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Renovation with Internal Insulation and Heat Recovery in Real Life – Energy Savings and Risk of Mold Growth

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ABSTRACT

This paper presents a pilot project for renovation of a large residential area; focus is on energy consumption and risk of mold growth. The renovation included internal insulation of walls with capillary active insulation material, balanced mechanical ventilation with heat recovery and insulation of floor towards basement. These types of measures are not completely new and have been used in other buildings as well, however the measures may be either risky regarding mold growth or the effect is uncertain with the specific external wall composition. A pilot project including six apartments was performed to test the measures in these specific buildings. Furthermore, six reference apartments were monitored simultaneously.

For two years, energy use for heating was measured as well as temperature and relative humidity in the internal insulation, indoors and outside. The insulation was dismantled in two apartments after two years, to test for mold growth at the original wall surface.

In extreme cases, the relative humidity in the walls behind the insulation system was up to 90 % RH shortly after installation, and mold growth models predicted growth of mold. However, the relative humidity decreased, typically to 70 % RH in the second winter. The inspection and measurements after the removal of the insulation material did not show signs of mold growth. Apparently, the used insulation material can be used in this specific case without risk of mold growth. Energy savings for heating was measured and calculated to around 25 %. However, the electricity use for ventilation was almost equal to savings from heat recovery.

KEYWORDS

Internal insulation; capillary active material; measurements; moisture; heat

INTRODUCTION

To save energy a large residential area from the 1950s is considered for renovation. The intent of the project is to demonstrate that energy savings are possible and moisture-safe using internal insulation with capillary active insulation materials combined with insulation towards a basement and mechanical ventilation with heat recovery. The case is Folehaven; a large urban area in Copenhagen, Denmark consisting of three-story apartment houses with approx. 74,200 m² heated floor area, rented out by a housing association. The brick masonry expression of the area is deemed worthy of preservation because of its architectural value. Internal insulation is therefore the only option for energy improving the walls. The Danish National Building Fund subsidizes energy-saving measures in social housing projects; however, the fund only subsidizes known and low risk measures. Traditional internal insulation with mineral wool and vapor barrier is not considered among these, due to high risk of mold growth, which has been experienced in other dwellings. Capillary active insulation materials have a specific pore size and pore distribution, allowing moisture to be transported by capillary suction from an area with capillary condensation to a more dry area, i.e. from the intersection wall/insulation material to the inside. Capillary active materials have been investigated by several researchers (e.g. Häupl et al, 2003; Pavlík and Černý, 2009; Vereecken

and Roels, 2015). However, well-documented projects with more than two years' experience are rare. Therefore, the objective of this pilot study is to provide documentation of the hygrothermal effects – including energy savings – of internal insulation with capillary active materials in these specific buildings. This would comply with The Danish National Building Fund requesting measurements conducted over a longer period e.g. five years in Denmark.

METHODS

The test site

The settlement Folehaven consists of 55 three-story apartment houses with 932 apartments. The buildings were built 1952-1962, and the materials may vary from building to building; generally, the walls are 360 mm thick made of bricks outside (110 mm) and lightweight concrete (240 mm) and plaster on the inside. The horizontal divisions are made of concrete. Attic and basement are unheated. Six apartments in the same staircase were chosen for the pilot project, see Figure 1. All apartments had a size of approx. 75m². Energy saving measures were installed in the summer of 2015. As a reference, six apartments were chosen, these were not renovated, however; layout, location and orientation were similar to the test apartments.

Figure 1. a) Layout of two apartments. Red designation is an internal apartment and blue designation is an apartment with a gable. In the grey area, a suspended ceiling is used to hide ventilation ducts. b) Cross section of the three apartments, basement and attic.

Several possibilities to reduce the energy consumption of the settlement Folehaven were considered but abandoned: External insulation was excluded for architectural reasons; internal mineral wool insulation with vapor barrier was deselected due to moisture risk from leaky vapor barriers; vacuum panels were rejected due to the high price and not being adjustable on site. New more energy efficient windows were considered, however, windows were renewed within the last 15 year and the building owner wanted to take advantage of the remaining service life. The attic floor was recently insulated. Conclusively, few options were left:

- Mechanical ventilation with heat recovery to replace the old system with natural ventilation through opening of windows and the stack effect of a ventilation shaft leading from the bathroom to the rooftop.
- Internal insulation with materials that need no vapor barrier (capillary active materials), and insulation of the floor division towards the basement.

The insulation material was chosen based on several criteria; i.e. thermal conductivity, price, robustness and flexibility. It was decided to test PUR foam with thin calcium silicate channels every 40 x 40 mm (λ -value of 0,031 W/m·K). The gable was insulated with 80 mm and the facades with 50 mm due to large windows and limited space behind installations.

Energy-saving potential

The energy savings were theoretically calculated and measured on site. The theoretical energy consumption for heating and ventilation was calculated using the software program Be10 (DBRI, 2015). U-values and Ψ -values were calculated through detailed 2D thermal calculations of assemblies before and after renovation and used in the Be10 model.

Energy consumption for room heating was measured with energy meter on the main heating pipes in the basement. Energy meters were installed on the mixing pipes before the after-heating surface of the ventilation system. Furthermore, the ventilation unit's electricity consumption was measured. The measurements covered the period April 2016 to March 2017 as a comparison between the test apartments and the reference apartments. The set point for the ventilation unit was 21 °C; however, at outdoor temperature above 18 °C, the after-heating surface was bypassed.

Onsite measurements of temperature and moisture

Temperature and relative humidity were measured and logged:

- Hourly in three rooms inside the six test apartments and six reference apartments with data logger Lascar EL-USB 2+ (Lascar Electronics) before and after the renovation. Data collection time: September 2014 to August 2015 and again March 2016 to June 2017.
- Hourly outside with similar data loggers and collection time as used inside. Alternatively, equivalent measurements were obtained from the Danish Meteorological Institute, as some loggers were stolen during the test period.
- Hourly inside the wall, at the intersection between original wall and the new interior insulation material. In each apartment, eight to ten sensors (Tramex Hygro-i connected to Transmitter IP65) were installed. The signals from the transmitters were collected by Profort mini data collector and were accessible via Internet. All instruments from BMT instruments (BMT Instruments). Data collection time: From December 2015 and ongoing.

Dismantling of insulation

Two years after installation, the interior insulation material was dismantled in two test apartments to inspect the area behind the insulation for mold growth; a check whether reality corresponds with mold growth models using actual hygrothermal measurements. One apartment was chosen because the installation of the insulation material was not in accordance with the guidelines of the manufacturer. The other apartment was chosen because the moisture load was high in this apartment before the renovation and measurements inside the wall showed high relative humidity the first winter after the installation of the insulation material. After dismantling the insulation material, the walls were visually inspected and Mycometer tests (Reeslev and Miller, 2000) were performed in critical areas. In the apartment with high moisture level behind the insulation material, additional mold tests were made with pressure plates and tape strips that were investigated in a microscope.

RESULTS

Energy consumption

The energy consumption for heating in the six renovated apartments during the heating season 2016/2017 was measured to 31.2 MWh at an average indoor temperature of 22.2 °C. The reference apartments with similar indoor temperature had a consumption of 41.1 MWh. This corresponds to a 24 % reduction in the energy consumption for heating or 9.9 MWh/year. Table 1 shows the theoretical calculation of the savings for the six apartments. The total energy savings for heating are 10.4 MWh/year. The specific fan power for the ventilation was 800 J/m³, which for an air change of 516 m³/h in constant run corresponds to 1.0 MWh/year.

Table 1. Theoretical calculation of U-value, air changes and energy saving for heating.

Measure	U-value ^A [W/m ² K]		Air change [m ³ /h]		Heating energy saving	
	Before	After	Before	After	MWh/year	%
Internal insulation of walls	1.05	0.65			7.3	70
Insulation of floor	0.70	0.40			2.2	22
Balanced ventilation ^B			344 ^C	516 ^C	0.9	8

^A U-values includes the linear thermal transmittance. ^B Heat recovery of 80%. ^C Air change before is 2/3 of the air change after which correspond to 0.5 h⁻¹.

Measurements of temperature and relative humidity

From October until March the average indoor temperature was 22.3 °C and 22.2 °C in the winter 2014/15 in the test apartments and the reference apartments, respectively. In the winter 2016/17 the average indoor temperature was 21.9 °C and 22.5 °C, respectively. The average outdoor temperature was 6.1 °C in the winter 2014/15 and 4.9 °C in the winter 2016/17.

Indoor relative humidity depends on moisture content in outdoor air, moisture supply depending on ventilation rate and use of the apartment, and the indoor temperature. To eliminate the influence of temperature of the indoor air, the results of the measurements in one room in a test apartment is presented in Figure 2 as moisture supply.

Figure 2. Moisture supply in a bedroom in one of the test apartments before and after the renovation. Compared to other apartments, the moisture supply was high before the apartment was renovated. The straight line in the middle covers the period without measurements.

Figure 3 shows a typical example of the temperature and relative humidity measured at the intersection of the interior insulation material and the existing wall. The most extreme case, and therefore, the one with the highest risk of mold growth, had a relative humidity of approx. 95 % RH in the winter 2015/16 at a temperature of 5-10 °C. The following winter the relative humidity had decreased to approx. 85 % RH at a temperature of 5-10 °C. The interior insulation was dismantled in that apartment.

The visual inspection of the walls after dismantling the interior insulation material did not show any signs of mold growth. This corroborates with the Mycometer tests, where only one test was higher than level A (background level). The highest Mycometer number was 34 i.e. very low number at level B (typical for e.g. dust), that goes from 25-450 (Reeslev and Miller, 2000). In the same point, the pressure plate test showed more than 50 colony forming units. All tape tests showed few spores but no mycelium on the wall.

Figure 3. An example of typical conditions measured in the intersection between interior insulation material and existing wall.

DISCUSSIONS

Energy

The settlement Folehaven had from 2013-2016 an energy consumption for heating of 143-147 kWh/m², compared to key figures for the council housing sector, this is about 30 kWh/m² or 20 % higher than average. The findings from this study showed that the heating energy consumption could be reduced by 24 % when insulating the floor above the basement, installing internal insulation and balanced mechanical ventilation with heat recovery. If the savings found in the six apartments can be applied to the entire settlement, the heating energy consumption could be reduced to 109 kWh/m². These savings are obtained in six apartments where three have gables and three are internally located. As 1/3 of the staircases only have internally located apartments, the total savings might be lower. The indoor temperature was at a similar level before and after renovation, thus the rebound effect was minimal. In this pilot project, the energy use for running the ventilation corresponded to the heat savings obtained from the heat recovery. Furthermore, the ventilation rate was increased after renovation.

Temperature and relative humidity

The indoor climate varied in the different apartments but were within what was to be expected in apartments according to ISO 13788 (ISO, 2012). However, the moisture supply in Figure 2 was high before the renovation. After the renovation, the moisture supply decreased to normal level, probably due to the installation of a mechanical ventilation system. In apartments where the moisture supply was low before the renovation, no change could be detected.

When the measurements from behind the insulation material were used in mold growth models like Viitanen et al. (2011), mold index > 1 was to be expected in a few points, however, the inspection did not show mold in these areas. That may be because the walls were completely cleaned before the insulation material was installed, therefore, there was no organic material in the area, and theoretically dirt could not enter, i.e. no nutrients for the mold. In one point, the Mycometer level was B and there was mold growth on the pressure plate. However, the tape test combined with the Mycometer test indicated, that there was no active growth in the area. In areas where the relative humidity was high in the beginning, it decreased in the next winter; probably some build in moisture from the application with wet glue mortar had to dry out. Consequently, it is still necessary to follow the relative humidity and temperature in the wall to see how the system will perform over time. Especially because the two winters were mild compared to winter in the Danish reference year.

CONCLUSIONS

Renovation of buildings with special architectural appearance often ends in discussions of the possibility of applying external or internal insulation to save energy or improve the indoor environment. Therefore, it is important to decide what is most essential; obtaining energy savings, improving indoor environment, architectural value, etc. It is the author's opinion that moisture safety is crucial. When this is ensured, the heating energy savings in renovation projects can be calculated relatively easy. In this case, 24 % savings were documented.

When buildings are internally insulated, the indoor moisture supply becomes critical. Some users may not be aware of this; therefore, combining internal insulation with mechanical ventilation is a good idea, as the study confirms that mechanical ventilation reduces the moisture supply in apartments where the moisture supply was high.

Although the investigation of mold growth did not reveal any danger, it is still too soon to conclude that the investigated type of internal insulation is moisture safe in these apartments. Partly because mold models indicate, that mold growth may occur, partly because the two winters have been mild. Furthermore, it is important to notice, that the investigation only apply to these specific buildings. There is still a need to investigate how the internal insulation materials perform in other buildings; this applies to energy savings as well as moisture risk.

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REFERENCES

- BMT Instruments: <http://www.bmtinstruments.dk/shop/traadloest-maalesystem-23c1.html>
- DBRI, 2014. Energi-benchmark fra SBI. Available: <https://sbi.dk/it-vaerktoejer/Documents/Groent-regnskab/Energi-benchmark-fra-SBi.pdf>
- DBRI. 2015. Be10: Calculation Program for Documentation of the Energy Use in New Buildings. Available: <https://sbi.dk/beregningsprogrammet/Pages/Start.aspx>
- Häupl P., Jurk K. and Petzold H. 2003. Inside thermal insulation for historical facades. In: *Research in building physics: proceedings of the 2nd international conference on building physics, Leuven, Belgium, 14–18 September*, p. 463–469.
- ISO. 2012. *ISO standard 13788:2012*. Hygrothermal performance of building components and building elements - Internal surface temperature to avoid critical surface humidity and interstitial condensation - Calculation methods
- Lascar electronics: <https://www.lascarelectronics.com/easylog-data-logger-el-usb-2plus/>.
- Pavlik Z and Černý R., 2009. Hygrothermal performance study of an innovative interior thermal insulation system. *Applied Thermal Engineering*, Volume 29, Issue 10, July 2009, Pages 1941-1946
- Reeslev M. and Miller M. 2000. The MycoMeter-test: a new rapid method for detection and quantification of mould in buildings, p. 589–590. In: *Proceedings of Healthy Buildings 2000*, vol. 1. SIY Indoor Air Information OY, Helsinki, Finland.
- Viitanen H., Ojanen T., Peuhkuri R., Vinha J., and Lähdesmäki K. 2011. Mould Growth Modelling to Evaluate Durability of Materials, p. 409-416. In: *Proceedings of 12. International Conference on Durability of Building Materials and Components*. Porto.
- Evy Vereecken E. and Roels S. 2015. Capillary active interior insulation: do the advantages really offset potential disadvantages? *Materials and Structures*, September 2015, Volume 48, Issue 9, pp 3009–3021