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Laboratory investigations of moisture conditions in wood frame walls with wood fiber insulation

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Abstract

The purpose of this study was to investigate the moisture conditions in wood frame walls with wood fiber thermal insulation in a Nordic climate. Laboratory measurements were conducted on 15 different wall configurations. The test results showed that the wall configurations with wood fiber insulation performed rather similar as those with mineral wool, in regard to measured relative humidity at the external side of the insulation layer. The laboratory tests showed that wood fiber insulation in wood frame walls holds interesting building physical properties related to moisture uptake and transport.

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Keywords: Woof frame wall, wood fiber insulation, moisture, hygrothermal, smart vapour barrier, vapour retarder

1. Introduction

Wood fiber based thermal insulation has been produced and used to a certain extent in some European countries, especially Germany, Austria and Switzerland. In the Nordic countries however the use has been sparse, and there have been few local producers. Wood fiber based products may have better environmental properties, i.e. in regard to CO_2-emmision from materials, which could be beneficial for instance in Zero Emission Buildings. This could be an argument for increased use of wood fiber insulation. In regard to building physics the hygroscopic characteristics of wood based insulation are interesting, since it is well known that the moisture capacity of wood fiber or cellulose insulation is higher than for instance mineral wool. Many claim this will have a positive effect on the general moisture conditions experience within a wood frame wall. Simonson et.al. [1] performed hygrothermal simulations for a wood frame construction in a Nordic climate and found that the risk for mould growth was lower when using cellulose fiber insulation, instead of mineral wool. Vinha [2] also performed hygrothermal simulations of wood frame walls, and found for instance that with a highly hygroscopic thermal insulation material a more vapour open vapour barrier is acceptable compared with for instance walls with mineral wool.

The purpose of this study was to investigate the moisture conditions in wood frame walls with wood fiber thermal insulation in a Nordic climate. One particular goal was to see if there was any effect of the higher hygroscopic capacity of wood fiber insulation, as compared to mineral wool. In addition the effect of various types of wind and vapour barriers were investigated.

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2. Method

2.1. General

Laboratory measurements have been conducted on 15 different wall configurations, or test cells. The test cells were given a one-dimensional configuration (area 600 x 600 mm2) omitting the effect of the wood frame and any internal convection.

It should be mentioned that the project in which these tests were a part, also included a laboratory test with five full height wood frame walls including the effect of the wood frame and any internal convection, another laboratory test with five full height wood frame walls including the effect of both internal and forced convection. Another test where the same test cells and walls were wetted to imitate a heavy rain leakage were also conducted. The measurements results are planned to be compared with hygrothermal simulations, and thereafter use the calibrated hygrothermal model to perform parametric studies for various Nordic climates. These results will be reported later on.

The test cells had various combinations of wind barrier, thermal insulation (loose fill/batt wood fiber or mineral wool) and vapour barrier or retarder. The test cells were mounted between two climate chambers, simulating respectively an outdoor and indoor climate for a period of six months. The outdoor climate varied between a winter, a spring/autumn and finally again a winter temperature level. The indoor air humidity was varied between three different levels. The test cells were instrumented with relative humidity and temperature sensors.

The following type of wood frame wall was tested (from exterior side):

- 12 or 50 mm asphalt impregnated porous wood fiber board or spunbonded polyethylene foil
- 300 mm thermal insulation (batt/loose-fill wood fiber or batt glass wool)
- Vapour barrier (PE-foil), vapour retarder ($S_d = 2m$), smart vapour barrier or no barrier
- 12 mm gypsum fiberboard

The measurements took place in the laboratories of Department of Civil and Transport Engineering, Norwegian University of Science and Technology, during spring/summer 2014, and lasted over 6 months..

2.2. Experimental set-up

The 15 test cells were built into a wall separating two climatic chambers as shown in Fig. 1a. The cells were separated by a 48 x 300 mm laminated wood frame. The wood was covered by a liquid dispersion-based membrane. This was done to avoid any moisture exchange between the insulation and the wood frame, i.e. to achieve close to one-dimensional conditions. The perimeter of the wall was insulated by 100 mm EPS to avoid any thermal disturbance at the edges. Between the wind/vapour barrier and wood frame a strip of silicone was added to secure a very good airtightness. The wind and vapour barrier were held in place with 36 x 48 mm battens.

The placement of the relative humidity and temperature sensors are shown in Fig. 1b. Two sensor was placed in each test cell, respectively at the interface between wind barrier and the insulation and at the interface between the vapour barrier and the insulation. In addition an extra sensor was placed into the insulation, 50 mm from the wind barrier, in 10 of the cells. To be able to do that the batt insulation was divided in 50 + 50 + 200 mm thick layers. Thin fishing lines fastened to the wood frame were used to keep the sensors in exact correct location. The sensors were of the type EE06 with range 0 – 100% RH and an accuracy of ± 3 % RH. Before the test they were calibrated at 50 and 75% RH.

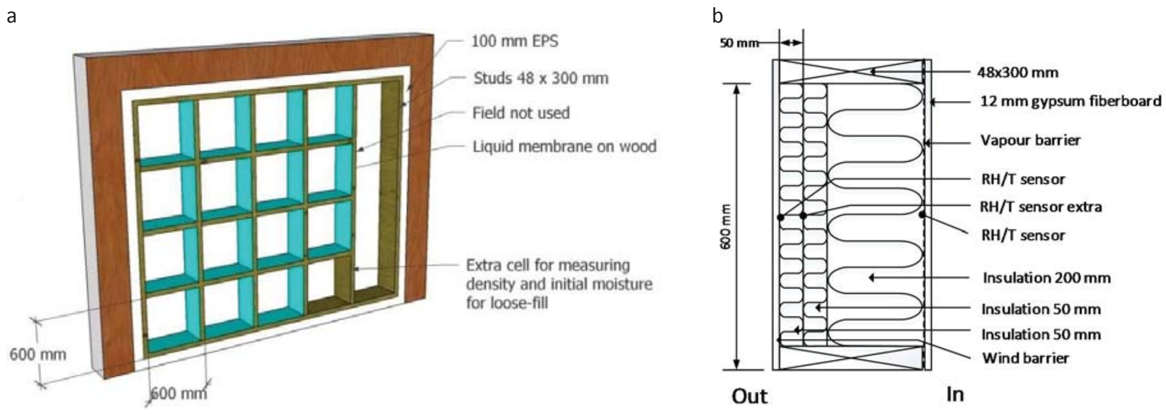

Fig. 1. (a) The test wall with 15 cells; (b) Instrumentation and placement of sensors in each cell.

2.3. Materials

The wood fiber insulation was tested in two variants; batt insulation and loose-fill, both from a German producer [3]. The batt insulation has a density of 50 kg/m^3, while the loose-fill normally has a density between 38 – 45 kg/m^3. In addition to wood fibers the products contains polyolefin fibers and ammonium phosphate. For other properties and the rest of the materials, see Table 1. For more information about the smart vapour barrier see product information from the producer [4]. The loose-fill insulation was blown into the cells as described by producer. Of the 15 cells; eight had wood fiber batt insulation insulation, three had loose-fill wood fiber insulation insulation and four had glass wool insulation.

2.4. Boundary and initial conditions

The external and internal boundary conditions were selected to represent three following periods, first a winter period with moderate indoor air humidity (day 1 – 56), thereafter a warmer spring/autumn period with low indoor air humidity (day 57 – 132) and finally again a winter period with a high level of indoor air humidity (day 133 - 195), see Figure 2 and Table 2. It was planned to have constant indoor climate during the three periods, but due to problems with the HVAC facility we did not achieve constant conditions, as can been observed particularly for RH indoors during period 1 and 3.

Table 1. Material properties

	Material	ρ (kg/m^3)	λ_d (W/mK)	S_d (m)
Wind barrier	12 mm wood fiberboard [a)]	235	0,048	≤0,2
	50 mm wood fiberboard [a) b)]	280	0,048	≤0,4
	Foil of spunbonded PE fibers	-	-	0,023
Insulation	Wood fiber batt	50	0,038	-
	Wood fiber loose fill	38 – 45	0,040	-
	Glass wool batt	16	0,035	-
Vapour barrier	Vapour retarder	-	-	2,0
	Smart vapour barrier	-	-	0,25 - 26
	0,15 mm polyethylene foil	-	-	≥40
Interior lining	12,5 mm gypsum fiberboard	1150	0,32	0,16

[a)] Porous fiber board coated externally with a combination of bitumen and recycled newspaper to form a moisture resistant skin.
[b)] Consists of two identical 25 mm boards

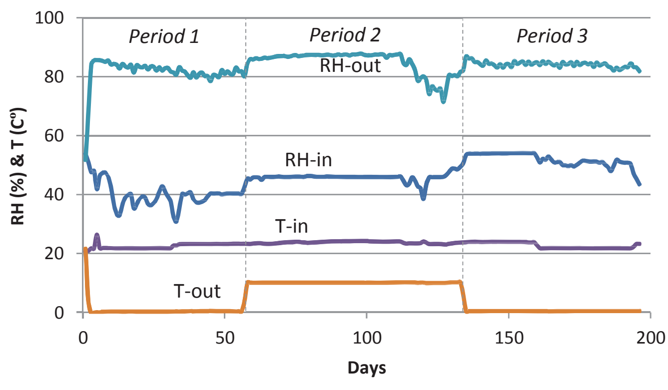

Fig. 2. Outdoor and indoor boundary conditions.

Table 2. Average indoor and outdoor boundary conditions for each of the three periods. Δv is the moisture supply (difference in moisture concentration between indoor and outdoor air).

	RH in (%)	T in (ºC)	RH out (%)	T out (ºC)	Δv (g/m^3)
Period 1	40,1	22,5	81,6	0,8	3,8
Period 2	45,9	23,7	84,9	10,1	1,8
Period 3	51,8	22,7	84,2	0,6	6,2

Due to the high hygroscopic capacity of the wood fiber insulation, the initial moisture content after installation may be of huge importance for the measurement results. Therefore the wood fiber batt insulation was conditioned to stable conditions in the climate room at an average 72% RH and 21 ºC, before installation and starting of the tests. The moisture content of the wood fiber batt insulation at installation was found to be 10,5 weight% after drying at 70 ºC. The loose-fill could not be conditioned in the climate room, but was blown into the cells some time before the test started and exposed to 72% RH and 21 ºC at both sides of the cells. The conditioning was therefore not perfect, but dependent on the vapour transfer through the various wind and vapour barrier layer until the test started. An extra cell, see Figure 1a, was blown at the same time as the 15 ordinary cells to find the initial moisture content and density. This extra cell had spunbonded polyethylene foil (S_d = 0,023m) as wind barrier and vapour retarder (S_d = 2 m) as internal barrier layer. The moisture content for the loose-fill wood fiber (for the extra cell) at start of the tests was found to be 10,9 weight%. The dry density was 35,8 kg/m^3, and if we assume a moisture content at delivery of approximately 6,5 weight% the density after blowing would have been approximately 38 kg/m^3.

3. Results and discussion

Some of the main results are shown in Figures 3 - 6. Focus has been put on showing the RH at the interface between insulation and the wind barrier, as this typically is the critical area in terms of highest risk for mould growth. The RH at the sensor points 50 mm from wind barrier and at the interface between insulation and vapour barrier are shown in a few of the figures.

The RH are shown at the wind barrier (12 mm fiber board) and vapour retarder (S_d = 2m) for the three various insulation materials in Figure 3. Outside of the vapour retarder we can see that the glass wool reaches stability very quickly after the test has started, while the wood fiber insulation has not even reached stability when period 2 is starting. This is probably due to the uniform high initial moisture content (~10 kg/kg) in the wood fiber insulation, which takes a lot of time to redistribute or dry to the exterior. It should be mentioned that in reality the insulation will not have such a uniform moisture content during ordinary use in winter time, since the redistribution of moisture will be a gradual process when we go from summer to winter. I.e. this will mainly happen directly after installation. This redistribution of initial moisture content during period 1 will probably affect the RH at the wind barrier, and could be an explanation why the wood fiber insulation is approximately 8 % RH higher during period 1 compared to the glass wool. When period 2 starts we see that the wood fiber outside the vapour barrier reaches stability much faster than in period 1 (after approximately 10 days), while the glass wool has reached stability after two days. The RH at the wind barrier is higher for the wood fiber insulation for all periods, but in period 2 and 3 the difference is not so high as in period 1 when the effect of high initial moisture content is at its highest. Also at the wind barrier we can see that the glass wool reaches stability faster than the wood fiber insulation, especially in the transition between period 1 and 2. When looking at the test cells with a polyethylene foil (S_d > 40 m) instead of vapour retarder we see almost the same pattern as in Figure 3.

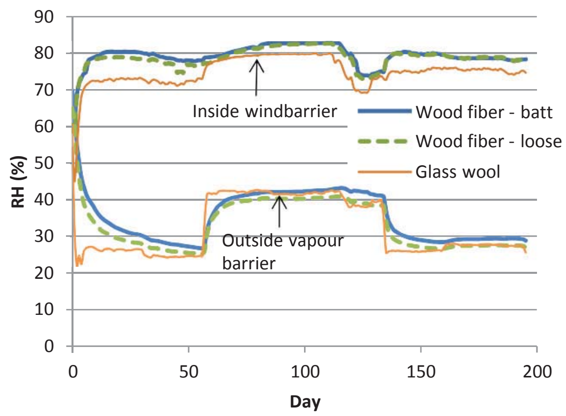

Fig. 3. RH at wind barrier (12 mm wood fiber board) and at vapour retarder (S_d = 2m) for the different types of insulation.

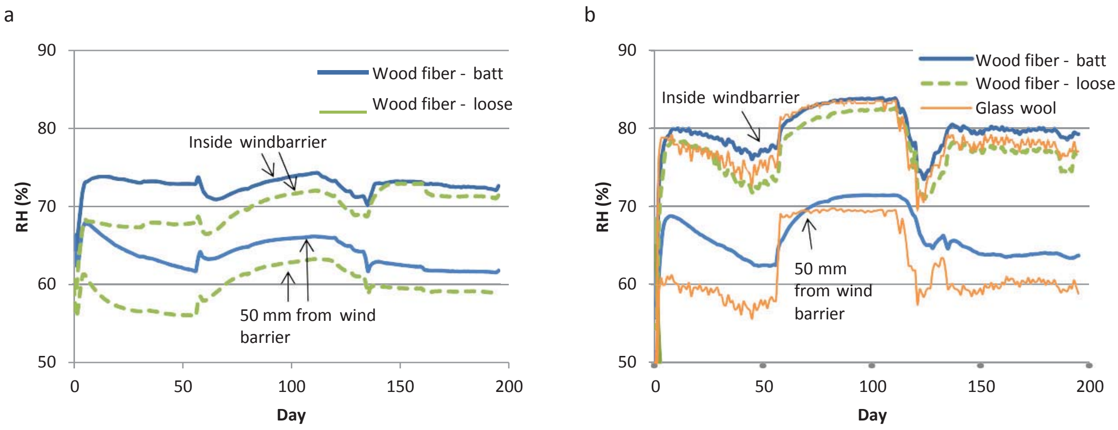

Fig. 4. RH at wind barrier and 50 mm from wind barrier for different types of insulation with vapour retarder (S_d = 2m). (a) Wind barrier = 50 mm wood fiber board; (b) Wind barrier = spunbonded polyethylene foil.

In Figure 3 we see an indication that the RH is lower for the loose-fill wood fiber compared to the wood fiber batt insulation, both at the wind barrier (only period 1) and at the vapour barrier the whole period. For the other types of wind barriers, this is even more pronounced, see Figure 4. With a spunbonded polyethylene foil the RH at the wind barrier is 3-5% RH lower for the loose-fill during the whole test period as shown in Figure 4b. With a 50 mm wood fiber board as wind barrier we see a similar effect in Figure 4a, both at the wind barrier and 50 mm into the insulation. Here the effect is most pronounced the first part of the test. Part of this effect, at least the higher difference during period 1, could be explained by the fact that the loose-fill and batt insulation were not conditioned the same way. The loose-fill had to be conditioned for a period after been blown into the cells, i.e. the wood fiber loose-fill may not have reached stability at 72% RH as the batt insulation did. We see the highest difference in Figure 4a for 50 mm wood fiber board as wind barrier, this representing the highest resistance for moisture uptake in the loose fill insulation during conditioning period. Other explanations for this difference could be the density difference or a different vapour permeability.

In Figure 4 b it is interesting to observe that the difference between the glass wool and wood fiber insulation in RH at wind barrier is not very big, the glass wool having an RH approximately between the wood fiber loose-fill and batt. In addition we see that the response time for changes do not differ so much at the wind barrier of spunbonded polyethylene foil. This is probably due to the fact that the wind barrier is very vapour open (S_d = 0,023 m), meaning that the RH will follow the external RH to a higher degree. But going only 50 mm into the insulation, we can see that the high moisture capacity of the wood fiber insulation slows down the response time for changes in boundary conditions.

It is expected that we will see some effect of the type of vapour barrier. In Figure 5 we see that the RH at wind barrier is lower for PE-foil compared to the vapour retarder. This is as expected, especially during period 3 where the moisture supply is very high. At the same time, we also see a tendency that the smart vapour barrier perform slightly better than the PE foil. At least for period 1, this could be explained by some drying to the interior in the initial phase when the moisture content in the interior part of the insulation still is high. The highest levels for RH are observed when no vapour barrier is used, see figure 5b. This means that the exterior vapour resistance (S_d = 0,4 m) is higher than the interior resistance (S_d = 0,16 m), which are far from typical recommendations. However, even when the moisture supply is very high in period 3, the RH at wind barrier is under 90% for the case with no vapour barrier. The reason for this is obviously the thick and thermally insulating 50 mm wood fiber board, increasing the temperature and thereby decreasing the RH. For a wind barrier with low or very low thermal resistance the RH will probably be much higher. It is however interesting to note that when using a wind barrier with high thermal resistance such as 50 mm wood fiber board, you may get a more robust construction which actually can handle relatively low vapour resistances at the warm side without moisture damages. One requirement is that such a thick wind barrier can withstand for instance mould growth in the inner part of the product, since the RH here might get higher than at the interior of the wind barrier.

The effect of various wind barriers are shown in Figure 6a. We see again the general positive effect of using a wind barrier with high thermal resistance such as 50 mm wood fiber board. The difference between the 12 mm wood fiber board and the very vapour open spunbonded polyethylene foil is however not very big. The positive effect of some thermal resistance for the 12 mm wood fiber board, is probably counteracted by the spunbonded polyethylene foil being more vapour open. It should however be noted that during the warmer period 2 the construction with spunbonded polyethylene foil reaches the highest RH during the whole measurement periods. This warmer period may also be critical due to higher temperatures increasing the risk for mould growth.

In Figure 6b two alternative constructions with wood fiber insulation and 12 mm wood fiber board, one with vapour barrier of PE-foil and the other with a smart vapour barrier is compared to a common modern wood frame wall with spunbonded PE as wind barrier, glass wool and PE-foil as vapour barrier. In general we see that the wall configurations with wood fiber insulation performs just as good as the one with glass wool.

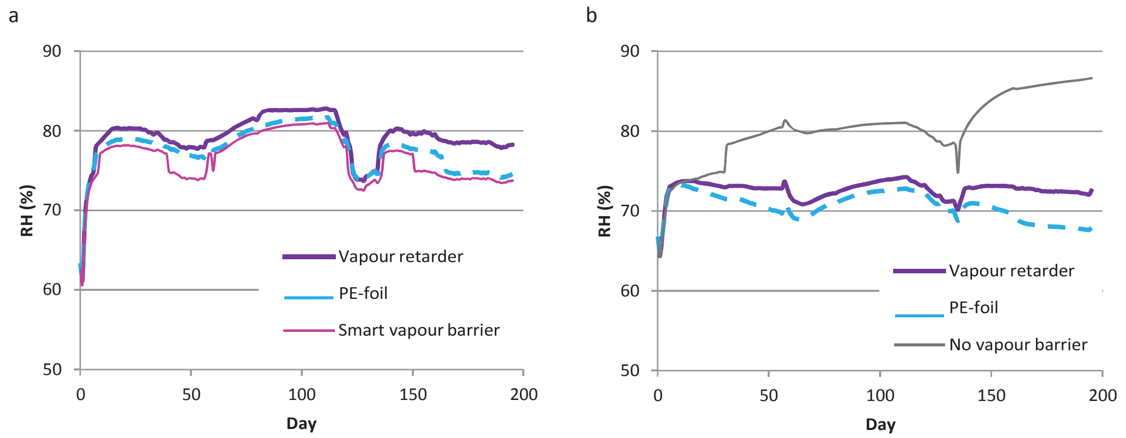

Fig. 5. RH at wind barrier for wood fiber batt insulation for different vapour barriers. (a) With 12 mm wood fiber board; (b) With 50 mm wood fiber board.

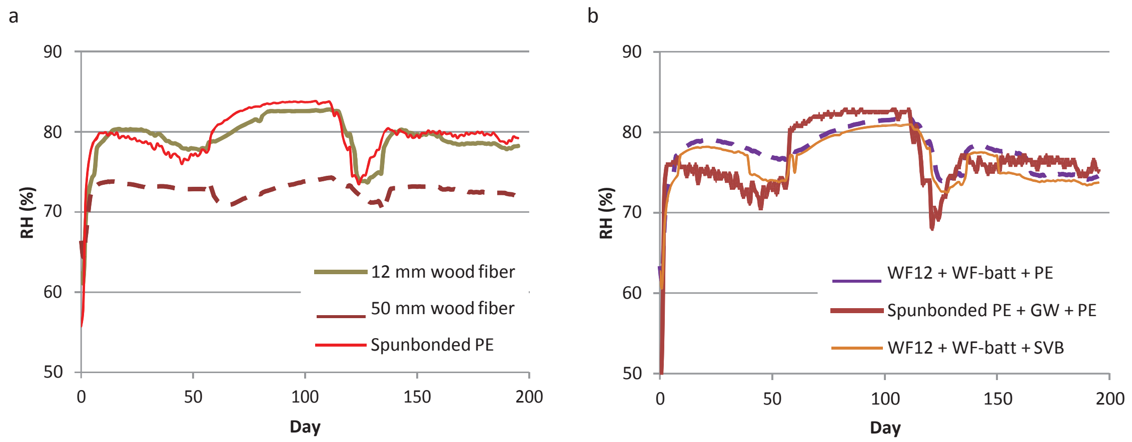

Fig. 6. RH at wind barrier for different combinations. (a) With wood fiber batt insulation and vapour retarder (S_d = 2m). (b) WF = 12 mm wood fiber board, GW = glass wool, SVB = smart vapour barrier

4. Conclusions

The test results showed that the wall configurations with wood fiber insulation performed rather similar as those with glass wool, in regard to measured relative humidity at the external side of the insulation layer. Depending on the type of wind barrier the wood fiber insulation performed slightly worse or similar to the glass wool during winter conditions, and slightly better or similar during summer conditions. The glass wool on the other side had a substantially faster response time in drying and wetting compared to wood fiber insulation. There were indications that loose fill wood fiber insulation performs slightly better than batt wood fiber insulation. Factors having a positive influence on the moisture conditions were using a thick (50 mm) wood fiber board as wind barrier, and a so-called smart vapour barrier. All of the tested constructions stayed below a relative humidity of 85%, even for a winter period with very high indoor air humidity and a relatively vapour open vapour retarder.

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