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Interior insulation retrofit of a brick wall using super insulation materials: design of a field testing in an industrial brick building

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ABSTRACT

The societal demands on a more energy efficient building stock in Sweden creates challenges to find suitable retrofitting measures. One of the measures currently discussed is to use interior insulation. This measure leads to a reduced temperature in the wall, which increases the risk for elevated moisture levels in the wall. When the thickness of the insulation layer is limited, super insulation materials (SIM) may be used. SIM can be divided into advanced porous materials, such as aerogel blankets (AB), and vacuum insulation panels (VIP). Often moisture from the outside is the major moisture source why a solution may be to apply a water repellent substance on the surface. A previous study showed that it is difficult to predict all the uncertainties in the laboratory using hygrothermal numerical simulations. This paper presents the design of a field investigation of a homogenous brick wall where AB and VIP are installed as interior insulation.

KEYWORDS

Listed building, brick wall, interior insulation, super insulation material, moisture

INTRODUCTION

The demands on a more energy efficient building stock in Sweden creates challenges to find suitable retrofitting measures. Around 25% or the energy use in buildings in Sweden is used in buildings from before 1941. Out of these buildings many are built in brick masonry and have not been renovated before, which means they are practically non-insulated. The energy use in these buildings can be reduced by adding insulation to the walls. The conventional thermal insulation materials, such as fiber glass and EPS, often demand a thick layer of insulation to reach the energy targets. Super insulation materials (SIM) are thermal insulation components with a 2-10 times higher thermal resistance than the conventional insulation materials. The thermal transmittance (U-value) of the building envelope can thereby be substantially reduced using a limited additional insulation thickness.

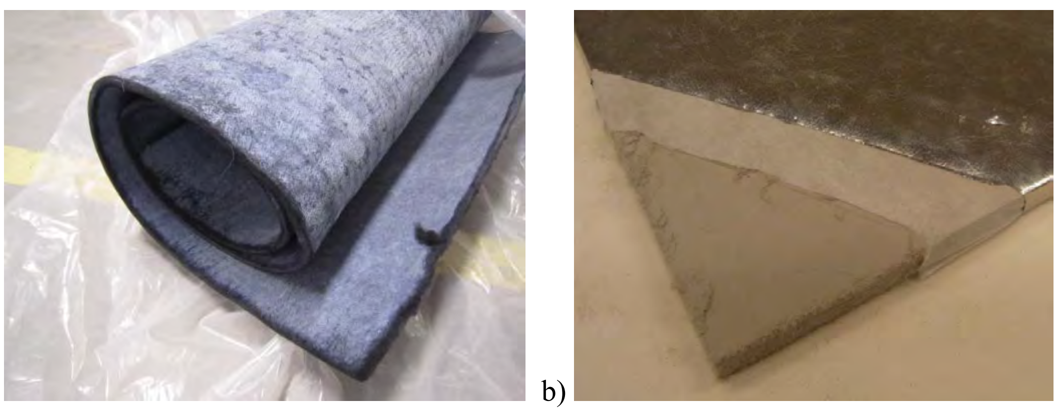
Additional insulation can be added either to the interior or exterior side of a wall. Exterior insulation is preferred since the hygrothermal performance of the wall is in many cases improved compared to interior insulation. Interior insulation leads to a reduced temperature in the wall which increases the risk for elevated moisture levels in the wall (Künzel, 1998). Also, internal connections, such as intermediate floor beams, make it difficult to reach a continuous layer of insulation, thus resulting in large thermal bridges. Earlier research has shown that interior insulation decreases the drying-out capacity of the wall and thereby increases the risk for freeze-thaw damages in brick walls. In older brick constructions there is risk for frost damage when they are exposed to driving rain and fluctuating temperatures. Internal insulation can increase the risk of structural damages even more (Mensinga et al., 2010).

Often moisture from the outside is the major moisture source. Consequently, one solution may be to apply a water repellent substance on the surface. This measure leads to less moisture into the construction (Sandin, 2003). There are several different impregnations available which can be applied to the surface of the façade. However, for brick masonry it is important to make sure that the surface is free from cracks and other defects. Otherwise, the impregnation can have adverse effect on the performance of the façade, since the drying out capacity is decreased while water can still enter the cracks. Slapø et al. (2017) tested four different impregnations on a brick wall with fresh mortar. They recommend great care when using the substances on brick walls in areas with much driving rain and frequent freeze-thaw cycles.

This paper presents results from a laboratory study of a brick wall and the first results from a field investigation of a homogenous brick wall insulated on the interior. Hygrothermal simulations in WUFI 2D were used to predict the hygrothermal performance for different designs. Previous studies have shown that it is difficult to predict the real performance of full-scale wall assemblies in the laboratory. For instance it is not possible to replicate old brick masonry walls in the laboratory and the climate is difficult to simulate (Johansson et al., 2014a). This calls for investigations in the field. Here, an old industrial brick building located in a cold and moist climate was selected where aerogel blankets (AB) and vacuum insulation panels (VIP) were installed as interior insulation. There were challenges to implement the internal insulation in the building. One of these was the ground water rising in the brick masonry which had to be taken into account.

INTERNAL INSULATION WITH SUPER INSULATION MATERIALS

When the thickness of the insulation layer is limited, SIM may be used. Two examples of SIM are AB and VIP, see Figure 1. VIP are rigid panels which cannot be cut on site and are sensitive to puncturing. Therefore, attention has to be paid in the design of details and envelope components. AB are more similar to conventional fiber-based insulation materials. They can be cut at the construction site and adapted to the specific measurements. VIP were first tested in buildings in the early 1990s which were later followed by several case studies both in laboratory and in the field. AB have been installed in various building assemblies since the early 2000s (Adl-Zarrabi & Johansson, 2018).



a) b)

Figure 1. Super insulation materials; a) aerogel blanket (AB), b) vacuum insulation panel (VIP).

Among the important material properties for building materials are thermal conductivity, heat capacity and vapor diffusion resistance. The hygrothermal properties for AB and VIP differ subtantially. The thermal conductivity of AB is 0.015-0.020 W/(m·K) and 0.002-0.008 W/(m·K) for VIP (Heinemann, 2018). The vapor diffusion resistance of AB is around μ=5 which is a factor five higher than mineral wool. The blankets are coated with a water repellent substance which reduce the liquid water transfer. The VIP on the other hand, are wrapped in an air and moisture tight metallized multi-layered polymer laminate which gives a vapor and liquid water transfer only at the edges between the VIP (Johansson et al., 2014b).

NUMERICAL SIMULATION AND LABORATORY STUDY RESULTS

Up until the early 1900s, hydraulic lime mortars were used in brick masonry buildings in Sweden. These have large tolerances to movements caused by temperature and moisture fluctuations, while one of the disadvantages is the longer curing time compared to mixtures of lime and cement mortar. In a previous numerical study to design a laboratory study (Johansson et al., 2014a), a mortar with a short curing and adhesion time, but with similar hygrothermal properties as the hydraulic lime mortar, was desired. To resemble the properties of an old brick wall it was also important to use a brick and mortar similar to what was used in Sweden during this time period. It was shown that the moisture content in the wall was highly influenced by the properties of the brick and mortar. The time before the walls were saturated differed with a factor of 6 between the least and most permeable bricks while the type of mortar influenced the drying of the wall. The mortar giving the lowest drying rate was the pure cement mortar while the mixture of lime and cement gave a lower drying rate than pure lime mortar.

In the numerical study, a historical brick was investigated with a thickness of 250 mm and a 10 mm thick layer of fine lime cement mortar between the bricks (Johansson et al., 2014a). On the interior of the bricks, 4 cases were simulated:

1) reference wall without insulation ($h = 8$ W/(m^2·K), $s_d = 0.2$ m),
2) vapor barrier (high performing) on the interior ($h = 8$ W/(m^2·K), $s_d = 1\,500$ m),
3) 60 mm AB ($h = 0.242$ W/(m^2·K), $s_d = 0.2$ m),
4) 20 mm VIP (moisture resistance as vapor barrier) ($h = 0.242$ W/(m^2·K), $s_d = 1\,500$ m).

The initial conditions of the materials were 20°C and 50% RH and the interior climate was 20°C and 40% RH. The exterior climate was based on the HAMSTAD benchmark with an exterior surface heat transfer coefficient of 25 W/(m^2·K) and a wind dependent vapor surface transfer coefficient. The walls were well protected with a rain water absorption factor of 0.1, i.e. a small amount of rain was available for capillary absorption assuming that the remaining water runs down the façade or splashes off at impact. The results from the one-dimensional numerical simulations of the four cases are shown in Figure 2.

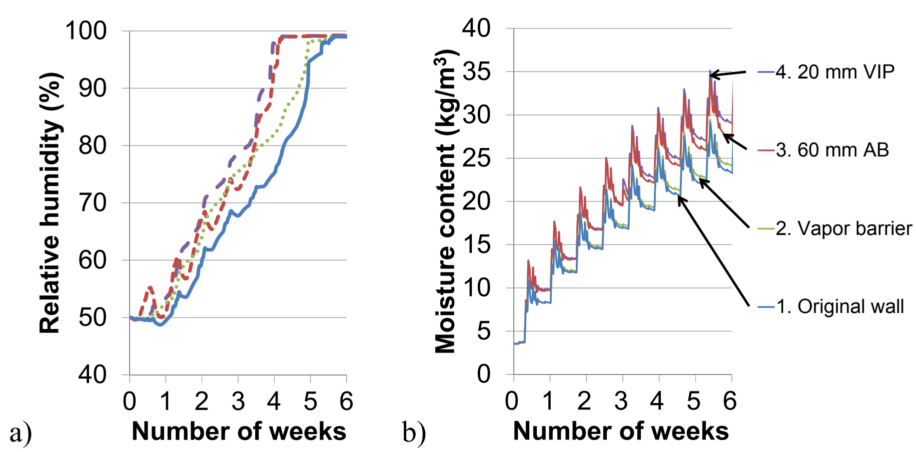


Figure 2. a) Numerically simulated RH 60 mm from the interior of the brick. b) Numerically simulated moisture content in a 250 mm thick wall (adapted from (Johansson et al., 2014a)).

Adding a vapor barrier to the interior of the brick wall does not change the total moisture content in the wall compared to the case without the vapor barrier. However, at the location 60 mm from the interior surface of the brick, the RH is higher than without the vapor barrier. This is caused by the restricted drying from the interior surface of the wall. In the two walls with a layer of interior insulation, both the RH and the moisture content increases compared to the case without interior insulation. The wall with the vapor open insulation has a slightly lower RH and moisture content than the wall with VIP. The main part of the vapor and water flow in the wall is caused by the rain on the exterior surface. Thus, the indoor moisture load is of minor importance for the conditions studied here.

Based on the results above, a brick wall was built in the laboratory of NTNU and SINTEF Building and Infrastructure in Trondheim, Norway. The wall was tested in a large-scale building envelope climate simulator where it was exposed to a temperature gradient and cycling climate with driving rain. The wall was first tested with 20 mm VIP on the interior and then without any layer on the interior side. The wall was divided in two parts (upper and lower) by a horizontal ledge made by a rubber strip to stop liquid water from being transported along the wall. Even though the temperature in the wall was lower in the case with interior VIP, the RH in the upper part of the wall increased more in the wall without VIP. For the lower part of the wall, the RH increased slower on the interior surface of the brick during the first few days, but was then equal to in the middle of the wall. The time before all sensors reached 100% was 180 h for the wall with interior VIP and 170 h for the wall without VIP.

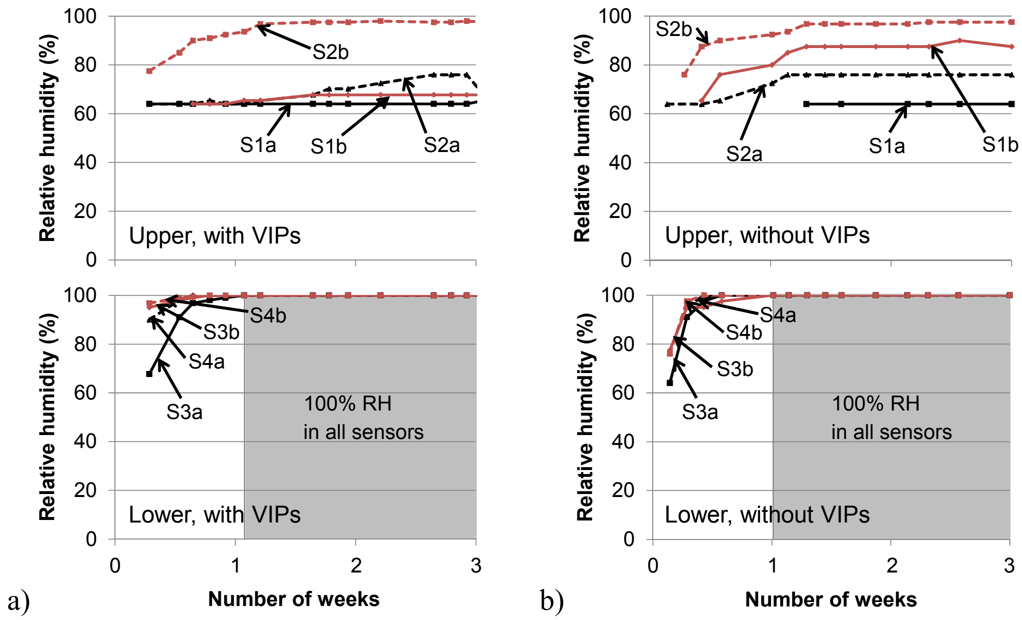


Figure 3. Measured moisture content: a) with VIP in the upper and lower parts of the wall. b) without VIP in the upper and lower parts of the wall. The sensors were located in the mortar in the middle of the wall (S1b-S4b) and in the mortar on the interior surface of the brick (S1a-S4a) (adapted from (Johansson et al., 2014a)).

CASE STUDY BUILDING

An old industrial brick building south of Gothenburg on the Swedish west-coast is under initial testing for evaluation of AB and VIP on the interior of the wall. The building was constructed in 1896 and has been reconstructed several times since then. The case study building was used for paper production which was in operation until the paper mill was closed in 2005. Left deserted, the building was vandalized and degraded rapidly due to the cold and humid climate. The remaining heritage values and character defining elements of the building have been evaluated and one of the features that are considered important is the brick façade. Therefore, interior insulation is thought to be an interesting solution to reach sufficient energy performance. A small room was constructed inside the building with insulated (170 mm mineral wool) floor, walls and roof and the exposed brick wall, see Figure 4.

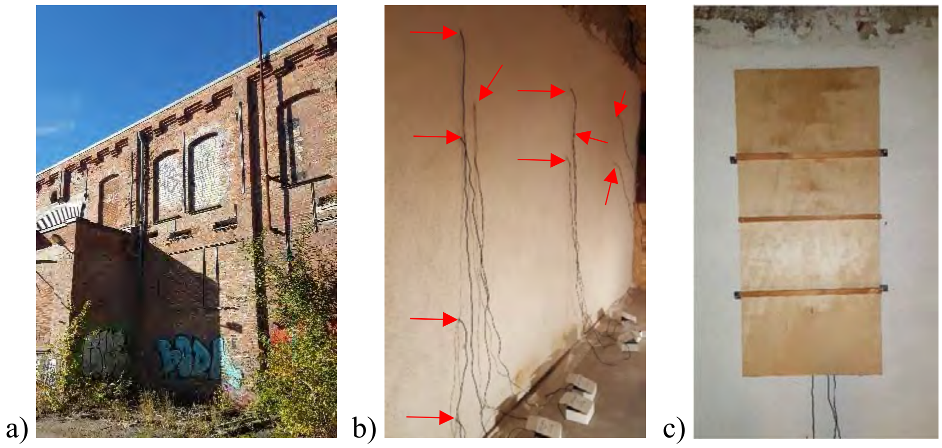


Figure 4. a) Industrial building from 1896 in south of Gothenburg, b) Sensors (marked with arrows) in the brick in the plastered brick wall, c) The test room with installed VIP and AB (removable for inspection of the wall).

Prior to the installation of the internal insulation, the existing plaster was removed from the interior brick surface. There was substantial capillary suction from the ground. The initial measurements showed that the rate of water flow in the bricks is approximately three times higher than that in modern bricks. The room on the inside of the brick wall was heated to around 22°C and ventilated by natural ventilation through two openings. The air in the room was circulated by a fan to create homogenous temperature and moisture conditions in the entire room. The temperature and relative humidity of the air is measured by three sensors. The measurement accuracy is ±2.5% for relative humidity in the range of 10 to 90% and ±0.5°C for temperature at 25°C. The temperature can be measured between -40 to 85°C (GE Sensing, 2007). A weather station monitors the outdoor temperature, relative humidity, wind speed and rain intensity on a free field, nearby the façade.

The brick wall is divided into three parts (500 x 1,200 mm) where AB and VIP is tested and compared to a non-insulated reference. The wall is equipped with 10 hygrothermal sensors that every hour register the temperature and relative humidity. The sensors are wireless Sahlén sensors (wood moisture sensors) which measure the weight percentage moisture in a piece of birch around the sensor. The measurement range corresponds to 60% to 100% RH. The size of the sensors is 40 mm x 13 mm (height x diameter), inserted in a 15 mm wide hole in the wall.

In the field study building, the temperature and relative humidity were measured during 20 December, 2017, to 29 January, 2018. The temperature was on average 4.1°C and varied between 0.9°C and 9.5°C. The relative humidity was on average 92.8% and varied between 66.7% and 100%. This can be compared to the outdoor temperature and relative humidity in a nearby weather station which was on average 3.0°C and 87% relative humidity. The outdoor temperature varied between -7.9°C and 10.0°C and the relative humidity varied between 48.0% and 100%. This gives a moisture excess of 0.8 g/m^3 in the building. The moist and cold climate give several challenges for the application of internal insulation in the field study building. Consequently, the installation of the AB and the VIP was delayed until mid-June, 2018.

CONCLUSIONS

A brick wall was insulated on the interior with AB and VIP to evaluate the hygrothermal performance before and after this measure. In a previous study, hygrothermal numerical simulations and laboratory measurements showed that it is important to investigate the amount of moisture from driving rain. The properties of the interior insulation material showed to have a lesser influence on the moisture accumulation rate. The rain load was the dominating factor determining the vapor and water transport in the wall. Having the possibility of inward drying lowered the moisture accumulation rate slightly. However, during dry periods with less rain, the VIP reduce the drying capacity of the moisture in the brick. In the end it was difficult to predict all the uncertainties in the laboratory measurements using the hygrothermal numerical simulations. This calls for field investigations.

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