Retrofitting Timber Frame Walls with Vacuum Insulation Panels

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Introduction

An U-value of 0.35 W/(m^{2}K) (about 10 cm mineral wool) in walls was required in Norwegian buildings in the 1970s (Building regulations 1969), whereas today the requirement is an U-value of 0.18 W/(m^{2}K) (TEK 1997), i.e., nearly 50 % less. The passive houses have even higher requirements. Retrofitting of buildings with vacuum insulation panels (VIPs) might be advantageous as passive house standards may be achieved without major changes to the building structure. Adding insulation on the exterior may prevent moisture problems as the temperature in the old wall structure rises, and furthermore reduces the effect of thermal bridges. However, a vapour tight layer on the cold side increases the risk of condensation inside the wall, especially if the thermal resistance of the VIPs is reduced due to ageing or puncture. This work investigates ways of retrofitting timber frame walls, both with VIPs on the cold side and with VIPs on the warm side. A wall section with different test fields were placed between two climate chambers with indoor climate and outdoor climate. Moisture and temperature conditions in the wall were measured, analyzed, and compared with numerical simulations and calculations.

Experimental

The test module contains four fields as seen in Figs.1-2. Field 3 (F3) is built without VIPs and represents the original structure before retrofitting, i.e. a reference field of a timber frame wall from the 1970s. The three other fields (F1, F2, and F4) represent three different ways of improving the thermal insulation of the reference field by VIP retrofitting (Fig.2).

- F1: outside 30 mm VIP
- F2: outside 20 mm VIP
- F3: reference field
- F4: inside 30 mm VIP

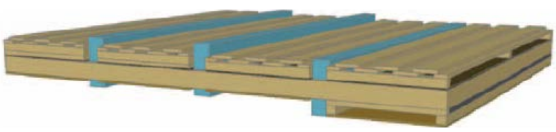

Fig.1. The test module in 3D view, as seen from the bottom.

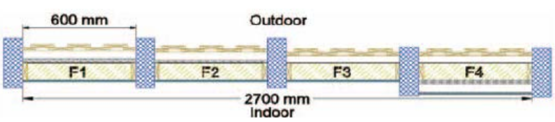

Fig.2. Horizontal cross-section of the test module. Note that the fields have no vapour barrier.

The build-up of the field F2 from outdoor to indoor:

- Vertical wooden cladding.
- Furring strip attached with a tailor-made fastening bracket as shown in Fig.3.
- VIPs for F2 (20 mm), joint not taped. The VIPs were attached with the same tailor-made fastening bracket.
- Wind barrier (WB), i.e. a bitumen-impregnated paper in common use in the 1970s.
- 98 mm mineral wool.
- Plasterboard.

Fig.3. Principle of the fastening bracket. The left photo shows the fastening brackets used in the middle of the wall (between two VIPs, fastened on a wooden stud), and fastening brackets used at the top plate. The three other photos show different stages in the installation of the fastening bracket between two VIPs.

In order to be able to measure condensation on a surface, a tailor-made moisture sensor was developed (Fig.4). The principle is to measure the electrical resistance on a thin paper layer taped on the respective surface, i.e. the measurement will be as close to the material surface as possible.

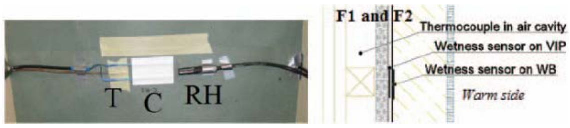

Fig.4. Left photo depicts the thermocouple (T), wetness sensor (C), and RH air sensor (RH) as installed on the wind barrier (WB) before the mineral wool was added. Right drawing shows a cross-section of F1 and F2 with a wetness sensor both on the WB and on the joint between two VIPs at the middle of the fields. The thermocouple in the air cavity is also shown, while other sensors on the WB are not depicted.

Altogether, 36 sensors of three different types were used in the experiment, i.e. thermocouples (T), air humidity sensors including thermocouples (RH), and wetness sensors (C), as depicted in Fig.4. The most critical location for condensation was considered to be on the warm side of the VIPs in F1 and F2 (Fig.4), and at the warm side of the wind barrier at the reference field (F3).

The test wall module was built between two climate rooms in the laboratory. The temperature at the cold side was set to -18°C. The RH in the outdoor climate was not controlled. In the indoor climate, the temperature was held constant at 20°C, while the RH was adjusted in the following *climate steps* of 10 % (~moisture excess):

1. RH 30 % (~4 g/m^3)
2. RH 40 % (~6 g/m^3)
3. RH 50 % (~8 g/m^3)
4. RH 60 % (~10 g/m^3)

Both 1D and 2D simulations of the thermal and the hygrothermal performance of the fields have been performed. The two simulation programs WUFI Pro (WUFI 1D 2008) and WUFI 2D (WUFI 2D 2010) have been used. The climate file applied in the simulations is based on the logged temperature and RH in the climate rooms during the experiment. That is, the simulation results and the logged values from the experiment could be compared directly.

Additional calculations that investigated condensation risk at the VIPs in F1 and F2 were performed. The basis of the calculations was the standard for hygrothermal performance of building components EN ISO 13788 (2001), which describes a method for addressing a critical limit for surface condensation accounting for the parameters mean monthly external temperature and RH, and internal temperature and moisture excess for the respective building. For further experimental details it is referred to Sveipe et al. (2011).

Results and discussion

The U-values of F1 and F3 were calculated according to EN ISO 6946 (2007). The calculated values for F1 were 0.143 W/(m^{2}K), 0.181 W/(m^{2}K) and 0.262 W/(m^{2}K) for pristine, aged and punctured VIPs, respectively. For F3 the result was 0.411 W/(m^{2}K).

The experimental moisture and condensation results are depicted as RH equivalent versus time at different locations inside F1 in Fig.5, for climate steps 3 (50 % RH) and 4 (60 % RH). Figure 6 depicts similar results for F2. None of the fields experienced condensation during climate step 1 or 2, with a RH of ~30 % and ~40 %, respectively. For further plots of different fields and climate steps see Sveipe et al. (2011).

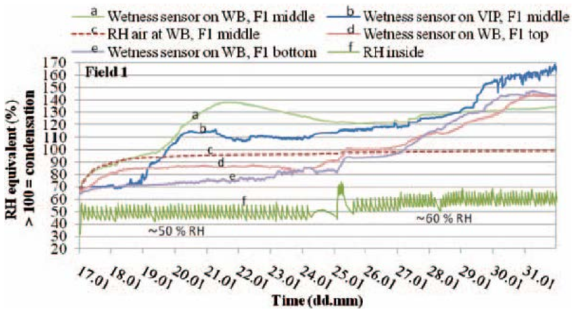

Fig.5. Moisture sensors in F1 during climate steps 3 and 4. The RH equivalent values of the four wetness sensors, as well as the RH air sensor are shown. The climate room RH was ~50 % from day 17 to 24, and ~60 % from day 26 to 32 (graph f).

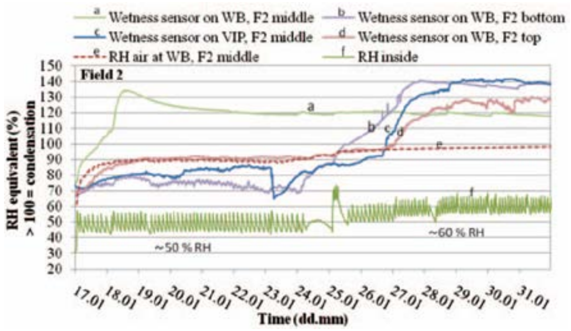

Fig.6. Moisture sensors in F2 during climate steps 3 and 4. The RH equivalent values of the four wetness sensors, as well as the RH air sensor, are shown. The climate room RH was ~50 % from day 17 to 24, and ~60 % from day 26 to 32 (graph f).

The wetness sensor shows condensation (value above 100 %) when the RH air sensor shows about 95 % RH (Fig.5). A possible explanation is that the RH air sensor is located about 5 mm from the WB. Moreover, the wetness sensor is more influenced by condensed water on the vapour barrier than the RH air sensor.

Figure 7 shows the simulated RH compared to the measured, see Sveipe et al. (2011) for further results.

The calculations of condensation-start-limits are shown in Fig.8, illustrating what external temperature and internal moisture excess may cause condensation on the VIP surface for different conditions (thermal conductivities) of the VIPs.

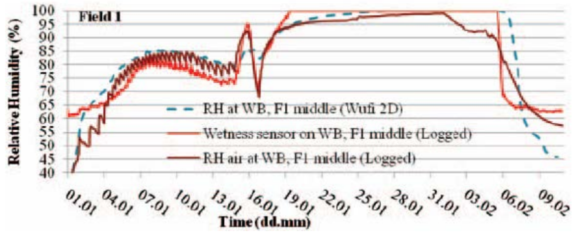

Fig.7. RH simulated in WUFI 2D, and measured RH in the middle of F1.

The calculations in Fig.8 are based on an interior temperature of 20°C and an exterior RH of 80 % (except the upper graph with an exterior RH of 60 %). It is important to emphasize that the constructions do not have a vapour barrier on the inside, and are hence considered as a worst-case wall compared to a normal wall built with a vapour barrier.

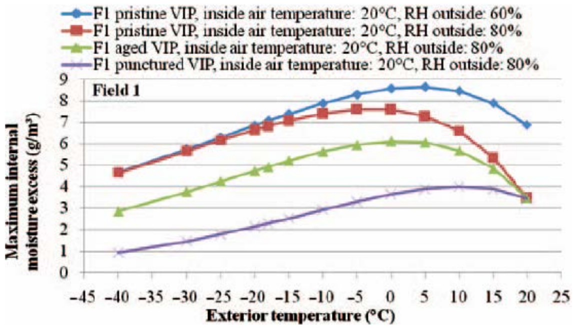

Fig.8. Maximum moisture excess before condensation on VIP in F1.

Conclusions

Experimental work has been carried out on a test wall retrofitted with VIPs and built between two climate rooms with an indoor and an outdoor climate. Simulations showed good correlation with experiments. Calculations of threshold limits for condensation on the VIPs in the structure were performed with respect to different outdoor temperatures and internal moisture excess.

In total, the results from the experiment, the simulations, and the condensation controls conclude that timber frame buildings thermally insulated with 100 mm mineral wool, might be retrofitted at the exterior side by adding 30 mm VIPs in a continuous layer, as long as certain limits to outdoor temperature, internal moisture excess and indoor temperature are provided. The condensation calculations emphasized the importance of avoiding puncturing of VIPs, and to account for the aged conditions of VIPs.

Acknowledgements

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References

Building regulations (1969) Kap. 54 –Varmeisolering og tetthet (Norwegian building regulations of 1969, chapter 54 –Thermal insulation and air tightness). Norway: Royal Ministry of Local Government and Labour.

EN ISO 6946 (2007) Building components and building elements - thermal resistance and thermal transmittance - calculation method.

EN ISO 13788 (2001) Hygrothermal performance of building components and building elements - internal surface temperature to avoid critical surface humidity and interstitial condensation - calculation methods.

E. Sveipe, B. P. Jelle, E. Wegger, S. Uvsløkk, S. Grynning, J. V. Thue, B. Time and A. Gustavsen, "Improving Thermal Insulation of Timber Frame Walls by Retrofitting with Vacuum Insulation Panels – Experimental and Theoretical Investigations", *Journal of Building Physics*, **35**, 168-188, 2011.

TEK, §8-2 (1997) Energibruk (energikrav revidert i 2007) (Building regulations of 1997, energy demands corrected in 2007, §8-2, Energy).

WUFI 1D pro, version 4.2 NBI/NTNU, Release 4.2.0.421.DB.24.63, 2008.

WUFI 2D, version 3.3, Release 3.3.1.60.DB.24.63, 2010.