XII DBMC
International Conference on Durability of Building Materials and Components
PORTO - PORTUGAL, April 12th-15th, 2011

Field Study of Hygrothermal Performance of Log Wall with Internal Thermal Insulation

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ABSTRACT

The energy efficiency of old wooden apartment buildings built before the Second World War need to be improved to save energy and increase thermal comfort. According to the regulations no changes outside the external wall on the facade are permitted. Internal insulation is a possible solution when the external style has a high value and must be preserved. Internal insulation consists high hygrothermal risks. This paper analyzes the measurement results of the temperature and RH of an internally insulated log wall. Six different solutions were used to insulate the log wall: three different insulation materials together with and without air/vapour barrier were used. According to the measurement results there is a high risk of condensation and mould growth inside the wall in dwellings with high humidity load. In the studied case the durability of the renovation solutions is questionable because the measurement results show inadequate hygrothermal performance of the internally insulated log wall. Based on the mould growth model, in all the cases the temperature and RH level inside the wall between the insulation layer and the log layer exceeded the temperature and relative humidity conditions favouring initiation of mould growth more than 75% of the time. To use the internal insulation it is recommended to lower the vapour pressure inside the wall by reducing the moisture excess inside the room by installing a mechanical ventilation system or increasing the vapour resistance by adding vapour retarding foil to the warm side of the insulation layer.

KEYWORDS

Hygrothermal performance, mould growth, internal insulation, wooden apartment building.

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1 INTRODUCTION

The wooden apartment building was the prevalent building type before World War 2 in the suburbs of many towns in Estonia. Currently these areas are listed as milieu or culturally valuable areas with specific planning and building regulations set to preserve the existing environment. The majority of old wooden apartment buildings have massive log (thickness typically 12-15 cm) walls without any additional thermal insulation. Walls are covered with external wooden cladding and internal plaster layers. Thermal transmittance of these types of walls is U_{walls}≈0.6…0.7 W/(m^2·K). The average air leakage value of the building envelope is n_{50}≈17 h^{-1}.

Estonian (57…59 N; 22…28 E) climate is characterized by cold and humid winters and warm summers with the average annual temperature +5.6 °C. The annual average number of heating degree-days tin S for indoor balance temperature of +17°C is 4249 days. Due to cold climate buildings are heated during winter.

In view of the fast increasing energy prices, living in buildings with low energy efficiency can become a very expensive ”pleasure”. By improving the building envelope with additional insulation, it is possible to save energy and increase thermal comfort.

Due to the regulations no changes outside the external wall on the facade are allowed to be done. Internal insulation is a possible solution when the external style has a high value and must be preserved. Internal thermal insulation may cause hygrothermal risks and special requirements for the properties of other material layers. The low temperature of the log layer has an effect on the partial vapour pressure conditions and can cause moisture risks on the log layer [Ojanen 2007]. It is possible to eliminate the problem of moisture diffusion with vapour retarder, but the problem with moisture convection may stay still [Ojanen and Simonson 1995]. External thermal insulation is a hygrothermally much safer solution compared to internal thermal insulation.

Nevertheless, many studies [Stopp, et al. 2001, Madĕra 2003, 2003, Häupt et al. 2004, Juhart et al.2005, Toman et al. 2009] have analysed the possibilities to use the internal thermal insulation for improving external wall structures. Even if the risks and solutions of internal thermal insulation are presented, most of these studies are concentrated on stone walls, as a typical wall structure in Central Europe, but many to the log walls. Saarimaa et al. 1985 and Koski et al. 1997 have analysed hygrothermal performance of additionally insulated log walls in Finland by visual inspection and mostly by momentary measurement of moisture content. It is possible to study many buildings with momentary measurement, but it is not clear if the measurement period is sufficiently critical over the whole year. Therefore long-term measurements are needed. Comparison of different materials and envelope solutions is necessary because they affect hygrothermal performance in different ways.

In this study six solutions of internal thermal insulation for the log wall are analysed based on follow-up field measurements. Hygrothermal performance is analysed based on the temperature and relative humidity measurements in the wall. Durability of refurbishment solutions is assessed in terms of the risk for mould growth and condensation inside the wall.

2 METHODS

2.1 Studied Wooden Apartment Building

The measurements were carried out in a typical wooden apartment building called “Lenderi Maja”, situated in a milieu valuable area in Tallinn. The building originates from the beginning of the 20th century. The building has two floors and a cellar, apartments are heated by stove and electrical radiators. There is a natural passive stack ventilation system in apartment with mechanical exhaust fans in the toilets (not permanently used). The test wall was situated in apartment 1 (on the first floor) on north-facing wall of the main bedroom.

The apartment building was studied under a larger national research project focused on the technical condition and service life of Estonian wooden apartment buildings. The building was under renovation and occupants decided to insulate walls with internal mineral wool insulation. After discussion, the occupants promised to conduct the follow-up measurements about the hygrothermal performance of the wall with internal insulation.

2.2 Studied Test Walls

The initial log wall construction consisted of a 140 mm log sealed with a tow and covered externally with sheathing paper and 20-mm wooden cladding.

Six different insulation solutions were analysed. The size of the analysed wall section was 60×60cm. All wall sections faced to the same wall of the bedroom. Test walls were separated by metal battens and polyurethane foam tightening. The solutions differed in the insulation materials and air barriers that were used, see Figure 1.

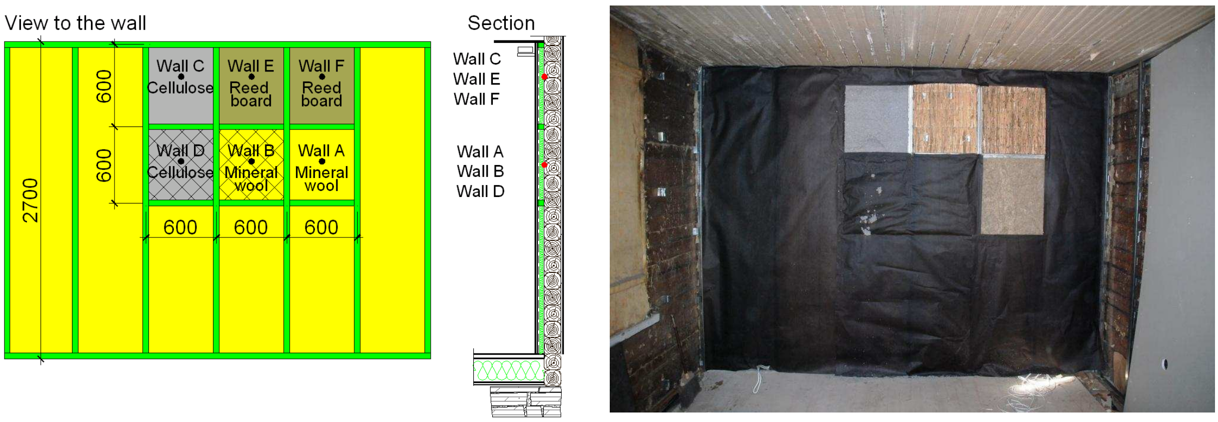

Figure 1. Temperature and relative humidity sensor positions on the log layer before the added insulation material (left) and a view of the insulated wall before the finishing layer (right).

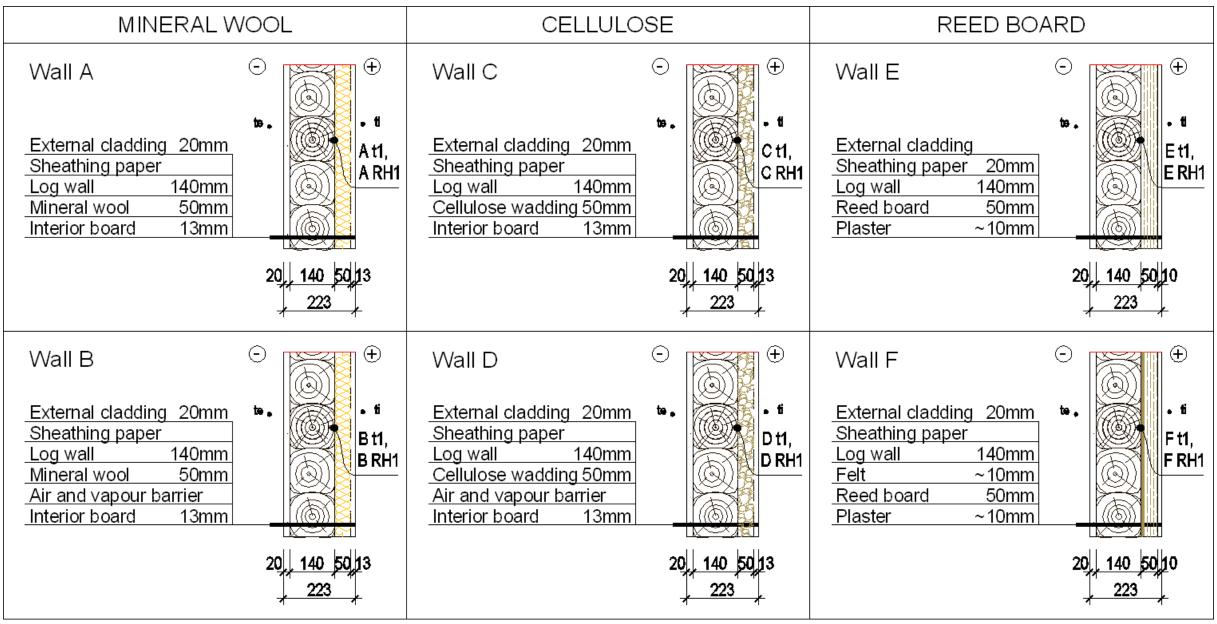

Figure 2. Sections of the studied test walls.

Altogether three different insulation materials were used: reed insulation mat (λ_{reed}≈0.054 W/(K·m)), cellulose insulation ($\lambda_{cellulose}$≈0.045 W/(K·m)), and mineral wool (λ_{mv}≈0.040 W/(K·m)). Insulation materials were used with and without air barrier and were finished inside the room with gypsum board or render. Air barrier paper impregnated with bitumen (Z_p 0.6·10^9 m^2sPa/kg) was used as an air barrier between the inside sheathing and the insulation material. Sections of the insulated log wall are shown in Figure 2.

2.3 Measurements

The values of temperature and relative humidity (RH) were measured with Ø 5mm sensors (Rotronic Hygroclip SC05; measurement range: –30 °C…+100 °C, 0…100 % RH with accuracy ±0.3 °C, ±1.5 % RH) inside the wall between the additional thermal insulation layer and the log layer (see Figure 2) and saved with a data logger. Temperature and RH inside the bedroom and outside the building were measured with data loggers (Hobo U12-013; measurement range -20…+70 °C; 5…95% RH, with an accuracy of ±0.35 °C; ±2.5% RH). All the measurements were taken at a one-hour intervals. The indoor data logger was placed in the middle of the bedroom and an outdoor temperature data logger was placed on the north facade of the building, protected from direct solar radiation.

2.4 Assessment of risk for mould growth

The risk of mould growth assessed according to the experiments reported in [Hukka & Viitanen 1999] suggest that covering the temperature range of 5-40°C the boundary curve for the risk of mould growth on a wooden material can be described by a polynomial function:

$$RH_{crit} = \begin{cases} -0.00267 \cdot t^3 + 0.160 \cdot t^2 - 3.13 \cdot t + 100 & ,when\ t \le 20°C \\ 80\% & ,when\ t > 20°C \end{cases}$$

The time of the temperature and RH conditions favourable for mould growth during the measurement period was calculated.

3 RESULTS

3.1 Climate Condition

Hourly temperature and RH's data measurements were taken and collected through out a near one-year period: 12.12.2009…6.10.2010. Outdoor temperature during the measurement period varied between -21.5°C…+33.6°C and RH between 22%...100%. During winter the average temperature was -7.4°C (min. -21.5°C, max. +4.2°C) and RH 89% (min. 62%, max. 100%). The annual indoor temperature in the bedroom varied between +13.5°C…+27.5°C and RH between 43%...83%. During winter months the average temperature was +17.4°C (min. +13.5°C, max. +24.5°C) and RH 64% (min. 43%, max. 74%).

Figure 3 left shows the dependence of the indoor temperature on the outdoor temperature. Each dot represents the measured value corresponding to the outdoor temperature. The indoor temperature depends quite linearly on the outdoor temperature. This indicates to problems with sufficient heating power of the heating system. The average indoor temperature stays below the lowest category of thermal comfort 50 % of the time during winter due to low indoor temperatures.

It is important to know the humidity load to assess the hygrothermal performance of the wall. Humidity loads are presented as internal moisture excess that shows the difference between the indoor and outdoor air humidity by volume. Dependence of the moisture excess on the outdoor temperature is shown in Figure 3 right. From this data, the 90 % critical level [Sanders, 1996] was calculated (black dotted line). This level means that hygrothermal loads higher than the determined critical value should not exceed 10% of the cases. During cold periods the weekly average internal moisture excess is between +7 g/m^3. Based on earlier studies in Estonian dwellings [Kalamees 2006], the studied apartment may be classified as a dwelling with a very high humidity load. The humidity load was high due to low ventilation (natural ventilation), higher occupancy (23 m^2/pers.), and possible drying out of structural moisture.

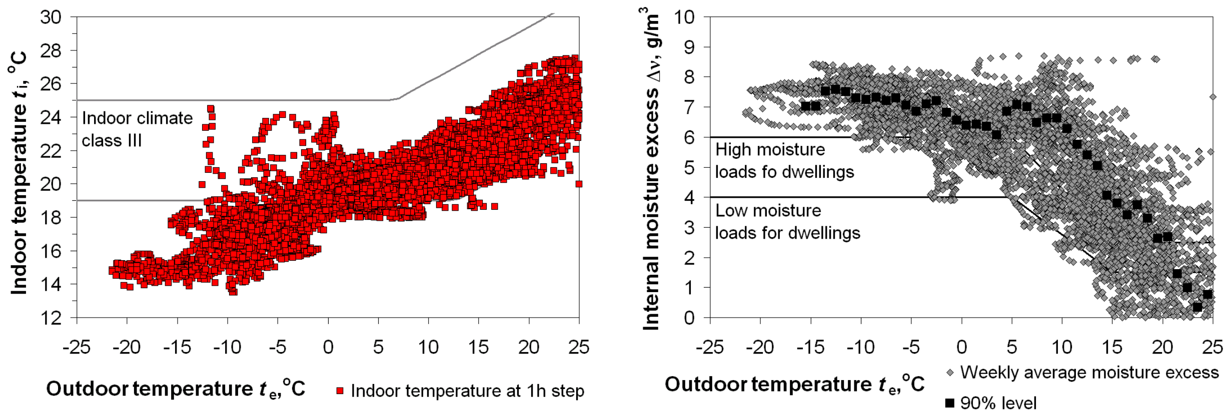

Figure 3. Dependence of the indoor temperature and moisture excess on outdoor temperature.

Due to low temperature and high humidity loads, indoor RH was high during cold period, Figure 4. The indoor RH stays above the criteria for indoor RH during winter in Estonia (RH 25…45%) most of the time.

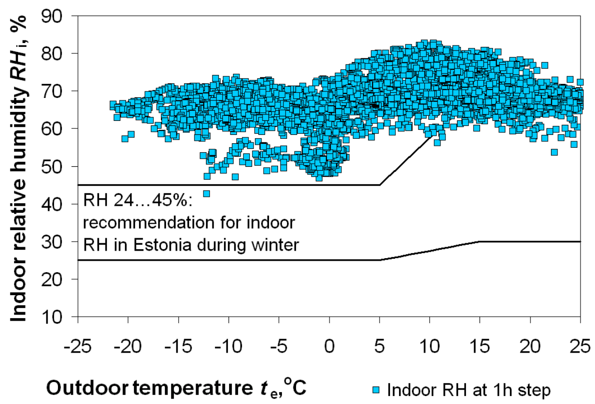

Figure 4. Dependence of the indoor RH on the outdoor temperature.

3.2 Hygrothermal Condition Inside the Wall

Reference point to assess the hygrothermal performance of the internally insulated wall was between the original log and the internal insulation.

Indoor and outdoor temperature as well as temperatures inside the wall between the insulation material and the log layer is shown in Figure 5 left. Steady-state distributions of temperature during February are shown in Figure 5 right. During the measurement period, the lowest temperature on the internal surface of the log was observed in the case of mineral wool insulation. This corresponds also well to the lowest thermal conductivity of this insulation material.

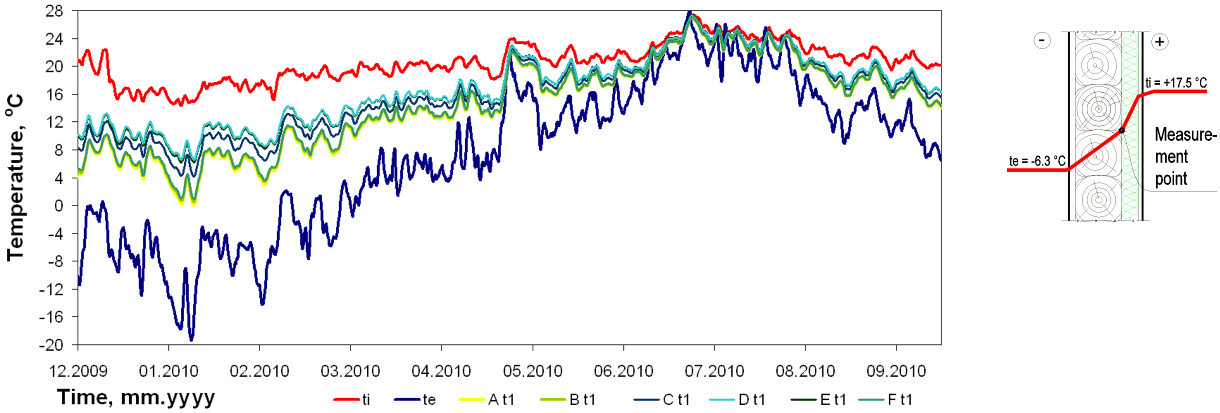

Figure 5. Measured daily running-average temperatures (left). The distribution of average temperature during February (right).

RH was high through out the winter-spring period, Figure 6. RH was close to the upper measurement limit, indicating possible moisture condensation to the inner surface of the log. Also, the calculated steady-state vapour distribution in the wall indicated possible moisture condensation in the wall between the insulation material and the log layer. The RH was highest in test walls with mineral wool insulation. On the other hand, test walls with mineral wool insulation dried more quickly than the wall with cellulose or reed insulation mat during summer period.

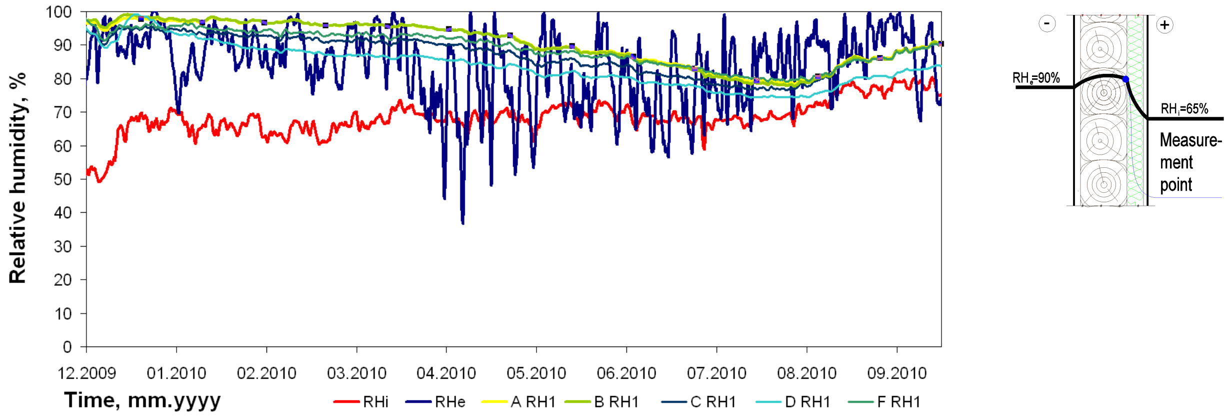

Figure 6. Measured daily running-average RH (left). The distribution of average RH during February (right).

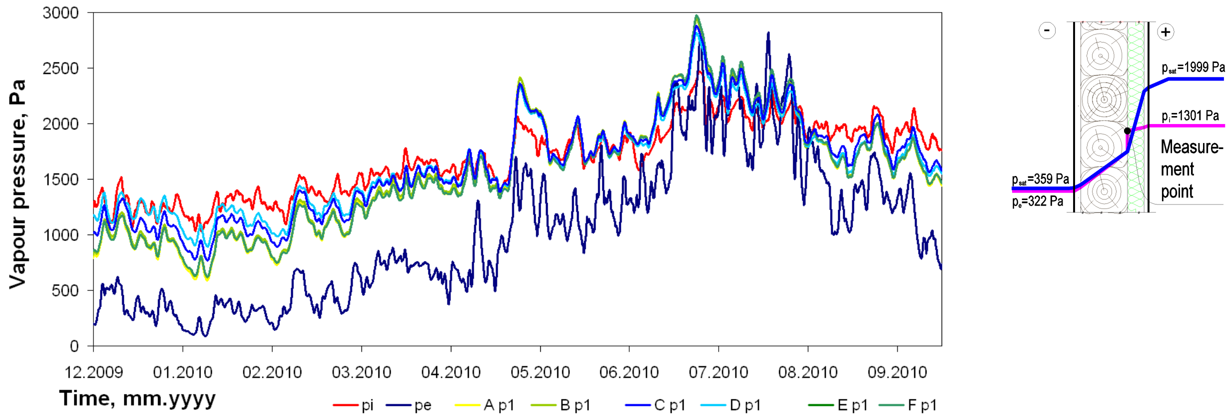

Figure 7. Measured daily running-average water vapour pressures (left). The distribution of average water vapour pressure during February (right).

Water vapour pressure on the indoor and outdoor air as well as inside the wall between the insulation layer and the log layer are presented in Figure 7. During the spring-summer period the air vapour pressure inside the wall was higher than the air vapour pressure in the bedroom, indicating the drying of the wall to the indoor air. Water vapour pressure was higher in the test walls with hygroscopic thermal insulation.

As the air pressure difference across the structure was ±2…3 Pa the main moisture transport mechanism is assumed water vapour diffusion.

The RH on the inner surface of the log wall stays at the high level during the whole measurement period. Based on the mould growth model [Hukka and Viitanen 1999] in all the cases, the temperature and RH level inside the wall exceeded the temperature and relative humidity conditions favouring initiation of mould growth on wooden materials, see Figure 8.

In the case of the mineral wool insulation temperature and RH conditions are favourable for mould growth more than 88% of the time. With cellulose insulation the risk for mould growth is higher in walls without air- and vapour barrier (84 % of measured time length) than with air- and vapour barrier (75 % of measured time length). With the reed insulation mat more than 93% of the time is favourable for mould growth.

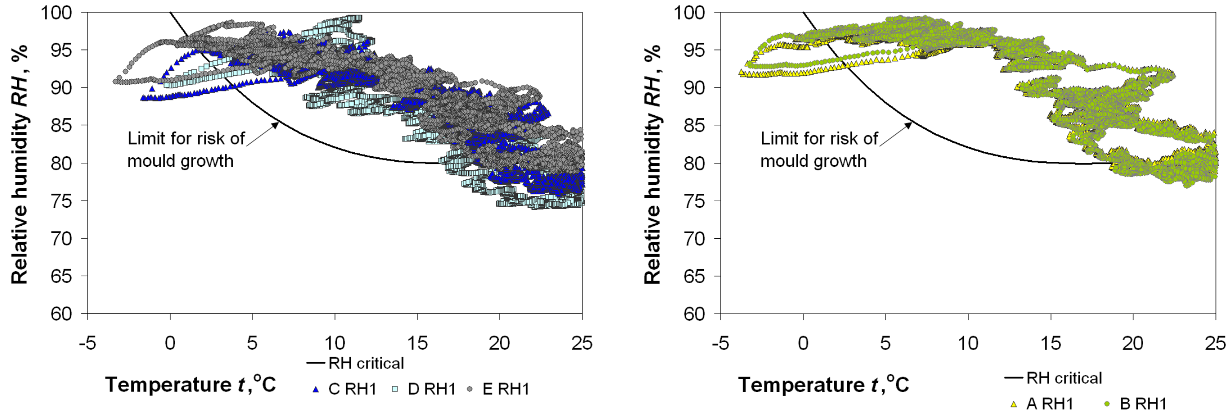

Figure 8. Temperature and RH conditions are favourable for mould growth for "green" insulations (left) and for mineral wool (right).

According to the mould growth assessment, there should be a high risk for mould growth. Nevertheless, the wall was not opened for examination. No visual inspections were done and no mould could be observed.

4 DISCUSSION

Field measurements showed a high humidity level in the internally insulated log wall. Hygrothermal conditions on the inner surface of the log wall were favourable for mould growth in all test walls. Insulation material (hygroscopic or not) did not significantly lower the risk for mould growth. Different test walls were separated by metal battens and polyurethane foam tightening to prevent diffusion and conduction between the test walls. Although there may have been some minor leaks between the test walls, the potential for the diffusion and conduction was low and possible heat and moisture movement between the test walls was probably minor.

Some earlier studies carried out in wooden buildings in cold climate conditions have shown the possibilities to assemble additional insulation layer inside a log wall without a vapour barrier [Saarimaa *et al.* 1985; Koski *et al.* 1997]. According to Saarimaa [1985] it is possible to use internal insulation without vapour barrier but there were too many uncertainties to be convinced that the measurement results assure it. According to Koski [1997] no hygrothermal problems occurred with log walls with internal insulation. Neither was there great differences discovered between the log wall with a vapor barrier and without a vapor barrier. The main reason for that was the internal sheeting. The internal sheeting proved to have a rather high vapor resistance compared to the sheeting used in this study. The internal sheeting had about five times higher vapour resistance than a gypsum board. Nevertheless the results obtained in the studies referred to were not based on many long-term measurements in dwellings with high humidity loads. To work out viable renovation solutions critical boundary conditions should be obtained.

The test walls studied were located in apartments with high humidity loads. This was caused mainly due to low air change rate (natural ventilation) because the ventilation system was not renovated. Therefore, to guarantee good indoor climate and energy efficiency of buildings, the following three components must be maintained in the process of renovation:

- hygrothermal performance of building envelope;
- performance of ventilation;
- performance of heating systems.

5 CONCLUSION

The measurement results of the temperature and RH of the internally insulated log wall were analysed. All the test walls with different thermal insulation resulted in high humidity levels that were favourable for mould growth on wooden material more than 75%...80% of the time. It was found that the vapour permeable air barrier paper mounted between the insulation material and the finishing layer has very low impact on the RH levels inside the wall and has no impact on temperature. High RH levels between the insulation material and the log layer correspond to the calculated steady-state winter conditions where the partial vapour pressure in the wall between the insulation material layer and the log layer exceeds the saturation pressure level. The internal insulation of the log wall could be used if the vapour pressure inside the wall is lowered. Thus the moisture excess inside the room by installing a mechanical ventilation system is reduced or the diffusion resistance by adding vapour retarding foil to the warm side of the insulation layer is increased.

Even the internal thermal insulation seems to be a possible solution when the external style has a high value and must be preserved, the solution should be carefully calculated in order to prevent occurrence of hygrothermally critical conditions. In the studied case the durability of the renovation solutions is questionable because the measurement results show inadequate hygrothermal performance of the internally insulated log wall. In addition, the high risk of mould growth can lead to mould problems that can cause health problems for the inhabitants of the apartment.

ACKNOWLEDGMENTS

The financial support of the Credit and Export Guarantee Fund KredEx and Tallinn University of Technology are gratefully acknowledged.

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