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Retrofitting of a listed brick and wood building using vacuum insulation panels on the exterior of the facade: Measurements and simulations

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ABSTRACT

Many old listed buildings have an unsatisfactory thermal performance compared to the standards of today. The listing often limits the position and necessary thickness of an added insulation layer in the building envelope. Vacuum insulation panels (VIP) present unprecedented possibilities to reduce the required thickness of the insulation layer. The aim of this study is to explore the performance of VIP in the retrofitting of listed buildings. The goal is to improve the thermal transmittance and moisture performance of the wall and the thermal comfort for the occupants. Hygrothermal sensors were installed in the wall of a listed building insulated with VIP on the exterior. Sensors were also installed in a neighboring (non-retrofitted) wall as reference. Through a comparative analysis of the measured data it was concluded that the hygrothermal performance of the retrofitted wall was substantially better than of the reference wall. The measurement results were also compared to hygrothermal simulations to quantify the improvements in the thermal transmittance and moisture performance. A deviation was found between the measured and simulated relative humidity in the wall which was explained by vertical air leakage paths in the wall.

1. Introduction

Old buildings are often protected for their esthetical and historical contribution to the society. Around 10% of the 3 100 000 Swedish buildings are considered to have some preservation value. Although the total number of specified listed buildings in Sweden is uncertain, an investigation in 8 Swedish counties in 2010 showed that it can be roughly approximated to 67 000 buildings or about 2% of the Swedish building stock. To that number around 2600 buildings are added every year [1]. Many of these listed buildings have a low thermal performance of the building envelope compared to the standards of today, leading to a high energy use for heating and an insufficient thermal comfort for the occupants. It is a challenge to increase the thermal performance while maintaining the qualities of the buildings and historical areas of interest.

According to a study by the Swedish National Board of Housing, Building and Planning [2], approximately 31% of the Swedish multi-family buildings are suitable for a façade retrofitting. Because of technical or preservation reasons, 41% of the buildings are not considered suitable while the remaining 28% are dubious. Depending on whether the thermal insulation is placed on the interior or exterior of the existing structure, different hygrothermal conditions are yielded in the construction. From a building physics perspective, exterior insulation of heavy-weight buildings is to be preferred because it keeps the heavy wall elements temperate and dry, and it is more effective against thermal bridges than the interior insulation. In case of interior insulation, some treatment of the exterior wall surface is needed to reduce the potential damages caused by driving rain [3]. Examples of listed buildings that have been energy retrofitted are available in the literature [4–6]. As for Sweden, an overview of four listed retrofitted buildings from the 1940s to 1960s in Gothenburg was presented by Johansson [7]. All the buildings had a brick façade and brick or aerated concrete walls. The retrofitting measures involved adding 30–50 mm glass wool on the exterior of the external walls, protected by either a layer of render or a ventilated façade board. The calculated U-value was reduced from 0.83–1.73 W/(m^2 K) to 0.13–0.5 W/(m^2 K) after the retrofitting depending on the existing construction and which measure that was used. Capener et al. [8] also studied a brick building in Gothenburg which was retrofitted with an external thermal insulation composite (ETIC) system involving 50 mm glass wool and two

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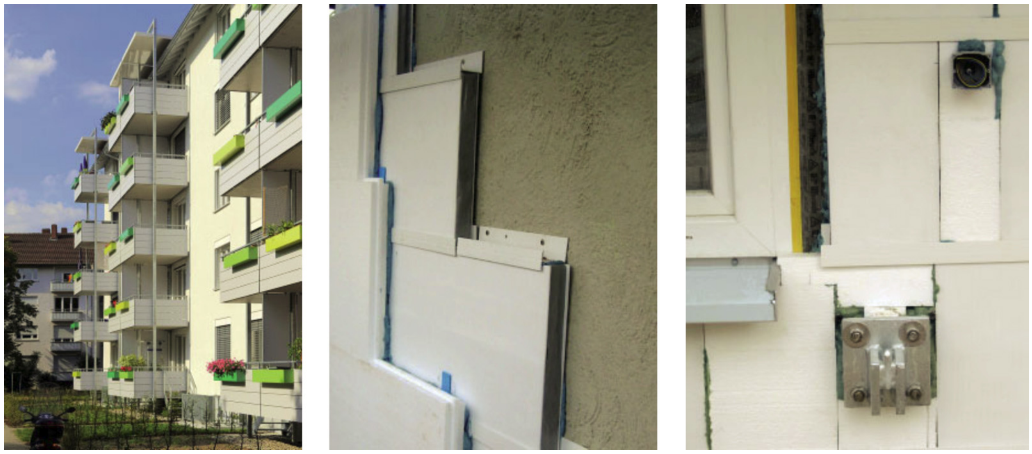

Fig. 1. VIP used in the retrofitting of a multi-family building in Karlsruhe, Germany. The 40 mm thick VIP was attached to the façade in a rail system and covered on the exterior by 50 mm EPS. The aim of the design was to maximize the surface covered by VIP.
Photo: Schöck Balkonsysteme GmbH, Brillux GmbH & Co. KG.

layers of external render. Measurements showed a 27% reduction in energy use and reduced moisture content in the wall. Another approach was proposed by Rasmussen [9] where 95 mm glass wool was added on the interior of a listed brick façade and 195 mm glass wool covered by render was added on the exterior of the remaining façades of a building from year 1900 in Copenhagen, Denmark. Often the thickness of the insulation layer is limited by the listing of the building since, in many cases, it is not allowed to change the exterior appearance of the façade, e.g. the depth of window placements and wall to roof connection. With high performance thermal insulation materials such as vacuum insulation panels (VIP), the required thickness of the insulation layer is reduced for the same thermal resistance. Alternatively a higher thermal resistance can be obtained with the same added thickness. Therefore it could be more appropriate to use VIP than conventional insulation materials when retrofitting the building envelope of listed buildings.

Examples of a number of different constructions where VIP has been used in retrofitted building envelopes have been reported in the literature. During 2002–2005 the international efforts in VIP research were assembled in the IEA/ECBCS Annex 39 High Performance Thermal Insulation (HiPTI). The project included monitoring and evaluation of 20 buildings with VIP in floors, roofs, walls, dormer windows and other constructions [10]. The number of case studies where VIP was used in façades is limited, but there exists studies of VIP used both on the interior [11,12] and exterior [13–15] of existing external walls. Some practical issues when retrofitting with VIP on the exterior were discussed by Zwerger and Klein [15] who investigated the use of VIP in an ETIC system such as the one presented in Fig. 1.

The aim of this study is to explore how VIP can be used when retrofitting listed buildings to improve the thermal transmittance and moisture performance of the walls and the thermal comfort for the occupants. The hygrothermal consequence of adding VIP to an existing construction is not well investigated. Most studies focuses on the thermal performance [16] and energy use [17]. However, there are exceptions where also the moisture performance was evaluated in laboratory investigations [18,19]. Dreyer and Korjenic [12] discussed the risk of damages to the existing construction due to the changed hygrothermal conditions in the wall.

In this study a brick and homogenous timber wall lacking thermal insulation was insulated on the exterior with VIP. The changed moisture performance of the existing structure and the influence by thermal bridges are analyzed and compared to an uninsulated reference wall. A pre-study where the retrofit design was investigated using a hygrothermal simulation tool was presented in [20]. The simulated temperature and relative humidity can now be compared to the 2.5 years measurements in the retrofitted wall. The simulations are refined using the measured indoor and outdoor climate together with more accurate material data and longitudinal air flow paths in the wall to explain the deviations between the simulated and measured hygrothermal performance.

2. Vacuum insulation panels

Vacuum insulation panels (VIP) are commonly used in refrigerators, freezers and cold shipping boxes where the space for insulation is limited. The component was introduced in the mid-1980s following the search for materials that could replace insulation materials which contained chlorofluorocarbons (CFCs), harmful to the ozone layer. The potential of using VIP in buildings was discussed by Simmler et al. [21] who argued that the energy use for heating of the old buildings in Europe could be reduced by a factor of three. This reduction leads to a decrease in the CO_2 emissions in the European Union by 8%, fulfilling the agreement by the European Union in the Kyoto Protocol. The higher thermal resistance of the VIP also increases the area which can be used for living by 9% compared to using conventional insulation materials in a single-family house [21]. However, VIP cannot be installed in buildings without considering the limitations of the component. The production of VIP results in rigid panels of defined shape and sizes which cannot be adapted on the construction site. The panels have to be treated carefully in all stages of the handling since damages eventually leads to loss of vacuum and a fivefold increase in the thermal conductivity. Over time, air and moisture leak into the VIP also leading to an increased thermal conductivity. The technical life time of a refrigerator is around 10–20 years, which is much shorter than what can be expected from a building. Buildings should typically last for 80–100 years without too much maintenance of the building envelope while VIP available today typically has a service life of around 25–40 years [22].

2.1. Core material and laminate

VIP is a composite which can be divided in two parts; the core material and the laminate, as shown in Fig. 2. The core material is a fine powder or fiber which is evacuated to pressures of 0.2–3 mbar and therefore should be able to resist the atmospheric pressure on the laminate, i.e. 0.1 MPa or 10 metric tons/m^2, without changing dimensions over time. The most common core material for VIP used in buildings in Europe is fumed silica while also glass wool and