Compact wooden roofs with smart vapour barriers – effect of wooden joists on drying of built-in moisture

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Abstract. The application of a smart vapour barrier in compact wood frame roofs has been investigated. The study was performed using a laboratory setup for small roof elements, exposed to a typical Nordic summer climate and a high level of built-in moisture. The concept of this study was to investigate how various types of wooden joists and their hygroscopic properties influenced the inward drying and moisture distribution within the elements. The results were compared to previous studies with similar roof elements without wooden joists. The results showed that the type and size of wooden joist influenced both the drying speed and the moisture level and distribution within the elements.

1 Introduction

Compact (unventilated) wooden roofs typically need a vapour barrier at the warm side to avoid vapour diffusion and convective moisture transfer from the interior. A traditional vapour barrier such as a polyethylene foil does however not allow drying to the interior, making the construction vulnerable to rain during construction or mounting (built-in moisture) or leakages occurring later on. For some years an alternative to these traditional vapour barriers have been on the market, so-called smart vapour barriers (SVB), also called "moisture adaptive" or "humidity dependent" vapour barriers. An SVB allows for some drying of any excess moisture within the construction to the indoor air during summer conditions, while at the same time preventing vapour diffusion from the indoor air into the construction during winter conditions. The SVB has a high vapour resistance when exposed to low relative humidity (RH) (typical winter condition), and a low vapour resistance when exposed to high RH (typical summer conditions for constructions with excess moisture). One of the first types of SVB was developed in Germany in the mid 90's [1], and it was first introduced as beneficial for unvented wooden roofs. There are a lot of studies on unvented roof systems with this product [2-5].

Since then and up till today there have been developed various similar products with RH-dependent vapour resistance. Some of these new products may have a higher resulting vapour resistance for winter conditions reducing the risk for interstitial conditions. And some may have a lower resulting vapour resistance for summer conditions, resulting in

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higher drying rate to the interior. Documented scientific studies of applications for these new products are however limited although they may have some advantages compared to the original SVB. To investigate the effect of some of these newer products some laboratory studies were performed [6-7]. The laboratory set up of these two studies did however not include the two-dimensional effect of the wooden joists, the only wooden part of these studies were the wooden roof sheathing. This study is a follow up study where the effect of the wooden joists have been included.

2 Laboratory tests

2.1 General

The application of a SVB in compact wood frame roofs was investigated in this study. The study was performed using a laboratory setup for small roof elements, exposed to a typical Nordic summer climate and a high level of built-in moisture. The purpose of these tests was to investigate how various types of wooden joists and their hygroscopic properties influenced on the inward drying and moisture distribution within the roof elements.

The measurements took place in the laboratories of Department of Civil and Transport Engineering, Norwegian University of Science and Technology, during spring 2017.

2.2 Experimental set-up

Four different wood frame roof elements with 300 mm insulation (called A, B, C and D) were tested. In addition some comparisons with a previous similar experiment [7] were made (element notified "1D" for one-dimensional). Element 1D is similar to element A except that the insulation thickness is 200 mm, and there is no wooden joist.

The roof specimens were built up in PVC-boxes; where the bottom of the boxes was used to imitate the roofing membrane and the rest of the materials were adjusted to fit the box, see Figure 1. The boxes had interior dimensions b = 0,57 m, l = 0,77 m and h = 0,30 m, and flanges onto which the SVBs and gypsum board were taped. The boxes were placed in a lifted test rig with bottom up, insulation on all sides to get isothermal conditions and a heating foil that could be controlled to give the wanted surface temperature on the roofing membrane (i.e. the bottom of the PVC-box). Each test box could be dismounted during the experiment to monitor the continuous weight loss. See details in Figure 1, 2 and 3.
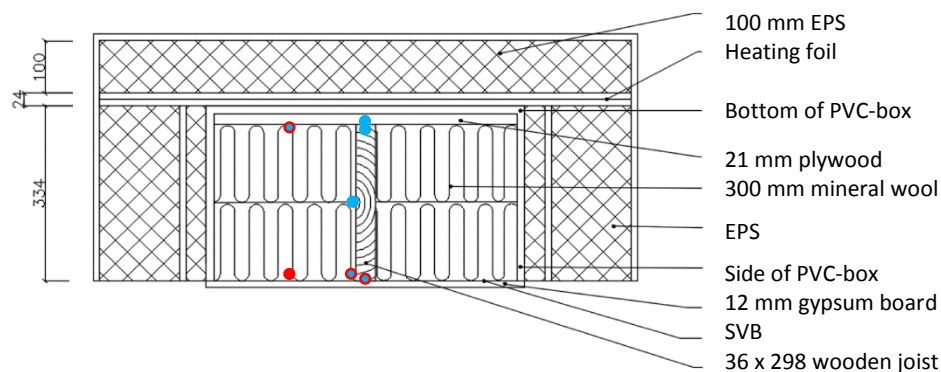

Fig. 1. Section of the test rig (element A and D). The coloured markings show the measurement locations (blue = only wood moisture, red = only RH/T, red/blue = both wood moisture and RH/T).

Fig. 2. Test box showing wooden joist, plywood (to the right) and measurement sensors before installation of SVB and gypsum board.

2.3 Materials

The SVB used in this test, AirGuard Smart, is a polyvinyl alcohol film (with spun bond polypropylene as reinforcement and protecting layer). The S_d-value is ranging from 0,05- > 30 m [9]. For one of the elements a newer version of AirGuard Smart was used (called generation 2). The S_d-values and its dependence of RH are relatively similar for both versions above 70% and below 50% RH, while in between 50 and 70% RH the generation 2 has a higher S_d-value (e.g. at 60% RH: $S_d \approx 2$ m (gen 1), $S_d \approx 4$ m (gen 2)). The gypsum board has an S_d-value of approximately 0,1 m.

2.4 Boundary and initial conditions

The external boundary conditions were given by the temperature controlled by the heating foil in the test rig. It was decided to simulate diurnal cycles of the external surface temperature over a period of 60 days, see Table 1. The diurnal cycles were chosen to be the same as in a previous experiment, where similar roof elements as in this test, but without wooden joists, were investigated [7]. The chosen diurnal cycles were selected based on a parametric study with WUFI 1D Pro [8]. The roof temperatures for shaded conditions (slope 55° and 90° to the north) were calculated for Trondheim and Oslo for the summer period (May-Sept), and the 60 days with warmest roof temperatures were selected (giving maximum roof temperature up to 38 °C). Since it was difficult to use the heating foil to recreate the exact temperature profile from the simulations (the "cooling" period after turning off the heating foil after reaching the maximum temperature took many hours), it was decided to use a somewhat lower maximum temperature that gave the same drying potential towards the interior summed up over the day.

The minimum temperature during night for these daily cycles in Table 1 was the same as the air temperature in the climatic chamber (23°C). The test rig was placed in a climatic chamber with constant indoor temperature and RH of 23°C and 50%.

To simulate built-in moisture from rain or an accidental leak the plywood sheathing was given an initial moisture content between 29-31 weight-% measured by gravimetric method

by immersion in water. The joists were given a lower uniform initial moisture content between 13-16 weight-% measured by gravimetric method, by being stored in a climatic chamber for four weeks at 33 °C and 75% RH. For detailed values see Figure 3.

Table 1. Chosen diurnal external surface temperature cycles during test period of 60 days.

Cycle no.	Number of days	Max. temperature (°C)
1	13	25
2	4	33
3	13	30
4	13	25
5	4	33
6	13	30

Element A

Roofing membrane

21 mm plywood (spruce) sheathing (u_{init} = 29 weight-%)

300 mm glass wool

Wooden joist (spruce) 36 x 298 mm (u_{init} = 13,5 weight-%)

SVB (Air Guard Smart-gen 1)
12 mm gypsum board

Element B

Roofing membrane

21 mm plywood (spruce) sheathing (u_{init} = 29 weight-%)

300 mm glass wool

Wooden joist (spruce) 36 x 298 mm (u_{init} = 14,5 weight-%)

SVB (Air Guard Smart-gen 1)
48 mm air gap
12 mm gypsum board

Element C

Roofing membrane

21 mm plywood (spruce) sheathing (u_{init} = 31 weight-%)

300 mm glass wool

I-profile joist(flanges: 2x45x45 mm laminated spruce + web: 8 mm medium density fiber board) (u_{init}=16,3 weight-%)
SVB (Air Guard Smart-gen 1)
12 mm gypsum board

Element D

Roofing membrane

21 mm plywood (spruce) sheathing (u_{init} = 31 weight-%)

300 mm glass wool

Wooden joist (spruce) 36 x 298 mm (u_{init} = 14,5 weight-%)
New generation SVB (Air Guard Smart-gen 2)
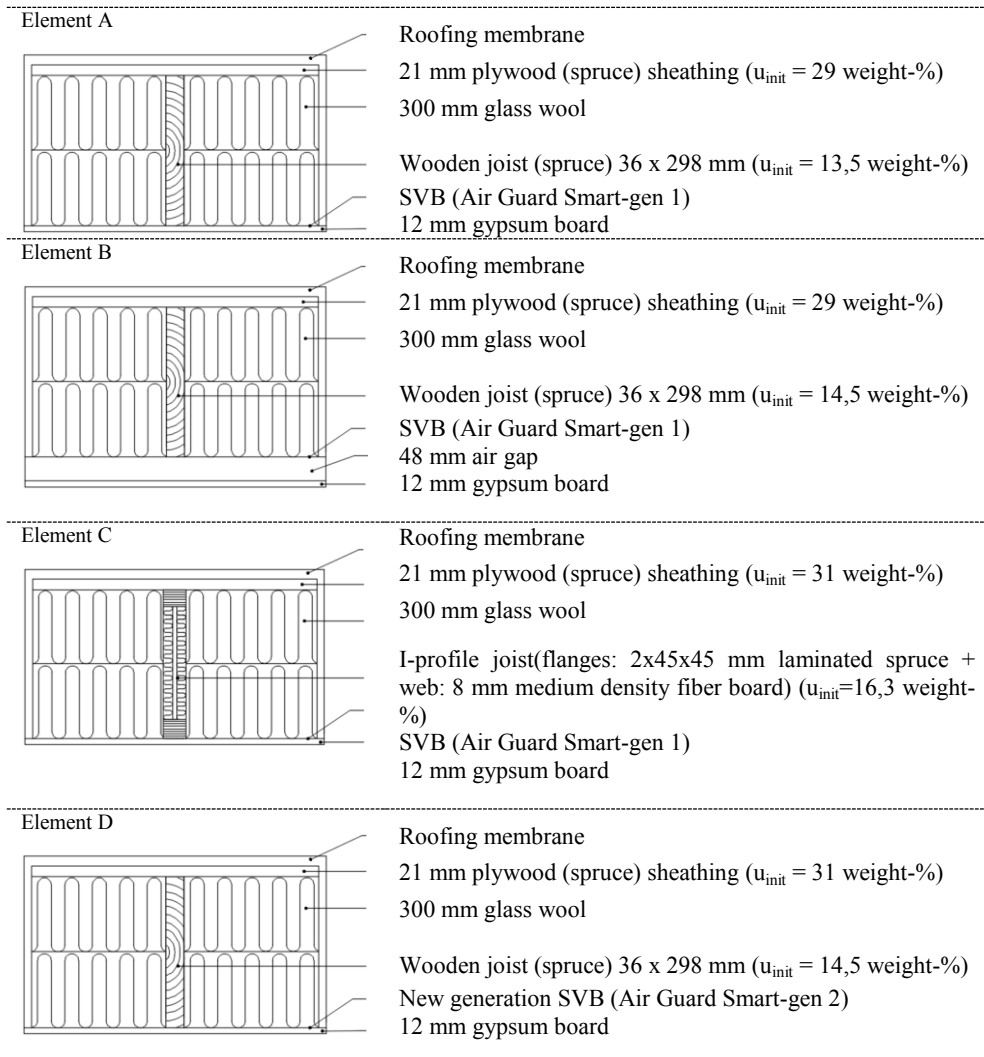12 mm gypsum board

Fig. 3. Description of the roof elements. Note that the "roofing membrane" is in fact the bottom of the test box. Initial moisture content (u_{init}) of wooden materials are also given.

2.5 Measurements

The test-rig were constructed so that the boxes could be dismounted and weighed regularly to follow the total drying of the configurations. In addition the wood moisture content, temperature and RH were measured several places in the roof elements, see locations in Figure 1. The moisture content of the plywood and wooden joists was measured manually by traditional resistance measurements, using screws (dimension 3,5 x 9,5 mm) with distance 20 mm as electrodes. A special calibration curve was used for the plywood. The RH and temperature of the indoor climate were also continuously logged.

3 Results and discussion

Figure 4 show the total drying at three different timesteps. After 30 days of drying all the five roof elements, except element D, have approximately the same total drying. The reason for the lower total drying for element D is probably due to the fact that the SVB (gen 2) has a higher vapour resistance than the SVB (gen 1) used in the other elements. The average RH over the SVBs varies between 60-70% over the measurement period, and for example at 60% RH the S_d-value for gen 2 is 4 m while it is only 2 m for gen 1. The element without a joist (1D) and the element with an I-profile joist shows a higher total drying after 7/9 days than the other elements. An explanation for this is probably that in the other elements (A, B and D) there is a larger volume of dry wooden materials temporarily absorbing some of the moisture that has dried from the plywood. It should also be mentioned that the 1D element has a lower insulation thickness, i.e. the vapour resistance from plywood to SVB is also lower.
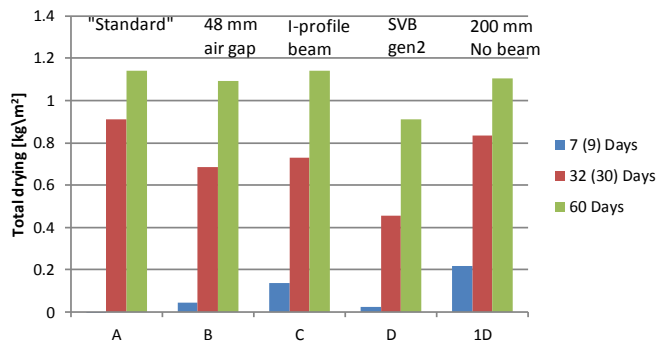

Fig. 4. Total drying after 7, 32 and 60 days (day number in parenthesis applies for "1D" element).

The RH at different locations in the elements are shown in Figure 5 and 6. It should be noted that the three first days in the diagrams is an initial period after production of the elements, but before the elements being placed in the test rig. In Figure 5a we can see that the RH below the plywood is between 82-87% RH for the first 13 days of the cycle (cycle 1), with a rather slow drying rate. When the higher outdoor temperature is applied (cycle 2 and 3), the drying rate gets much higher. After 30 days the RH below the plywood is between 70-76%. Element A has the highest RH, while element C has the lowest. It is however difficult to find some good explanation for these differences.
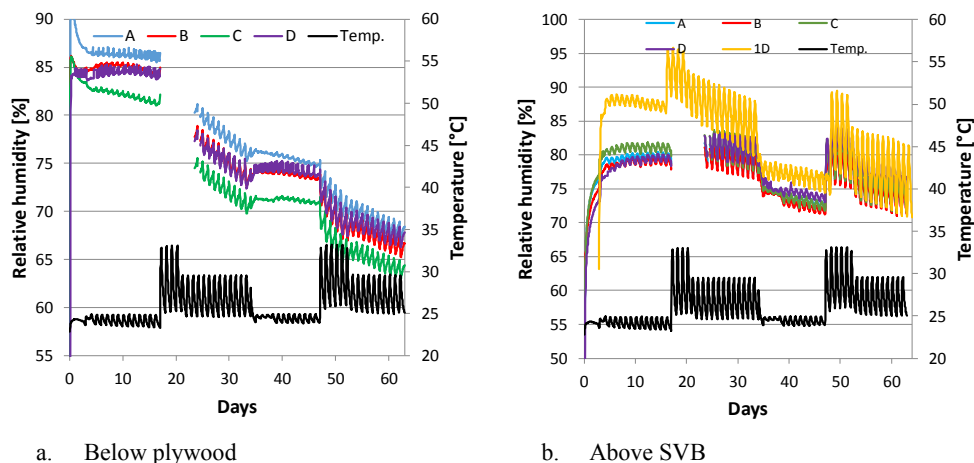
a.   Below plywood

b.   Above SVB

Fig. 5. Relative humidity below plywood (a) and above SVB (b), shown together with the temperature at the roof surface (heating foil). For the "1D"-element RH was only measured above the SVB.

In Figure 5b the RH above the SVB is shown. The difference between the four elements with wooden joist is not big, however the RH for element C is higher than the other three elements for the first cycle. This is as expected since during the first cycle the solid wooden joists (as in elements A, B and D) will absorb some of the built-in moisture transported by vapour diffusion from the plywood layer. The I-profile in element D has however less wooden volume, and thus a larger part of the moisture diffusing from the plywood will be transported directly towards the SVB. It is especially interesting to note the large difference between the element without wooden joist (1D) and the other elements. For the first 30 days the RH in element 1D is approximately 5-10% higher than the other elements, and the diurnal variations are also higher. Without relatively dry wooden joists in element 1D to absorb some of the moisture drying from the plywood, a higher amount of water vapour will reach the SVB and increase the RH. The average RH over the SVB will be higher, decreasing the vapour resistance of the SVB and thus also increase the drying to the indoor air during the first measurement period from the 1D element as we observed in figure 4.

The RH at different locations above the SVB are shown in Figure 6 for element A and C. In general RH for the measurement points below and beside the joist is lower than for the measurement point 150 mm from the joist, and the diurnal variations are also dampened by the wooden material – especially below the joist. This also applies for the last part of the measurement period, where the effect of initially rather dry wooden joists is reduced.
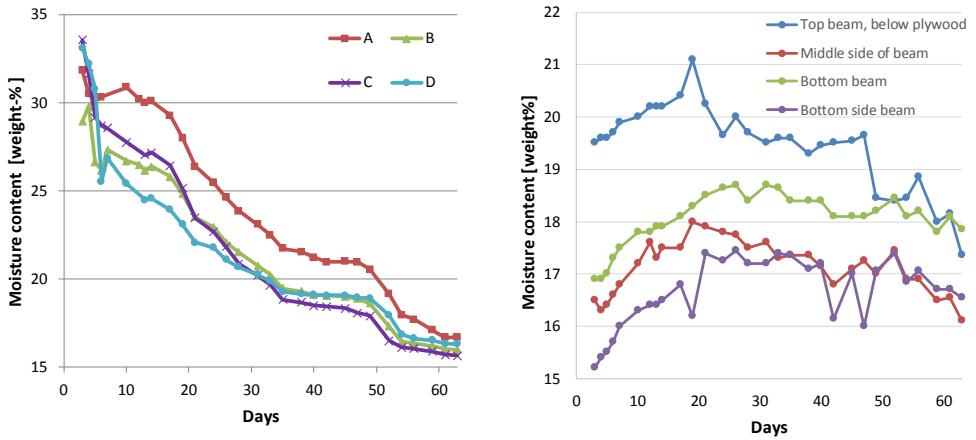
The moisture content of the plywood is shown in Figure 7a. Elements B, C and D follow the same drying pattern, and have reached a moisture content below 20 weight-% after 35 days. Element C have the highest drying rate during cycle 2 and 3, and reach the lowest level of all the elements. This is in accordance with the RH measurements shown in figure 5. The plywood layer in element A do however dry slower, and reach 20 weight-% after 50 days. It is difficult to explain why element A dry slower than element D. With the SVB (gen 2) of element D that has a higher vapour resistance for the relevant RH-interval one should expect the opposite result.
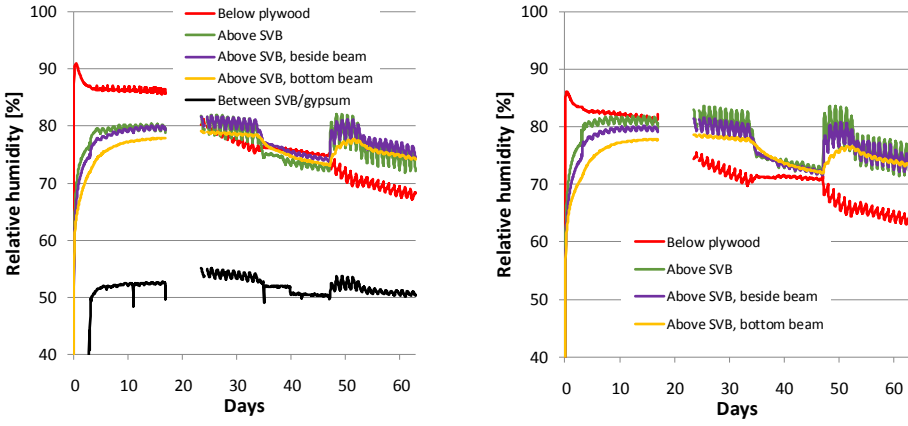
a.Element A (standard) b. Element C (I-profile)

Fig. 6. Relative humidity at different locations within the insulation cavity for element A and C.

a. Plywood (150 mm from joist) b. Element A

Fig. 7. Moisture content in plywood (all elements) and wooden joist (element A).

The moisture content at various locations in the joist is shown in Figure 7b for element A. The moisture content is generally increasing the first period, due to moisture uptake from a relatively low initial moisture content (approximately 14 weight-%). In the last part of the measurement period the moisture content is drying. We also see that the top part of the joist (below the plywood) has the highest moisture content, due to direct contact with the initially wet plywood. This also applies for the other elements. We also see that the bottom part of the joist have higher moisture content than the bottom side of the joist. This also applies for the other element, except for element D. This is unexpected since the RH-measurements shown in Figure 6 shows that the bottom part of the joist has the lowest RH. An explanation for this difference could be the fact that the measurement locations for RH and moisture content sensors are not exactly the same. The RH sensor in the bottom of the joist are embedded in a 10 mm deep cavity that has been cut out of the wood, while the moisture content electrodes are screws mounted from the bottom surface. The RH sensor at the bottom side of the joist is mounted innermost in the corner between the joist and SVB, while the moisture content electrodes are mounted 10 mm up from the SVB. Regarding

element D it is interesting to note that the difference between the various locations are rather small, and the maximum moisture content considering all locations are 18,5 weight-% (in bottom part of joist). The reason for this is not clear, but as shown in Figure 7a the plywood in element D has a high drying rate the first period.

4 Conclusions

One of the purposes of this study was to investigate the effect of the wooden joist and their hygroscopic properties on the inward drying during summer conditions and moisture distribution in the roof elements. The results indicate that the wooden joists do not have an effect on the total drying (in kg/m^2) after a long period of summer conditions. However, the effect is significant during the first period of drying, since the wooden joists (if they are initially relatively dry) may temporarily absorb by vapour diffusion some of the built-in moisture of the wet wooden roof sheathing, and thereby delay the inward drying to the interior air. The volume of the wooden joist, e.g. whether it is an I-profile or solid wood, also to some extent have an effect. In regard to moisture distribution inside the roof cavity it was found that especially the RH above the smart vapour barrier is highly influenced by the presence of wooden joists or not. This also indicate that hygrothermal simulations of compact wooden roofs should preferably be made with two-dimensional simulation tools.

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