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Long term monitoring of repaired external wall assembly

Susanna Ahola[a*], Jukka Lahdensivu[b]

[a]Ramboll Finland Oy, P.O. Box 718 FI-33101 Tampere ,Finland
[b]Tampere University of Technology, P.O. Box 600 FI-33101 Tampere, Finland

Abstract

This study discusses on hygrothermal performance of external wall assembly based on long term observation on relative humidity and temperature in layered external wall assembly, when the resistance of water vapor in insulating material is higher than in the main framing of the studied building. In this case the location of the vapor barrier must be examined more closely.
In 1974 completed building the facade of the building was made from concrete and bricks. The external wall assembly was repaired by replacing the thermal insulation and facade brickwork. The original brick-insulation-brick structure was unventilated like those used to be until mid-1980s. The repaired outer layer was constructed with a ventilation gap which satisfies the building codes in force. Old thermal insulation was replaced with aluminum foil backed polyurethane insulation. The aim of the study was to verify that the new structure was performing properly by measuring the circumstances inside the new external wall assembly. The performance of the repaired external wall was monitored by sensors installed in four depths and in five different locations in the building. Each of the sensors measured relative humidity and temperature for two years.
The repaired external wall assembly was observed to be performing correctly. The aluminum foil backed polyurethane insulation functioned as planned as wall assembly's thermal insulation and vapor barrier. Condensation of the indoor air into the structure was not detected during the measurement period. Neither was the outside air's relative humidity condensed outside the vapor barrier during the measurement period. There was no observation of the condensation neither in the ventilation gap, nor in the fire resistant mineral wool layer during the measurement period, in any inside or outside circumstances.

Peer-review under responsibility of the organizing committee of the 11th Nordic Symposium on Building Physics.

Keywords: Brick-insulation-brick structure; monitoring; relative humidity; condensation; diffusion

* Corresponding author. Tel.: +358 40 5163028
E-mail address: susanna.ahola@ramboll.fi

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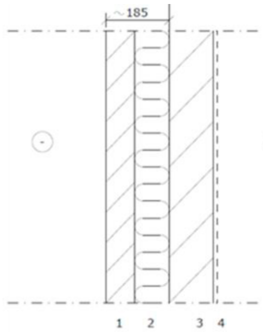
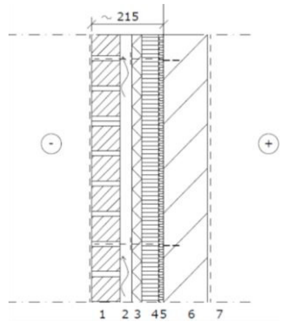
1. Introduction

The study discusses on hygrothermal performance of external wall assembly in listed educational building situated in mid-Finland. The building was completed in 1974 and completely renovated in 2012. This study concentrates on both reparation of the original brick-mineral wool-brick external wall assembly, and monitoring the on the success of the reparation. Structures of wall assemblies are shown in Figs. 1 and 2.



Structures
1 Fair-faced brick 85 mm
2 Mineral wool 100 mm
3 Fair-faced brick 130 mm

Fig. 1 The original external wall assembly



Structures
1 Fair-faced brick 85 mm
2 Ventilation gap 40 mm
3 Wind barrier insulation 30 mm
4 Polyurethane insulation 50 mm
5 Mineral wool mat 10 mm
6 The original fair-faced brick

Fig. 2 The repaired external wall assembly

1.1 Moisture sources of external wall assembly

Common sources of moisture in walls are air leakage in vapor barrier and accidental water leakage. In addition, the following sources were identified critical in this study:

Wind driven rain
The most important moisture source for external wall assembly is wind driven rain. The higher building, the more wind driven rain facades will get [1]. In Finland wind driven rain comes with south-west to south-east winds. Roughly it could be stated that in coastal areas of Finland 60 % of wind driven rain hits to facades while the share in inland is only 40 %. The difference is based on the higher wind speed during rain events in coastal area than inland [2]. The average wind speed during rain event in coastal area is 8 m/s and in inland 4 m/s. The amount of rain in coastal area is approximately 600 mm/a, and in inland app. 450 mm/a. [3]. Together with higher wind speed during rain events, facades in coastal area gets a lot more wet than in inland.

Brick is porous material and its capillary wetting receptivity and receptivity speed are high. Relatively thin brickwork could be totally saturated during rain.

Convection
In well performing ventilated wall structures convection is not normally an issue. But because of bad labor work, ventilation gap might be too narrow and mortar has a contact to inner wall structures. This phenomenon has been detected in several cases. Moisture from wet brickwork could connect to thermal insulation and other parts of wall assembly if mortar is connected to the thermal insulation in some parts of the wall assembly.

However, both wind driven rain and convection should not be an issue after the external wall assembly has been renovated, but they had very important role in degradation of the original one.

Diffusion
Moisture content difference in pore structure of material or in the air tends to stabilize during the time. Moisture tend to move due diffusion to lover moisture content, which means, that the direction of moisture flow will change according to moisture level of studied material. In external wall assembly this means moisture flow from outside to inside during rain events in summer time and from inside to outside during cold season.

In the cavity wall, where the outer layer consists of brickwork, saturated brickwork keeps the relative humidity of air in the ventilation gap relatively high during several hours after rain has been stopped. The air change rate on the ventilation gap depends strongly on windiness and temperature difference between ventilation gap and outdoor air. Usually air change rate is very small because of small ventilation holes in lower part of brickwork. In normal outdoor air circumstances the air change rate in the ventilation gap is app. 0-40 change in one hour depending on the height of the building [4, 5, 6, 7]. In older structures made before 1970s, those ventilation holes do not exist at all, which keep the moisture content in the ventilation gap even longer in high range.

Temperature in the ventilation gap increase during summer time in average 10 °C and even in winter 2 °C higher than outdoor air temperature because of high thermal capacity of brickwork and low air change rate [8]. In these moisture and temperature conditions there are favorable conditions for mold grow for very long periods [9]. Therefore, materials sensitive for mold growth should be avoided in ventilation gap, and air tightness of inner layer of the wall assembly as well as connections to windows etc. must be taken care.

Traditionally moisture diffusion thorough the external wall assembly is calculated inside to outside, because this is way for moisture movement during cold season of the year. And if the diffusion barrier in the inner lining is not tight enough, the moisture transported by diffusion will be condensed somewhere inside of the wall assembly.

1.2 The objective of the study

This study discusses on hygrothermal performance of layered external wall assembly based on long term measurements of relative humidity and temperature, when the water vapor resistance in insulating material is higher than in the main framing of the studied building. In this case the location of the vapor barrier must be examined more closely. Additionally, a hygrothermal circumstance in the wall assembly is not stable because of the varying outdoor conditions. The location of the vapor barrier was analyzed in the study based on field measurements.

2. Methods and data

Data from field measurements and meteorological observations is presented. All data is quantitative by nature.

2.1. Long-term field measurements

The moisture control of the renovated external wall assembly was observed by sensors which monitored relative humidity and temperature continuously. The sensors were installed inside the repaired wall during the renovation.

The sensors were installed in the following places inside the wall assembly (fig 3.):

1. 10 mm thick mineral wool between interior frame and polyurethane insulation
2. Aluminum backed 50mm thick polyurethane insulation
3. 30 mm thick wind barrier insulation
4. Behind the facade brick wall in the ventilation gap

The above mentioned sensors were installed in five different locations in the building's external wall assembly as follows:

- Sensor group #1, front side, third floor, 87
- Sensor group #2, front side, 88
- Sensor group #3, rear side, 89
- Sensor group #4, South-West corner, first floor, 90
- Sensor group #5, North-East corner, 92

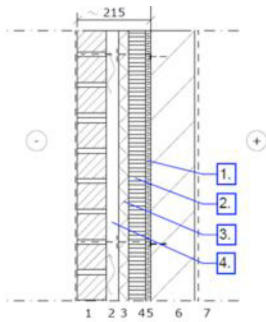


Fig.3 Sensor placements

There was no sensor installed inside the building, so the inside air temperature and vapor load was not known. There was also no sensor installed outside of the building. Outdoor data was gathered from Finnish Meteorological Institute's official weather station situated approximately 5 km from the building. The measurement periods of the installed sensors were reported during Oct. 3rd 2014 and Feb. 2nd 2016.

3. Results

3.1. Measurements from the sensor group #1

Sensors in group #1 were located in the 10 mm thick mineral wool between interior concrete frame and polyurethane insulation. An example graph is shown in fig. 4. The temperature in the mineral wool was app. +20°C around the year and relative humidity was between 20-50% depending on the heating season. The measured temperature matches closely the assumed inside temperature (+22°C). The heating season was also observable from the data: From October, the measured temperature was steadily between +21°C and +23°C, and at the same time the relative humidity in the mineral wool dropped from 45% to 20%. When the heating season ended in mid-April, measured relative humidity started to rise again and the peak values were reached between September and October.

In the measurement location 88 temperatures were slightly lower than in other measurement points. This might be explained by lower inside temperature in the adjacent room or air leaks in the wall assembly.

Relative humidity values higher than 85% were not detected in the data. This indicates that the conditions do not allow microbial growth based on the mold model in the material which has mold sensitivity classification 3, 'medium resistant'.

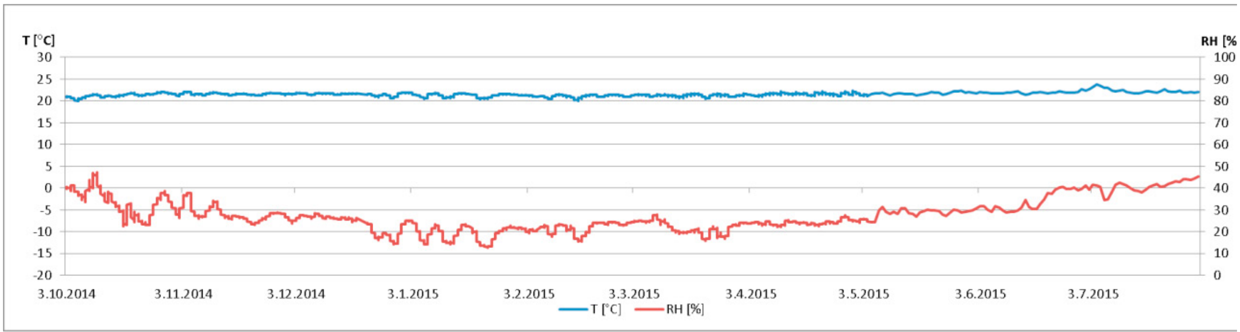


Fig. 4 The results from the sensor group 90, sensor #1, in mineral wool thermal insulation.

3.2. Measurements from the sensor group #2

Sensors in group #2 were located in the 50mm thick polyurethane insulation. An example graph is shown in fig. 5. The temperature in the polyurethane was ca. +20°C around the year and relative humidity was between 15 and 50% depending on the heating season. The heating season was observable also from this data, when the relative humidity dropped from 50% to 20% between October and April. During summer the relative humidity values were higher and the peak values (app. 50%) were reached between September and October. Additionally, it was observed that the moisture in this layer was mainly originating from the inside air of the building, because the relative humidity followed the same graph as the sensor group 1 in the mineral wool layer. Therefore it can be concluded that the aluminum foil backed polyurethane layer prevents the outside air moisture from penetrating the structure and it functions as a vapor barrier as planned.

In the measurement location 88 temperatures were slightly lower than in other measurement points as noticed also in sensor 1, and is therefore logical.

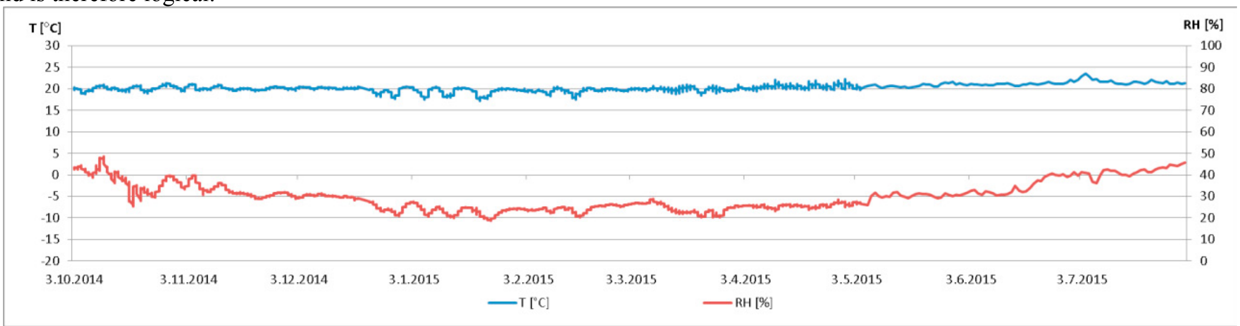


Fig. 5 The results from the sensor group 90, sensor #2, aluminium packed polyurethane.

3.3. Measurements from the sensor group #3

Sensors in group #3 were located in the 30mm thick mineral wool insulation, which performed as a fire resistant layer. In this layer the temperature graph follows the temperature measured from the ventilation air gap. An example graph is shown in fig. 6. During winter the temperature dropped below 0°C and in the summer the temperature was around +20°C. The circumstances which are critical for mold growth were not observed during the measurement period. Relative humidity was below 85% the whole time (and mostly below 80%, excluding short periods in few cases). The layer is also situated outside of the vapor proof polyurethane layer, which effectively prevents any impurities in the mineral wool wind barrier to enter the inside air.

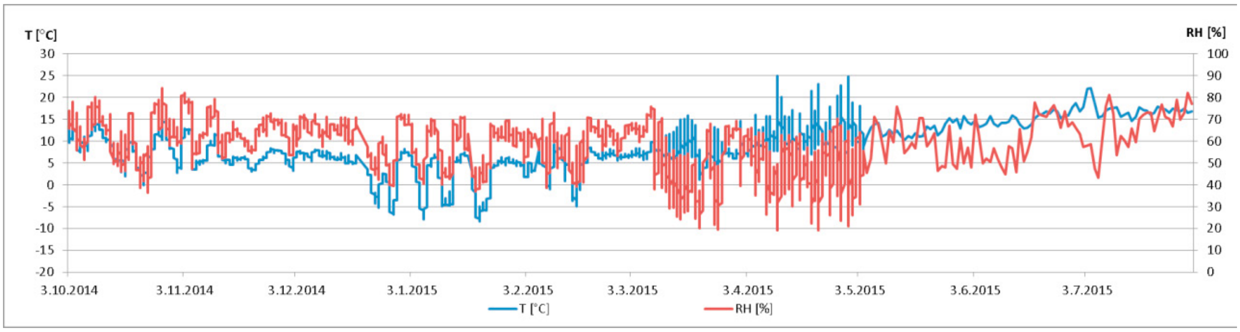


Fig. 6 The results from the sensor group 90, sensor #3, fire resistant layer.

3.4. Measurements from the sensor group #4

Sensors in group #4 were located in the 40mm air gap between the wind barrier and the facade brickwork. An example graph is shown in fig. 7. The sensors recorded relative humidity readings higher than 85% year around. This does not indicate direct risk of mold contamination, because the moisture is originating from outside air. It is shown in fig. 8. In typical Finnish outdoor climate the relative humidity is over 85% between September and April. It has been proven empirically that a wall structure with an air gap works correctly in these conditions. Furthermore, this kind of wall structure is following the current Finnish building codes in force.

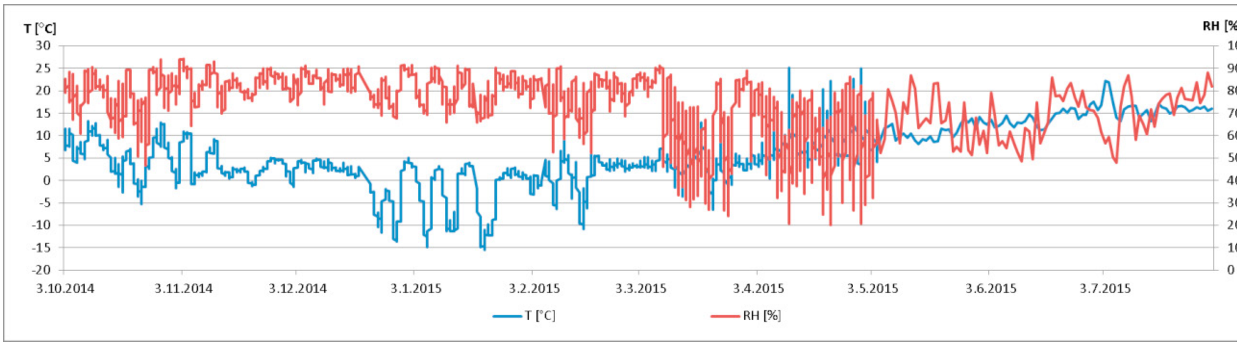


Fig. 7 The results from the sensor group 90, sensor #4, ventilation gap.

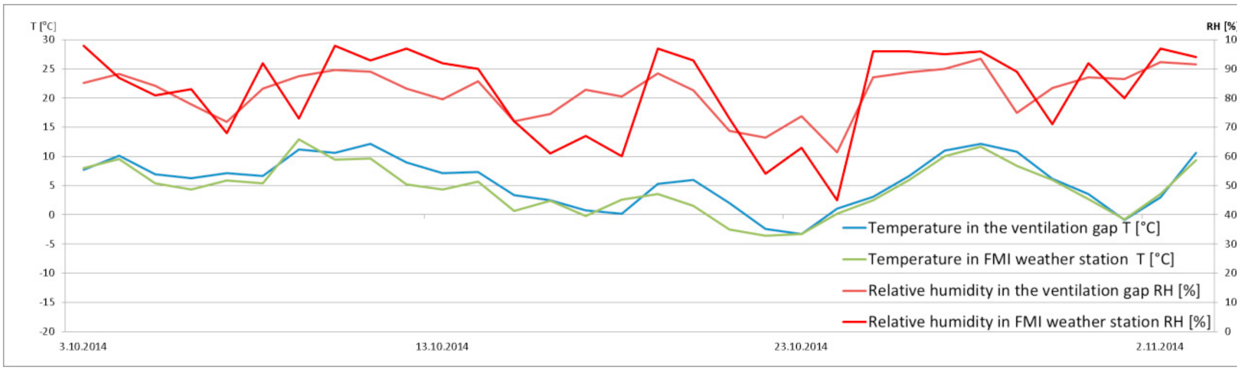


Fig. 8 The results from the sensor group 90, sensor #4 compared to outside air temperature and relative humidity [10]

4. Conclusions

The repaired external wall assembly performs correctly. Aluminum foil backed polyurethane layer performs both as a vapor barrier and a thermal insulation as planned. During the field measurement period no sign of condensation caused by inside air moisture in the wall assembly was detected. Again, no condensation was detected from the outdoor air moisture to the vapor barrier during the measurement period. Moreover, the favorable conditions for condensation were not recorded in the air gap or in the mineral wool fire resistant layer in any measurement.

The employed relative humidity sensors should have been recalibrated at least twice during the measurement period. However, it is not possible to calibrate sensors which have been permanently installed inside the wall. Typically, humidity sensors begin to show too high values as the measured value drifts 1-3% annually, depending on the sensor type. Because of this, the humidity sensor values should be considered only indicative after six months of the installation.

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[10] **(source: Finnish Metereological Institute)**