate impact for renovation and maintenance (see Fig. 6).

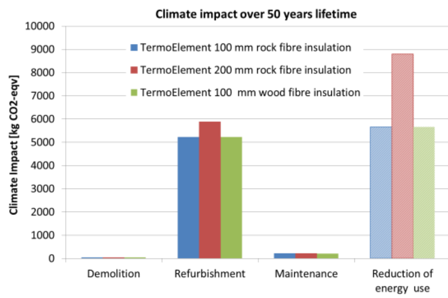

Fig. 6. Climate impact over 50-year lifetime compared to climate impact due to reduced energy use (patterned bar)

4.4 Execution stage - usability during renovation

When the old brick façade was removed, the fiberboard behind appeared to be in good condition. The removal was made before delivery of the elements, with all that this implies of exposure to the surrounding climate. Moisture measurements with a hand-held moisture meter (Delmhorst RDM-2S) about 30 mm into the wooden ground sill in several places showed MC between 17.5% and 22.8%, with an average of 19.8% (9 measurements), in the north façade, and between 13.5% and 19.0%, with an average of 15.4% (20 measurements), in the west and south façades.

Before the installation of the wall elements, a sill was screwed to the concrete foundation. The east wall near the hall had a different construction and was supplemented with studs, insulation and plywood before mounting the elements, and the concrete foundation wall was raised approximately 400 mm to avoid moisture impact from the ground near the garage door.

The elements were prefabricated and stored at the factory before transport, so that all elements were delivered at one time. They were unloaded and stored at the building site, covered with the packing for transport. The renovation started in November, and shortly thereafter, it started to rain and snow.

For old buildings, it is difficult to know precise measurements of windows and doors in advance, and the elements were therefore delivered without exact adaptions. The elements were 2.05 m and had low weight and were easy to handle and lift at the building site. There had to be some adjustments and cutting around windows and doors at the workplace.

There was some trouble with assembling elements because elements were stored and handled in wet and snowy weather on site, resulting in swelling of the wood and making the grooves too narrow and extra effort was needed to assemble the parts. This was labor-intensive banging with a hammer to bring together the element edges. Problems at the site with repacking and storage of elements after finished working days also increased the moisture impact on the elements. The rear was most difficult to fit as elements bent outward from the existing wall when simultaneously pulled together with straps. Average assembly time at the pilot project “Case Hedensbyn” was about 0.5 h/m^2 of façade when everything went well, and the assembly time was about 2–3 times longer where there were problems with the tongue and groove connections of the elements.

4.5 Conclusions and discussion

The renovation gives a certain energy saving in this case. The overall profit will not be that big, because the extra thermal insulation layer (100 mm) is relatively small due to the building conditions. The LCA calculations show that the saving of climate impact due to reduced heating energy during a service life of 50 years corresponds to the climate impact of the renovation measures. Moreover, the renovated building has, of course, an improved performance and a better indoor comfort level when the thermal bridges decrease. Environmental calculations show that with a thicker insulation, the reduction in climate impact during the use phase of the building increases more than the climate impact of the renovation. It also appears that there is a great potential to reduce climate impact from the wall element by selecting materials produced close to the element factory with a greater share of renewable energy as well as shorter transports.

From the data it can be concluded that, on average, the climatic conditions in the outer wooden layer are adequate in relation to little risk of mold or degradation due to high RH during normal use. Various software solutions have been used to evaluate the risk of condensation in the wall. All calculations show, in principle, similar results. Relative humidity will exceed 75–80% for shorter periods. However, the risk of condensation is very small (inside the outer wooden layer). The risk of microbial growth can be regarded as small. Probably, the wooden panel will absorb this moisture and even up the moisture content of the wooden panel, and no mold growth will occur. This will be followed up with sensor measurements during use.

WUFI® simulations had earlier been made for walls with Termowood elements with 40-mm multilayer wood panels and insulation thickness 250 mm [14]. Simulations over five years with climate data from Oslo, Norway, and indoor temperature 20–22 degrees did not indicate any risk of condensation on the outer panel. For only shorter periods, the relative humidity (RH) exceeded 80%, and moisture content (MC) in the external panel was less than 14.5%.

Assembly time per façade area was longer than expected, but then it should be taken into account that it was quite a small building, which usually means more time than average buildings, and it was a new type of prefabricated insulated element never tested for renovation before. A small construction project usually has a larger share of common jobs that affect the unit time for each building component. With improvements of tongue and groove joints, improved choice of element lengths and adaptations to fit existing building the installation process would be quicker and easier. A wider choice of element size (width and length) and improved batch packaging would also improve the speed of assembly and logistics at the building site. It appears that there is a great potential to reduce the assembly time with improved joints.

This paper shows the results for a single building, a small office building with quite thin added insulation. This building was suitable for a first test with this building system. Future studies on other types of buildings in other locations and climates are needed to further evaluate the system. Future work is also to improve the tongue-and-groove connection between elements to increase ease of application.

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