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Full-scale test of an old heritage multi-storey building undergoing energy retrofitting with focus on internal insulation and moisture

M. Harrestrup*, S. Svendsen [1]

Section of Building Energy, Department of Civil Engineering, Technical University of Denmark (DTU), Building 118, Brovej, 2800 Kgs, Lyngby, Denmark

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ABSTRACT

The hypothesis investigated in this article is: it is possible to carry out moisture safe energy renovations in the old existing multi-storey buildings with heritage value and still save 50% of the building's energy consumption by use of existing technologies. A holistic energy renovation on an old multi-storey building with heritage value was carried out. Focus was given to energy-saving measures that would preserve the original architectural expression of the building, such as internal insulation. Comprehensive measurements were performed on the energy consumption before and after the renovation to document the obtained savings. Numerical simulations were validated with the measurements in order to explain the savings and to carry out parameter variations on the energy saving measures. Since internal insulation was applied the durability and robustness were investigated and measurements of the temperature and relative humidity were performed in the wooden beams-ends embedded in the masonry brick wall. A solution where the insulation was stopped 200 mm above the floor was investigated. This increased the heat flows through the wall compared to a fully insulated wall, and calculations showed that the difference in the space heating consumption was 3 kWh/m^2/yr. The measurements showed the proposed solution should have no risk of moisture problems. The measured energy consumption was reduced with 47% whereas the theoretical reduction could be reduced with 39–61% depending on the room set-point temperature (20–24 °C).

1. Introduction

The EU roadmap aims at reducing greenhouse gas emissions and energy consumptions by 20% by 2020 and 80% in 2050 compared to 1990-levels [1] and Denmark has set an even more ambitious goal: being completely fossil-fuel-free by 2050 [2,3]. Energy retrofitting of existing buildings is vital for the achievement of reductions in energy use. However, challenges occur when it comes to retrofitting heritage buildings where the façade cannot be modified due to the architectural value of the building. Buildings with solid brick walls and wooden beam construction were constructed mainly in the period between 1850 and 1920. Approximately 20% of all dwellings in Denmark today are built within that period and represent a significant energy saving potential [4,5].

One study [6] investigated a holistic energy retrofitting of a multi-storey building with heritage value from 1930, which was constructed with solid brick façades and wooden beams. They found that it was theoretically possible to save 70% of the energy consumption without having to use external façade insulation. Funch and Graves [7] carried out a retrofitting of a historical building with solid brick walls and wooden beam construction and applied internal insulation at some facades. They found that it was possible to save 30% energy based on calculations but no further analyses were made on the use of internal insulation with respect to the moisture risk. Another study [5] investigated energy savings measures for the improvement of the thermal insulation of a building with solid brick walls and wooden beam construction. They concluded that it is possible to reduce the heat losses with 62% by applying internal insulation on the external facades, insulating the roof, and replacing the windows. These three studies are all based solely on calculations, whereas the research presented in this article also includes a comprehensive measuring program. Morelli et al. [8] studied different energy saving measures for heritage buildings and tested them in a test apartment. Measurements were

* Corresponding author. Tel.: +45 45 25 50 34.
E-mail addresses: marih@byg.dtu.dk (M. Harrestrup), ss@byg.dtu.dk (S. Svendsen).
[1] Tel.: +45 45 25 18 54.

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performed in the wooden beam-ends and in the interface between the brick wall and insulation and theoretical calculations of possible energy savings were carried out. They concluded that it was theoretically possible to save 68% of the energy consumption for the entire building and that the measurements showed no risk of mould growth or wood decay. The research reported here presents a similar analysis, but for an entire building block instead of only a test apartment. Also energy measurements are included, which was not the case for the research in Ref. [8].

Another study [9] carried out a retrofitting of a historical building, where internal insulation was planned. However, due to the risk of condensation they decided not to apply internal insulation. When the façade is insulated from the inside, the outer brick wall becomes cold and its drying potential is reduced. Condensation in the interface between the insulation and the brick wall can occur and can lead to mould growth [10]. Also the moisture and temperature conditions in the wooden beams are subject to change when internal insulation is applied so attention needs to be given to the risk of mould growth on the wooden surfaces and the risk of the wood decay, which, in extremis, can lead to fatal structural damage. Krebs and Collet [11] studied temperature and moisture content measurements in 30 wooden beam-ends. Insulation was applied at the interior at some walls and no insulation at others in order to compare the influence of the internal insulation. They concluded that wind driving rain did not have a significant influence and only a very limited risk for moisture problems in the beam-ends was present. Morelli and Svendsen [12] carried out a theoretical investigation on various intensities of wind-driven rain on façades using numerical simulation and [13] investigated the effect on the wooden beam-ends in a laboratory using vacuum insulating panels. Both studies concluded that wind driven rain has a great impact on the performance and durability of the wooden beam-ends. Kehl et al. [14] provided a literature review that also concludes that wind-driven rain has an important influence on the behaviour of moisture content and the risk of beam-end decay. The use of internal insulation is still in a grey zone when it comes to the safety with regards to possible moisture problems.

There is a need to find robust solutions for energy savings in the old heritage building stock. The solutions on the market today for heritage-valued buildings have still not been documented to the extent needed for the building sector to take responsibility for applying them on a large scale. While old heritage buildings have similar constructional trends, each is unique in their specific design, so solutions are difficult to standardize. There is a need to find standard solutions for the energy renovation of this segment of buildings that are technically feasible. Instead of aiming at saving the most energy, solutions that pay regard to finding a balance of energy savings and the durability in terms of reduced moisture risk needs to be in focus. Compared to the knowledge from the articles in the literature review this article presents new knowledge on full-scale tests of a multi-storey heritage residential building undergoing a deep and holistic energy renovation using internal insulation.

The aim of the research reported in the current paper was to set focus on creating solutions that save energy but also are moisture safe. The hypothesis is that it is possible to carry out moisture safe energy renovations in the old existing multi-storey buildings with heritage value and still save 50% of the building's energy consumption by use of existing technologies. A case study was used to test the hypothesis and an energy renovation was carried out in an old heritage multi-storey building. Internal insulation, new improved windows constructed to aesthetically match the old ones and mechanical ventilation with heat recovery was applied. Comprehensive full-scale measurements were carried out to demonstrate and document the obtained energy savings before and after the renovation and numerical simulations were compared with the measurements in order to evaluate the theoretical and actual savings against each other. Since internal insulation is an energy saving measure that could play an important role in the future energy renovations of heritage buildings, it is important to document the durability and robustness of it and find a compromise of reducing the heat losses through the wall and in the same time ensure moisture safe solutions. A comprehensive measuring program was established monitoring temperature and relative humidity (RH) in the wooden beam-ends embedded in the solid masonry wall in order to evaluate the risk of mould growth and woods decay.

2. Method

To evaluate energy savings the applied method compared theoretical calculations with full-scale measurements as described in the steps below. The applied method evaluated the durability of using internal insulation and was based solely on measurements in the wooden beam construction.

The first step was to document the energy consumption for the existing building before the renovation. The energy consumption for the existing building was calculated and validated with the actual measured energy consumption in the building. The calculations were carried out using the numerical building energy simulations software IDA ICE 4.5. The detailed simulation model is described under Section 3.2.1. The measurements for energy consumption before the renovation consisted of the average Space Heating (SH) and Domestic Hot Water (DHW) consumption over the period of 2007–2009.

The second step was to document the energy consumption for the renovated building. Heating consumption, including SH and DHW, and electricity consumption for ventilation were measured. The heating consumption was measured for the entire building and the relative use of SH was measured by heat meters on the radiator in all rooms. The electricity consumption for the ventilation was measured using HOBO loggers. The energy consumption for the renovated building was also calculated with IDA ICE and validated with the measurements monitored after the renovation. Real weather data was used as input in the simulation model.

After validating the model for the energy renovated building in IDA ICE *the third step* was to calculate the normalised annual energy consumption using standard weather data (Design Reference Year) (DRY) and user behaviour in order to be able to evaluate the results. Based on the normalised model the effectiveness of the various energy-saving measures implemented in the building were calculated in order to evaluate the influence of the individual energy saving measures.

The fourth step was to investigate the durability of the internal insulation and investigate whether it would lead to a risk of mould growth. Relative humidity and temperature measurements were carried out in the wooden beam-ends embedded in the masonry walls. A solution with 200 mm gap in the insulation above the floor was implemented, which is described under Section 3.3.2, and the reduced heat losses compared to the reduced heat losses of a fully internally insulated façade was estimated using Heat 2, which is a 2D heat transfer simulation software. Also the effect on the total building space heating consumption was estimated.

This method was applied in the context of a specific case study, as described below.

3. Case study – an old multi-storey building in Copenhagen with heritage value

The building is located in Copenhagen, Denmark, and was built in 1896. It is a multi-storey building with 6 floors with a heated area