In situ Measurements of Façade Retrofitted with Vacuum Insulation Panels

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Abstract

The goal to reduce the energy demand in the built environment applies also on listed buildings with special architectural and societal values. However, the possibilities of retrofitting façades of listed buildings are rather limited. This study concerns a 1930s multi-family building in Gothenburg where the ground floor is composed of 340 mm structural brick and the two upper floors of 80 mm structural timber walls. The façade is externally retrofitted using 20 mm Vacuum Insulation Panels (VIP), covered by 30 mm glass wool boards, which give a calculated reduction in U-value of 64%. Measurements of temperature and relative humidity in the wall from the period January 5 to March 22, 2011, are analyzed for the brick wall. The analysis show improved hygrothermal conditions compared to the case in a reference wall.

1. Introduction

The countries in the European Union have agreed on a reduction of the greenhouse gas emissions. The target is a reduction of 20% in 2020 and 50% in 2050, compared to the emissions in 1990. An identical target is issued by the Swedish Energy Agency concerning the energy use in the Swedish building stock. The need to reduce the energy demand in the building stock applies also on listed buildings with special architectural and societal values. However, the possibilities of retrofitting façades of listed buildings are limited as the appearance, nor the size (thickness), can be changed.

In listed buildings Vacuum Insulation Panels (VIP) might be one of the few solutions that are possible to use in order to decrease the energy use sufficiently so that the goals are reached. VIP is a novel thermal insulation material with a thermal conductivity of around 4 mW/m/K measured at the centre of the panel. With regard to ageing due to intrusion of gases and moisture, the thermal conductivity used in design is 8 mW/m/K. In case of a perforation of the panel, the thermal conductivity rises to 20 mW/m/K [1]. Moisture problems in the existing structure can arise if the insulation gets damaged and the temperature in the wall falls below the dew point.

Different examples of building parts insulated with VIP were investigated in the IEA Annex 39 HiPTI, active during 2002-2005. The conclusion from the annex was that VIP are feasible and could be an important mean for energy efficient buildings, but they were still too expensive to use on broad scale. However, studies on retrofitted façades with VIP show that they are possible to use [2]. An old semi-detached house in Nuremberg, Germany, was retrofitted with 15 mm thick VIP, secured by plastic rails, covered by an exterior layer of 35 mm polystyrene. Another system was tested in Bersenbrück, Germany, where 20 mm thick VIPs were integrated into 20 mm polystyrene on all sides. The panels were covered by 80 mm polystyrene on the exterior. In Trier, Germany, 12 terraced houses were partially equipped with a system of 20 mm VIPs laminated on both sides with polystyrene [3]. The investigations of the conditions after VIP was applied, focuses in all the above cases on the energy and thermal performance in the wall. The risk for moisture damages in an existing structure retrofitted using VIP, is not entirely clear.

The hygrothermal, i.e. heat and moisture, performance of an existing façade after retrofitting with a highly efficient insulation material has been investigated in [4]. The risk of mold growth in the wall needs to be studied to avoid risk of damaging the old construction. This paper is part of a doctoral student project where consequences on economy, building technology and energy efficiency caused by the integration of VIPs in an existing façade will be discussed. This paper presents the retrofitting case studied in the project, measurement layout and some initial results from the in situ measurements in the retrofitted façade, in comparison to a reference façade.

2. Retrofitted façade

For the study, a 1930s multi-family building in Gothenburg was chosen, see Figure 1. The building has three floors, where the ground floor is composed of 340 mm structural brick and the two upper floors of 80 mm structural timber walls. There is no additional thermal insulation in the walls. Over the exterior of the façade, there is a wooden cover boarding, separated from the load-bearing construction by a thin asphalt impregnated paper. On the interior of the wall there is a layer of reed and plaster which are bound together by wires. The windows in the building were changed in the 1970s, to a smaller size, fitted in the old window frame with glass wool insulation. Drawings and documentations of the technical details of the building are incomplete, thus the state before retrofitting is hard to evaluate.

Figure 1. The 1930s multi-family building in Gothenburg, retrofitted with VIP.

2.1. Theoretical U-value after retrofitting

In the beginning of the project, the entire façade was scanned by laser to find the exact dimensions of the wall and exact positions of the windows. The measurement showed that the total area of the façade is 133 m^2, whereof the two timber floors are 89 m^2 in total and the brick floor is 44 m^2. There are 12 windows on the façade measuring around 2.3 m^2 each varying in size and position. It was also found that the entire façade leans several cm between the corners.

One difficult part of the design was to attach the wooden cover boarding on the façade. The chosen attachment involves distances of glass wool boards, 50 mm wide and 20 mm thick, between the VIP. Glass wool has also been placed around the windows, to fill the space to the VIP and to correct the irregularities in positions. Over the entire VIP surface, 30 mm thick glass wool boards are mounted, and before the cover boarding there is a 38 mm wide air space, see Figure 2.

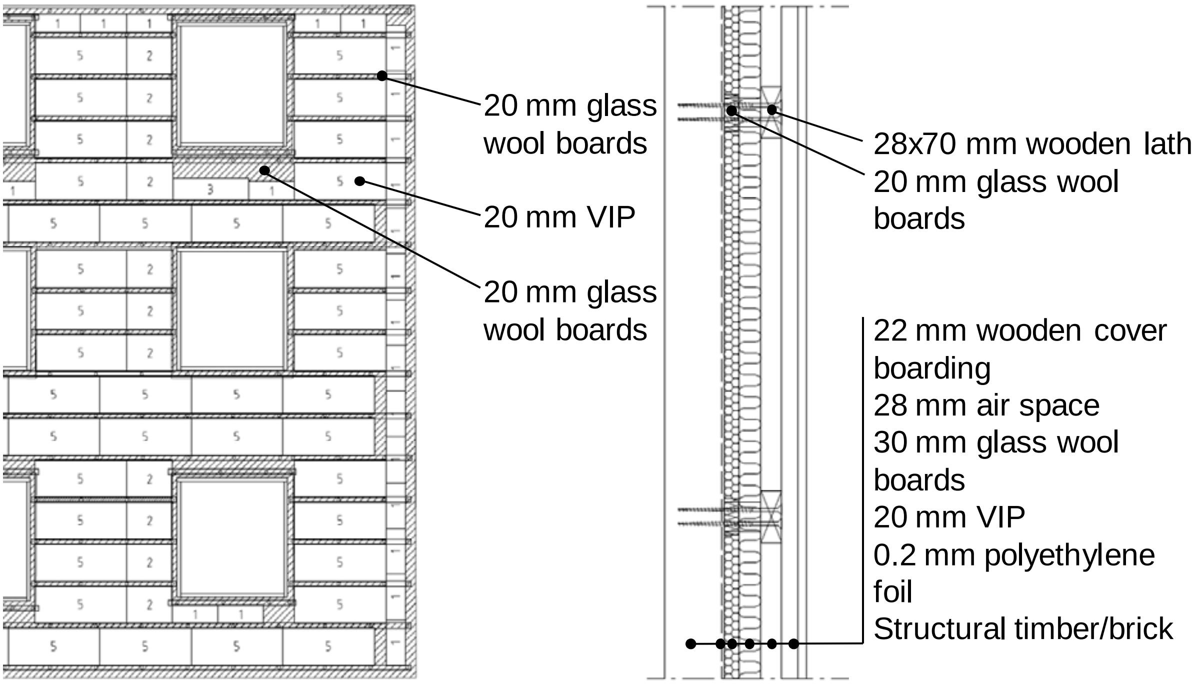

Figure 2. Wall layout after retrofitting with 20 mm VIP and 30 mm glass wool boards.

The original U-value of the wall is unknown, but numerical calculations with the software HEAT2 [5] show that it was around 1.12 W/m^2/K, both for the brick and timber walls. After retrofitting, HEAT2 calculations show that the U-value, without considering thermal bridges, is 0.23 W/m^2/K. Thermal bridges are created by the multi-layered foil around the panels and by the attachment of the cover boarding through the glass wool. The U-value increases to 0.40 W/m^2/K with thermal bridges, which means an increase by 74%. However, the calculated reduction in U-value is 64% after retrofitting.

2.2. Measurements in the façade

The aim of the measurements is to study how the existing structure is influenced when placing additional thermal insulation on the exterior and locate places where there is an increased risk of damages. Around the windows, only 50 mm glass wool insulation is added, which might cause risk for low temperature and possibly condensation. Three different positions around the VIP are interesting to study; behind the centre of the panel, at the VIP-VIP connection and where the VIP is connected to the 50 mm wide glass wool board laths. Figure 3 shows the principal locations of the sensors in the retrofitted wall.

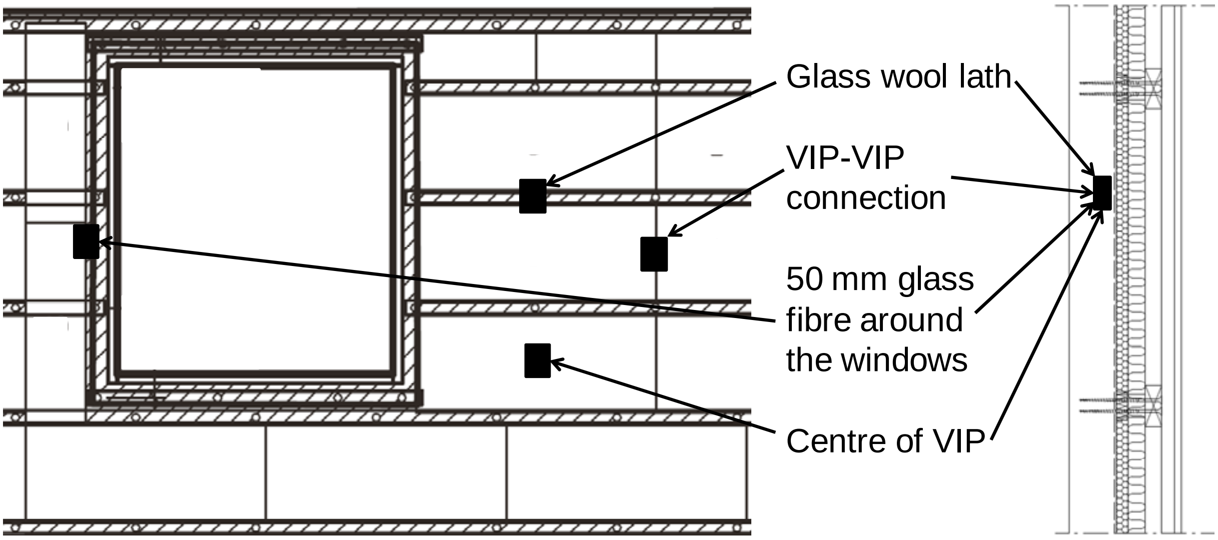

Figure 3. Locations of sensors in the retrofitted wall. All sensors are placed in the existing wall, on the interior of the polyethylene foil and VIP.

Inside the building, sensors are placed in four kitchens and on the exterior façade. The wall next to the retrofitted wall was chosen as a reference case, and one sensor is installed behind the cover boarding on the brick and wooden floors respectively. Measurement accuracy of the sensors is ±2.5% for relative humidity 10 to 90% and ±0.5°C at 25°C. The temperature can be measured between -40°C to 85°C [6]. The size of the sensors is 60x30x60 mm but they have been modified to become smaller, by removal of the pins measuring moisture content. In total there are 15 sensors installed at the site which send hourly readings through a wireless connection to a data acquisition gateway. The data is then transferred through a 3G connection to a network server.

3. Results

The hygrothermal sensors were installed in October, 2010 and deliver data each hour. However, problems with the wireless data transfer and erroneous software updates have caused major data loss during the autumn and winter. Only data from the period January 5 to March 22, 2011 is therefore presented in this paper. The brick wall is chosen for the analysis which is based on 24 hours moving averaged data. Figure 4 shows the temperature in the wall and indoors, compared to the reference wall, indoor and outdoor.

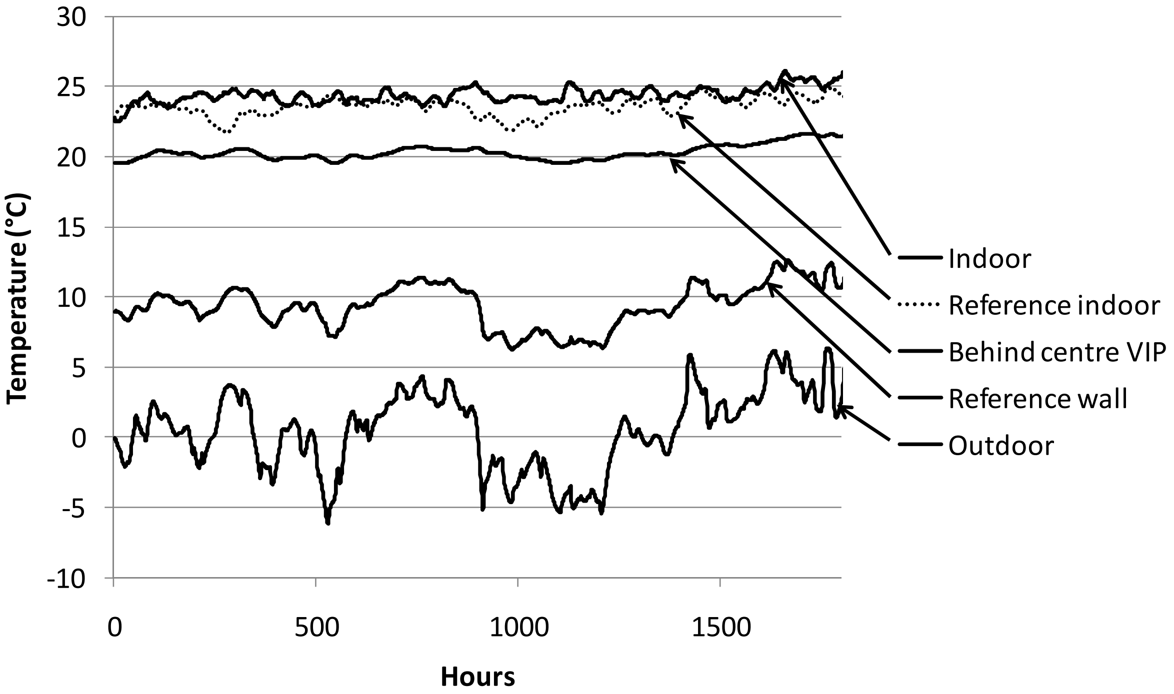

Figure 4. Daily averaged temperature behind the centre of the VIP and indoors, compared to the reference wall, indoor and outdoor. The measurement period is January 5 to March 22, 2011.

Indoor temperature is measured in the kitchen of the apartment closest to the location of the sensors in the wall. During the period, the temperature was on average 0.8°C higher in the kitchen with the retrofitted wall than in the reference kitchen. The higher temperature was caused by an unbalanced heating system in the building which caused the occupants to have their windows open very often, also during the cold season, and many technical appliances generating heat. However, with this fact taken in consideration, the temperature was on average 10°C higher in the retrofitted wall than in the reference wall. The corresponding vapor content is shown in Figure 5.

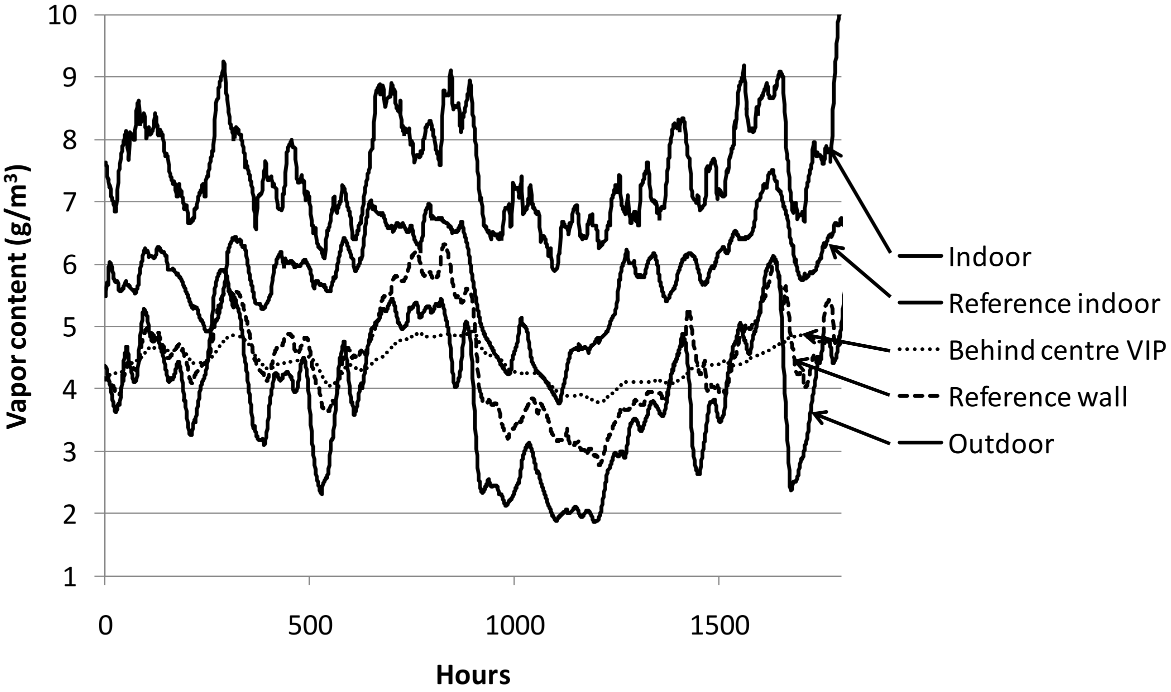

Figure 5. Daily averaged vapor content behind the centre of the VIP and indoors, compared to the reference wall, indoor and outdoor. The measurement period is January 5 to March 22, 2011.

The vapor contents in the air in the kitchens and in the reference wall were following the changes in the outdoor air closely. Behind the VIP, the vapor content was more stable with a slower response. The moisture supplies in the kitchens were 3.6 and 1.9 g/m^3, respectively in the retrofitted part and the reference part, which means that the retrofitted wall was exposed to a heavier moisture flux than the reference wall. The brick behind the VIP and in the reference wall had a similar moisture supply, on average 0.5 g/m^3. However, the temperature influence gave an average relative humidity of 22-27% with an average of 25% in the retrofitted wall, and 37-62% with an average of 50% in the reference wall.

The hygrothermal conditions on different locations in the wall, see Figure 3, can be studied. One sensor in the brick wall was mounted on the wrong location, which means that two sensors are located behind the glass wool laths and none behind the VIP-VIP connection. The temperatures at the different locations are presented in Figure 6.

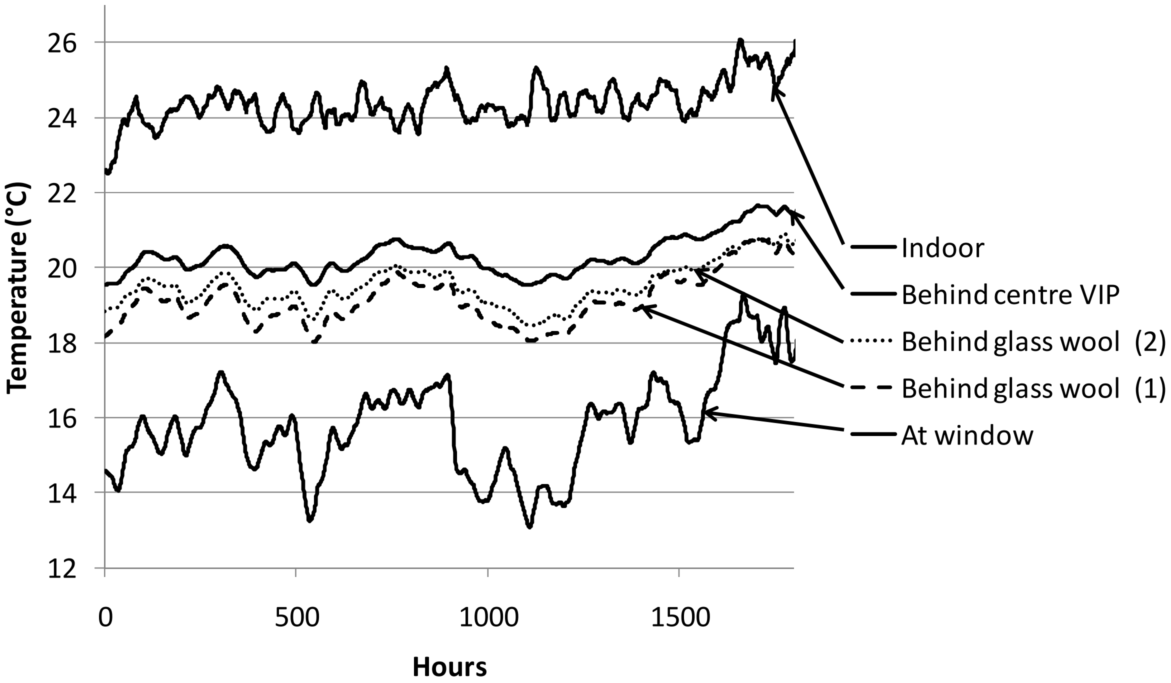

Figure 6. Daily averaged temperatures in the brick wall at different locations behind the VIP. The measurement period is January 5 to March 22, 2011.

All the temperatures measured during the period were following the same pattern, influenced mainly by the outdoor temperature. The temperature next to the window was lowest which was expected since there was least insulation around that location. The influence by the glass wool laths on the temperature was on average 1°C, compared to behind the centre of the VIP. There was a difference between the two measurements behind the glass wool of 0.4°C. The measured vapor contents are shown in Figure 7.

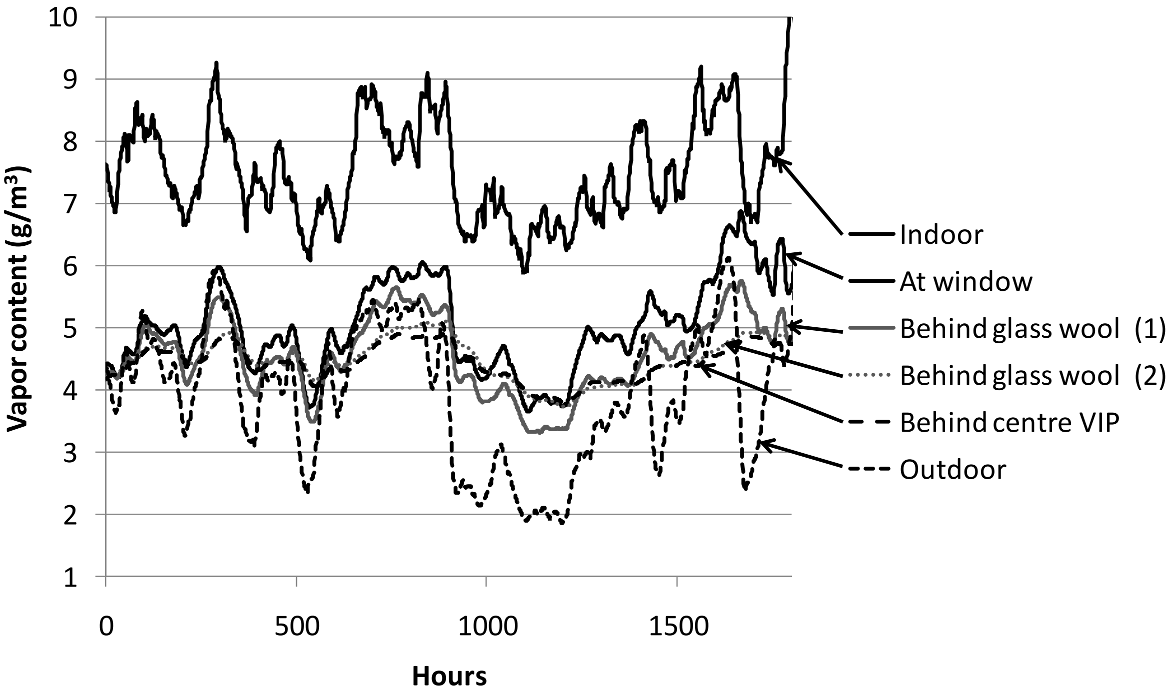

Figure 7. Daily averaged vapor contents in the brick wall at different locations behind the VIP. The measurement period is January 5 to March 22, 2011.

The vapor contents in the wall were higher than outdoors for most of the measured period. Indoors, at the window and at one of the locations behind the glass wool laths, the vapor content was following the changes in the outdoor air faster than in the two other locations. Behind the VIP and at one of the glass wool laths, the response to changing vapor content was slower. The reason for the difference could be a crack in the wall where an air flow is induced. Figure 8 shows the relative humidity at the different locations in the wall.

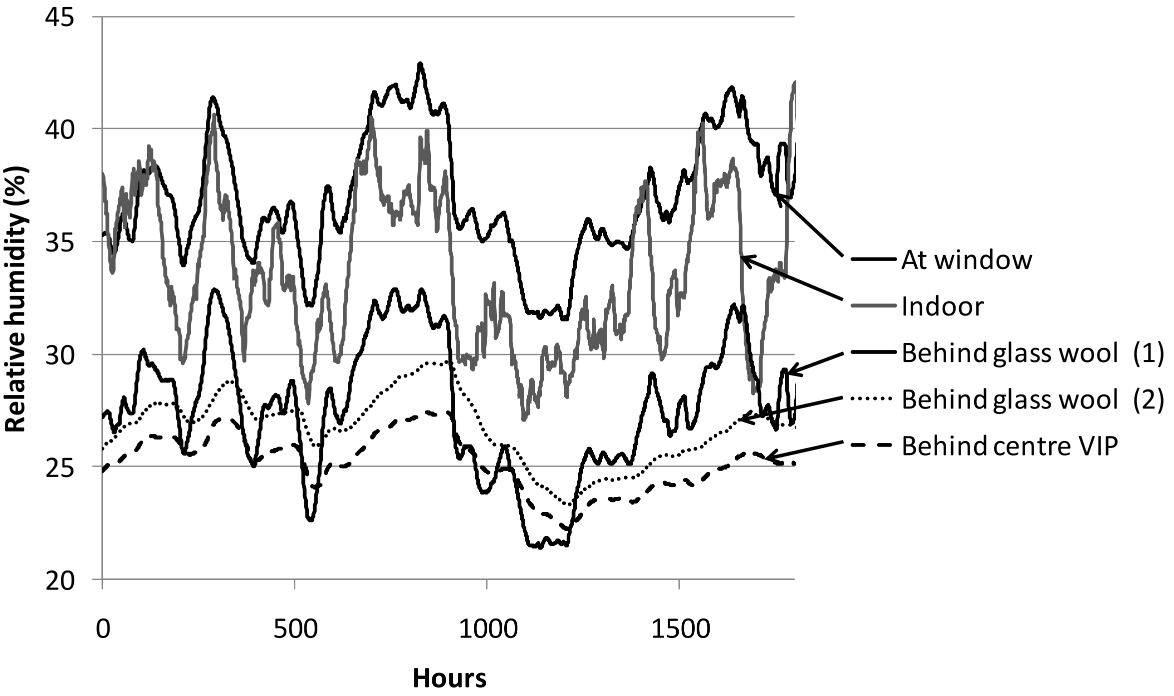

Figure 8. Daily averaged relative humidity in the brick wall at different locations behind the VIP. The measurement period is January 5 to March 22, 2011.

The relative humidity was low at all measured locations of the wall. At the window, the relative humidity is highest, varying between 32-43% with an average value of 37%. There was a difference between the two glass wool lath measurements; one case vary between 21-33% and the other case between 23-27%. However, the difference on the average relative humidity was only 1%.

4. Conclusions

A façade of a protected building was externally retrofitted using 20 mm VIP covered by 30 mm glass wool. After the retrofitting, temperature and relative humidity sensors are monitoring the wall at 15 different locations. For the part of the wall with load-bearing brick, the measurements during the first cold period showed that the relative humidity was lower in the retrofitted wall, compared to a reference wall.

Different locations around the VIP were monitored by the sensors. After the first cold season it can be concluded that the different locations had different hygrothermal conditions. As expected, the temperature was lowest at the window attachment and at the thermal bridges, compared to behind the centre of the VIP.

Future studies involve continued monitoring of the retrofitted wall, together with deepened analysis of the hygrothermal performance of the wall, such as calculations using the mold growth index. Also numerical simulations are needed in order to evaluate the causes of the differing results at the measured locations.

5. Acknowledgements

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