Assessment of the Risk for Mold Growth in a Wall Retrofitted with Vacuum Insulation Panels

Pär Johansson, M.Sc. [1]

[1] Chalmers University of Technology, Sweden

KEYWORDS: *vacuum insulation panels, retrofitting, multi-family building, window attachment, simulation*

SUMMARY:
Although the preservation of old buildings is important, it is also important to reduce their energy use. One possible solution to this challenge is to increase the level of thermal insulation in the exterior walls. This paper illustrates how novel vacuum insulation panels were used to increase the energy efficiency in the façade of a Swedish multi-family building from the 1930s. The durability of the chosen design was evaluated by numerical simulations of temperature and relative humidity in the wall. The hygrothermal performance of the wall assembly was studied based on different design options. The added thermal insulation changed the thermal properties of the wall. Before retrofitting, the outer part of the wall was exposed to larger shifts in temperatures during the warm and cold season than was the case after retrofitting. WUFI simulations showed that the moisture content of the wall is expected to decrease after retrofitting.

1. Introduction

In order to attain the targets set by the European Union to reduce greenhouse gas emissions by 20% from 1990 to 2020, existing buildings need to be more energy efficient (European Commission 2008). Limits on energy use have been implemented for newly constructed buildings, and focus is now shifting towards the existing building stock (Boverket 2010). The required efficiency can be obtained by combining different retrofitting measures such as heat recovery of the ventilation air and additional thermal insulation in the building envelope (Dalenbäck *et al.* 2005).

One way of reducing the energy use in existing buildings is to add thermal insulation to the exterior walls. Applying the insulation on the interior or exterior part of the wall yields different moisture content in the existing wall assembly. Although thick exterior insulation may change the original appearance of the building, exterior insulation is recommended for a sustainable moisture condition in the existing wall (Künzel 1998). A method for reducing the required thickness of the insulation layer is to use vacuum insulation panels (VIPs). The panels consist of a textile fiber-reinforced, carbon-opacified, fumed silica core wrapped in a multi-layered metal and polyester foil. To ensure low gas conduction through the panel, a vacuum of 1-5 mbar is applied, which gives a thermal conductivity of 4 mW/(m·K) through the panel. However, with regard to the thermal conductivity of the foil and connections between panels, a recommended design value of 8 mW/(m·K) should be used. The panels are fragile and the thermal conductivity of a perforated panel is 20 mW/(m·K) (Simmler *et al.* 2005).

The hygrothermal consequences of adding vacuum insulation panels to an existing wall is studied in a façade on a three storey 1930s multi-family building in Gothenburg, Sweden. The basement and ground floor walls of the building are composed of brick masonry, and the two upper floors are timber. The part of the timber wall below the window attachment is studied numerically in HEAT2 and WUFI to assess the changes in the hygrothermal performance caused by the changed thermal conductivity of the wall. The existing building structure is treated as a dry construction where the impact of the moisture conditions due to diffusion moisture profiles is studied. Rain penetration and wind pressure through the façade are neglected in the study. Only the risk for mold growth in the existing wooden structure is evaluated why no general conclusion based on other durability problems will be drawn. This paper is the first 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 only presents the initial results from hygrothermal simulations of different retrofitting designs.

2. The building

The building chosen for the study is a typical County governor's house (landshövdingehus) of Gothenburg, built in 1930. Today there are over 1 400 similar buildings in the Gothenburg region. There is no thermal insulation in the exterior walls, except that which is created by the 80 mm thick timber walls on the first and second floors and the 340 mm thick brick masonry on the ground floor. Between the structural wall and the wooden cover boarding, there was originally an asphalt impregnated paper, protecting the wood from exterior moisture. Though 80 years have passed since the building was built, the original wooden cover boarding was still in good condition. The exterior aesthetics of the building, see FIG 1, is protected by Swedish legislation as a cultural environment of national interest, which puts high demands on the design of the retrofitting solution.

FIG 1. The studied multi-family building with ground floor masonry walls and first and second floor walls with structural wood (not shown here). The façade to the right of the firewall is retrofitted with vacuum insulation panels and the left façade is kept as reference.

2.1 Retrofitting design

Vacuum insulation panels are sensitive to mechanical influence and demand an even surface when mounting them in the façade. The workmanship is another factor that should be handled with great care (Simmler *et al.* 2005). The existing wooden cover boarding was replaced with new panels of similar dimensions and the asphalt impregnated paper was replaced with a polyethylene vapor retarder, outside of the existing load-bearing structure, see FIG 2.

The chosen retrofitting design was to add 20 mm vacuum insulation panels, glued to the polyethylene foil. Around the windows, mineral wool was used to fill the distance from the panels. The mineral wool was needed because of the differing dimensions of the window attachments. To protect the vacuum insulation panels from damage during construction and afterwards, a 30 mm thick mineral wool board was applied on the entire façade. An air space of 28 mm was created between the new cover boarding and the mineral wool board, see FIG 2.

Wind and driving rain can cause large pressure differences through the façade since it is facing the southwest direction. The air barrier in the design is located behind the ventilated air space in the dense mineral wool boards. Also the VIPs and polyethylene foil are airtight. The connection between the walls and the windows is a crucial detail that has to be designed carefully to make it airtight. A special sealing membrane that is expanding when in contact with moisture has been used in the space between polyethylene foil and window frame.

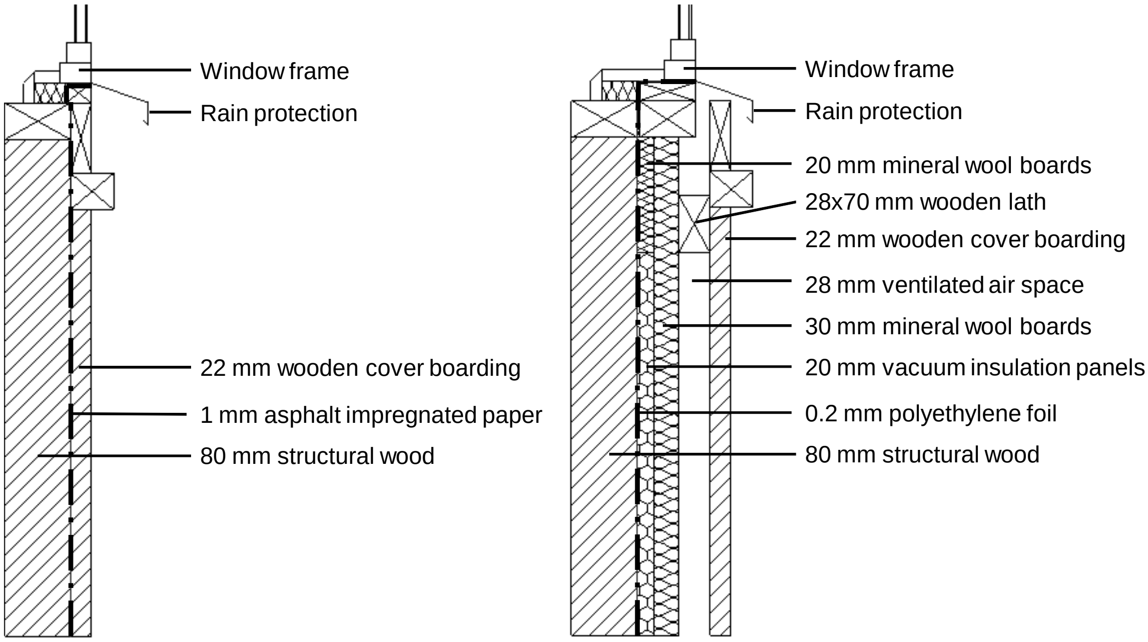

FIG 2. Wall with window attachment in the original wall (left) and in the chosen retrofitting solution (right) with specified materials and thicknesses.

2.2 Input data for numerical simulations

Hygrothermal performance assessment of the wall, see FIG 2, was based on stationary calculations in HEAT2 and transient hygrothermal simulations in WUFI 2D. The thermal and moisture properties of the vacuum insulation panels are different for the silica core and the surrounding multi-layered foil, see TABLE 1. As the foil is designed to stop gases from penetrating to the silica core, it is also vapor retardant. The foil is anisotropic since it consists of a number of layers of aluminum and polyester. The thermal conductivity in the radial direction is lower than in the longitudinal direction because of the additional thermal resistance caused by the polyester layers.

TABLE 1. Material data for the simulations: silica core in vacuum (1) and ambient pressure (2) and multi-layered foil in radial (3) and longitudinal (4) direction (Tenpierik & Cauberg 2007).

#	Thickness [mm]	Bulk density [kg/m^3]	Porosity [m^3/m^3]	Specific heat capacity [J/(kg·K)]	Thermal conductivity [mW/(m·K)]	Water vapor diffusivity [-]
1	19.8	200	0.9	850	5	1.3
2	19.8	200	0.9	850	20	1.3
3	0.1	189	0	134	540	Inf.
4	0.1	189	0	134	200 000	Inf.

In the WUFI simulations, the outdoor climate was based on measured data for a year in Gothenburg with an average of 8.8°C and 74% relative humidity. The interior climate was based on EN 15026 for the Gothenburg climate with a normal indoor moisture load, i.e. 60% relative humidity during summer and 30% relative humidity during winter. The initial conditions for the materials in the wall were 15°C and 70% relative humidity.

Closest to the indoor environment, a 20 mm thick interior gypsum board faced the structural wood. For the interior surfaces, a sd-value of 0.1 m and a surface heat transfer coefficient of 8 W/(m^2·K) were used. The exterior surface had an added sd-value of 0.3 m, and the heat transfer coefficient was wind dependent; the short wave radiation absorptivity was 0.3 and the long-wave radiation emissivity was 0.94. The rain absorption coefficient was 0.7. The airflow through the façade is neglected in the simulations and the ventilated air space treated as a non-ventilated air space.

2.3 Method of evaluation: mold growth potential

Temperature and relative humidity in different parts of the wall are rendered by numerical simulations. However, the analysis of the risk for moisture problems, e.g. mold growth in the wall, cannot be based only on these parameters. For this reason, the mold growth potential developed by Hukka and Viitanen (1999) was used to make it possible to derive the risk for mold growth in the wall and compare between different wall designs.

The mold growth potential is based on measurements of the mold growth on different wooden surfaces. The temperature on a surface, T , is used to calculate the critical relative humidity, φ_{crit}, using Equation 1.

$$\varphi_{crit} = \begin{cases} 100\%, T < 0\,°\text{C} \\ -0.00267 \cdot T^3 + 0.160 \cdot T^2 - 3.13 \cdot T + 100.0\,\%, 0°\text{C} \le T \le 20\,°\text{C} \\ 80\,\%, T > 20\,°\text{C} \end{cases} \qquad (1)$$

The relative humidity in a material varies with the changing temperature, which is also the case for the critical conditions for mold growth. The mold growth potential, Equation 2, is a ratio that takes these temperature dependencies into consideration.

$$m = \frac{\varphi(T)}{\varphi_{crit}(T)} \text{ [-]} \qquad (2)$$

Where φ current relative humidity (-)
φ_{crit} critical relative humidity, Equation 1 (-)

There is a risk for mold growth when the relative humidity in a material exceeds the critical relative humidity. This is the case when the mold growth potential is higher than 1. The risk for mold growth in the wall can be shown by studying the mold growth potential during a longer time period. Different design alternatives can be evaluated based on the time that the mold growth potential exceeds 1.

3. Results

The stationary simulations in HEAT2 showed that there is a risk for mold growth in the wall when considering the average climate for Gothenburg in October, 8.6°C and 81% relative humidity, and the indoor climate 20°C and 58% relative humidity, i.e. an indoor moisture supply of 3 g/m^3. The mold growth potential for the materials closest to the vapor barrier, between the structural wood and the vacuum insulation panels, was calculated. Four cases were studied: with or without 30 mm mineral wool and evacuated or penetrated vacuum insulation panels, see FIG 3. Indicated in the figure are the thermal bridge created at the interface between the mineral wool and multi-layered foil surrounding the vacuum insulation panels.

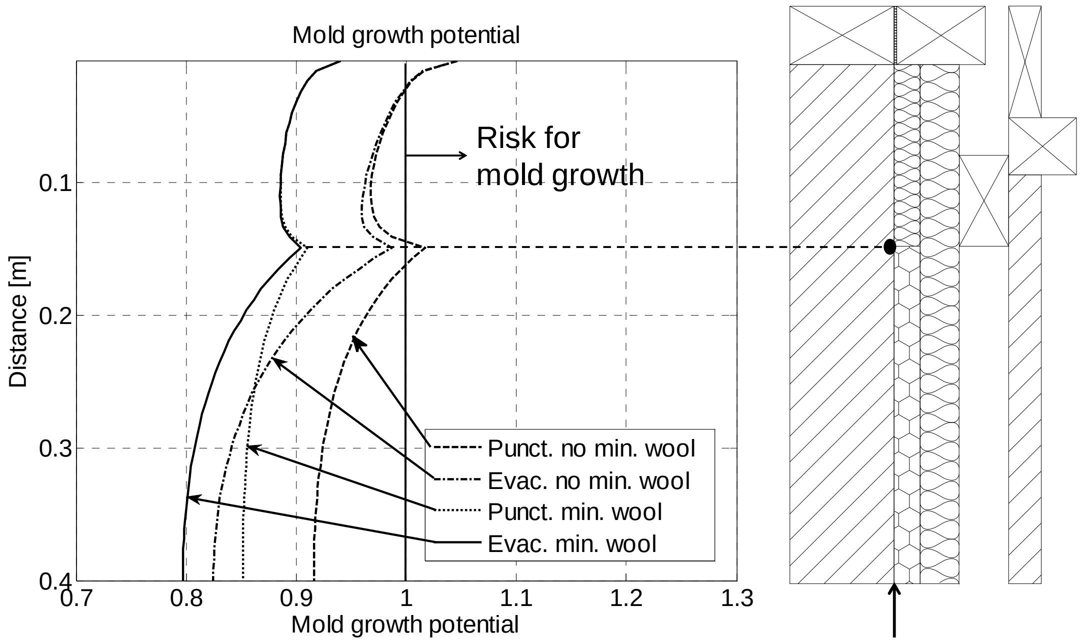

FIG 3. Mold growth potential for the wood closest to the vapor barrier, indicated by the arrow. Four cases are studied, of which the two without mineral wool exceed the critical relative humidity. There is only 20 mm thermal insulation in these cases and a total of 50 mm in the other two.

FIG 3 shows that there might be a risk of moisture damages in the wall. In WUFI a parametric study was performed to take the dynamic effects from the heat and moisture buffering capacity of the materials into account. In FIG 4, the results from five years of simulation, starting in October, of four cases (before retrofitting, VIPs without 30 mm mineral wool, VIPs with 30 mm mineral wool, but without 28 mm air space and VIPs with 30 mm mineral wool and 28 mm air space) are presented.

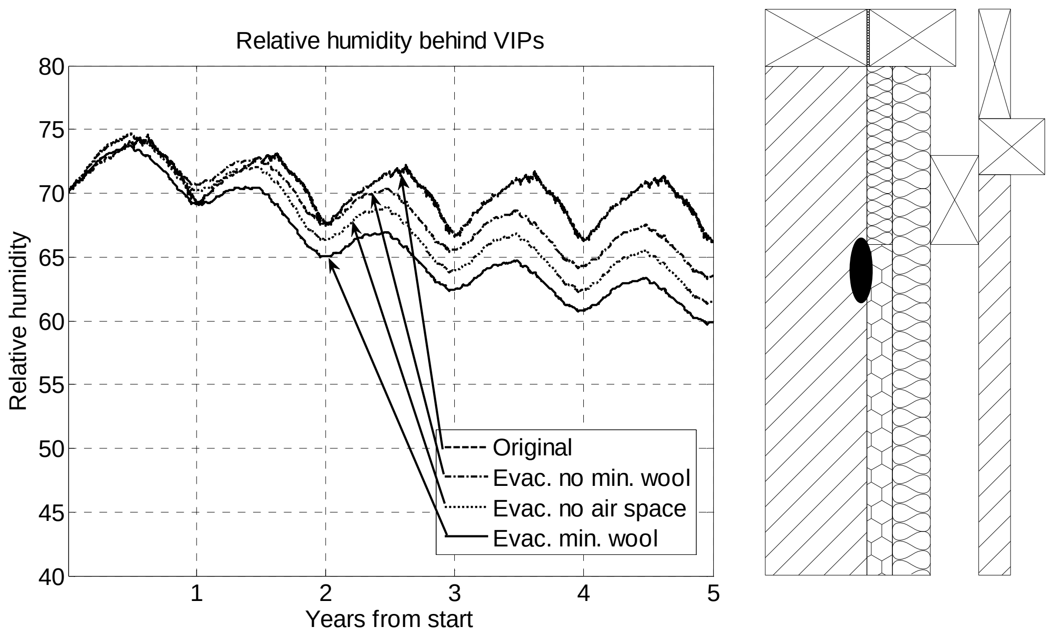

FIG 4. Relative humidity in the wood behind the vacuum insulation panels (marked by the dot) for the original wall, evacuated panel without mineral wool, without air space and with both mineral wool and air space. The relative humidity is constantly below the critical relative humidity and decreases towards a stable level.

During October 2010, temperature and relative humidity sensors were activated in the kitchen of one of the apartments on the second floor of the building. Results from these measurements showed that the indoor air temperature remained constant around 25°C and the relative humidity was between 30 to 50%. In order to take account of these increased heat and moisture fluxes in the apartment, WUFI simulations with a higher indoor temperature and relative humidity were done, see FIG 5.

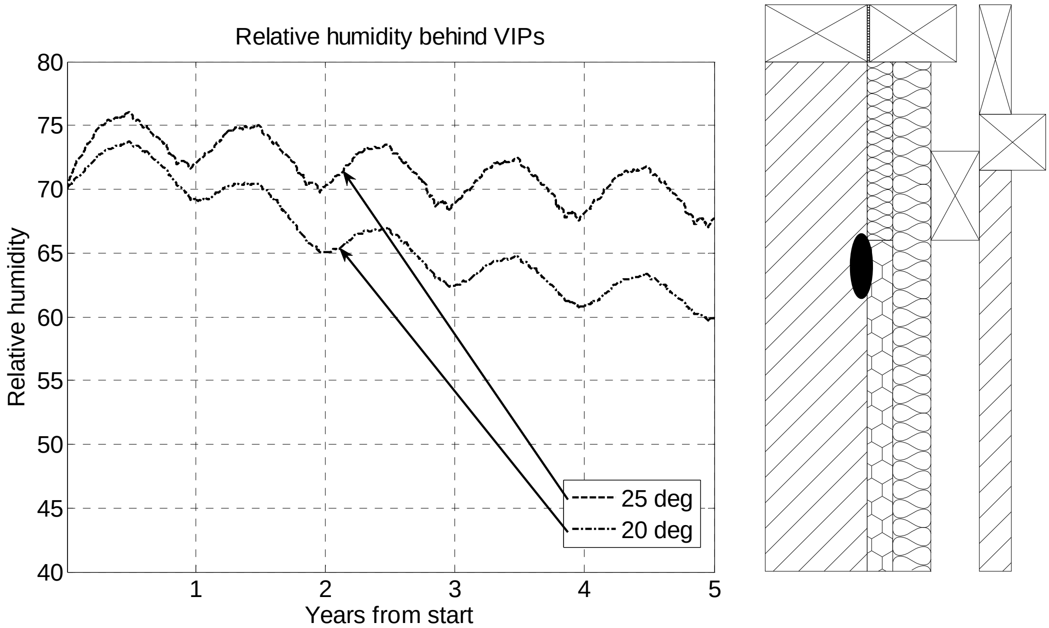

FIG 5. Relative humidity in the wood behind the vacuum insulation panels (marked by the dot) for the chosen retrofitting solution. The warmer indoor climate raises the relative humidity in the wall.

The case with a higher indoor temperature generated a larger heat and moisture transport into the wall from the apartment than the case with a lower temperature did. The wall is drying out slower in the case with higher indoor temperature than in the case with a lower temperature. Problems are not likely to occur since the relative humidity is below the critical level for mold growth in the wood.

The time it takes for the wall to dry after a moisture leakage has occurred might be prolonged after the retrofitting, since the added polyethylene foil only allows inward drying. FIG 6 shows the time it takes for the wall to approach equilibrium after a material containing 65 gram water is added to the construction on the interior of the polyethylene foil.

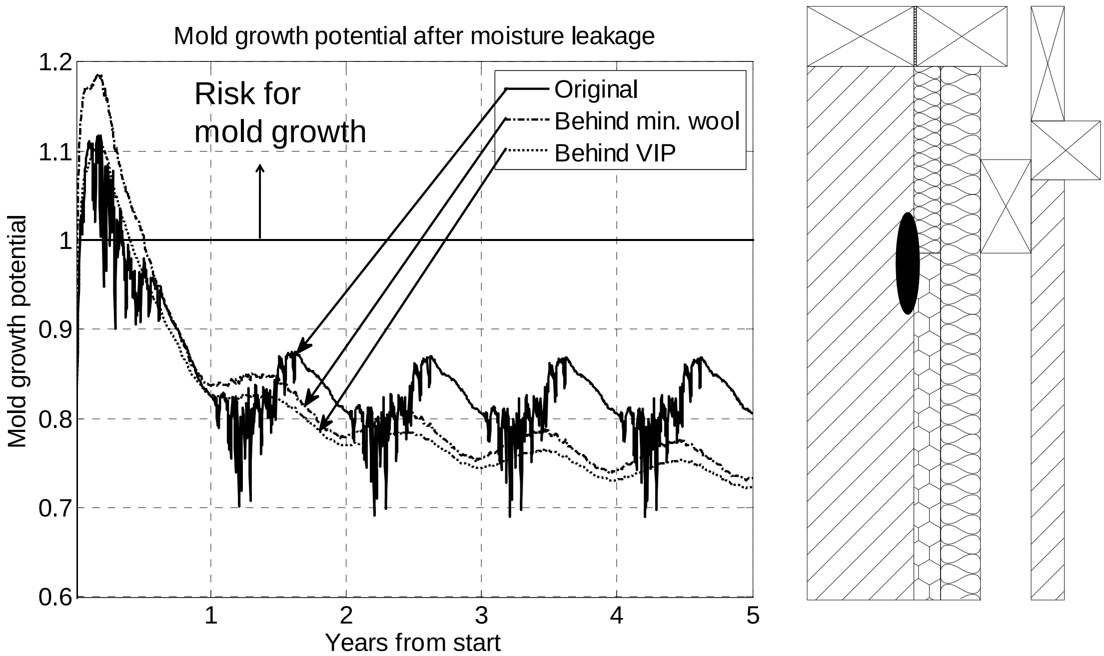

FIG 6. Mold growth potential for the wood in the original wall, behind the mineral wool and vacuum insulation panels, respectively, after a moisture leakage has occurred on the interior of the polyethylene foil (marked by the dot). The mold growth potential is higher behind the mineral wool boards than behind the vacuum insulation panels. The wood in the original wall dries faster than the wood placed behind the mineral wool and vacuum insulation panels.

After approximately 137 days, the wood behind the vacuum insulation panels has dried so that the mold growth potential is below the critical level. For the wall behind the mineral wool it took approximately 179 days to reach the same state. In the wood behind the asphalt impregnated paper in the original wall there was risk for mold growth for 100 days.

4. Conclusions

A façade in a three story 1930s multi-family building in Gothenburg, Sweden was insulated with vacuum insulation panels. The building had a brick masonry ground floor and two upper timber floors. With vacuum insulation panels, the thermal insulation was increased substantially without changing the appearance of the building. The timber wall was studied in HEAT2 and WUFI to obtain the stationary and transient hygrothermal conditions in the existing load-bearing timber construction after retrofitting.

The wall with 20 mm vacuum insulation panels, 30 mm mineral wool and 28 mm air space showed lower relative humidity and mold growth potential than did the other evaluated alternatives. Comparing the original wall with the different retrofitting designs showed that it could be improved using all the evaluated designs.

The stationary calculations of the wall indicated a high mold growth potential in the parts close to the thermal bridge between the mineral wool and multi-foil envelope around the vacuum insulation panels. Transient simulations, taking the dynamic heat and moisture buffering capacities of the materials into account, showed that the mold growth potential did not reach critical levels. However, if a moisture leakage on the interior of the polyethylene foil would occur in the wall, the time it take for the wall to dry increase if it is insulated with vacuum insulation panels. The drying is started in October which is followed by the cold season which to some extent could explain the long time that the materials in the wall are exposed to critical moisture conditions.

Vacuum insulation panels are very fragile and must be stored and handled with great care to avoid damage and perforation. The simulations in this study have shown that there are no major consequences to the moisture conditions in the wall assembly in case of a perforated panel. Still, the large potential energy savings are lost if a panel is perforated. Therefore it is recommended to take care in the design phase and spend time on the details and attachment solutions.

Still remaining to be investigated is how a continuous moisture leakage into the wall would affect the conditions of the wood behind the mineral wool and vacuum insulation panels. Also, the effects on the panels themselves by high moisture content in the surrounding materials need to be investigated further. The increased temperature in the existing wall might lead to less moist conditions that are drier than what the old structural wood can manage. Moisture induced movements and cracking in the wall due to drying might have an effect on the service life of the vacuum insulation panels.

5. Acknowledgements

The work is supported by the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning (FORMAS) and the public housing corporation Familjebostäder i Göteborg AB.

References

Boverket. 2010. EU-direktivet om byggnaders energiprestanda - konsekvenser och behov av förändringar i det svenska regelverket: En redovisning av Boverkets regeringsuppdrag N2010/1474/E. Karlskrona, Sweden: Boverket.

European Commission. 2008. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - 20 20 by 2020 - Europe's climate change opportunity. Retrieved from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52008DC0030:EN:HTML:NOT.

Dalenbäck, J.-O., Göransson, A., Jagemar, L., Nilsson, A., Olsson, D., & Pettersson, B. 2005. Åtgärder för ökad energieffektivisering i bebyggelse - Underlagsmaterial till Boverkets regeringsuppdrag beträffande energieffektivisering i byggnader (M2004/4246/Kb). Gothenburg: Building Services Engineering, Chalmers University of Technology.

Hukka, A., & Viitanen, H. A. 1999. A mathematical model of mould growth on wooden material. Wood Science and Technology, 33(6), 475-485.

Künzel, H. 1998. Effect of interior and exterior insulation on the hygrothermal behaviour of exposed walls. Materials and Structures, 31(2), 99-103.

Simmler, H., Brunner, S., Heinemann, U., Schwab, H., Kumaran, K., Mukhopadhyaya, P., et al. 2005. Vacuum Insulation Panels. Study on VIP-components and Panels for Service Life Prediction of VIP in Building Applications (Subtask A): IEA/ECBCS Annex 39.

Tenpierik, M., & Cauberg, H. 2007. Analytical models for calculating thermal bridge effects caused by thin high barrier envelopes around vacuum insulation panels. Journal of Building Physics, 30(3), 185-215.