Moisture properties of vapor open roofing underlays in winter conditions

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Abstract

Vapor open roofing underlay`s mounted according to the acknowledged guidelines in Norway have in the past cold winters experienced problems with rim and melt water on the interior side of the products. When the temperature is below zero, diffusion of water vapor leads to accumulation of rime/ice on the underside of the roofing underlay. This can, when the outdoor temperature quickly rises above zero degrees, lead to dripping from the roofing underlay, experienced as a water leakage through the ceiling for users of the building. This water can cause short-and long term damages to the building elements such as window frames, ceiling plates, gypsum boards in both walls and roofs etc.

An extensive laboratory experiment was conducted in 2010-2011 at SINTEF Building and Infrastructure, Trondheim, Norway. The objective was to investigate the water vapor resistance in vapor open roofing underlays in temperatures below zero, with potential for rime/ice on the underside of the products. The water vapor permeance is the roofing underlays ability to transport water vapor from one side of the product to the other. The purpose of the experiment was to investigate if and how the vapor permeance of the material changes when rime/ice is formed on the interior side of the product. The research question was to investigate if the potential for further accumulation of rime/ice increase when there is ice on the product?

The water vapor permeance is often referred to as the water vapor resistance, which is the reciprocal of water vapor permeance. High water vapor permeance leads to a low water vapor resistance. The water vapor resistance is often referred to as s_d-value: water vapor diffusion-equivalent air layer thickness. The s_d-value is the thickness of a motionless air layer which has the same water vapor resistance as the specimen.

The results show that most roofing underlays have approximately the same water vapor resistance in temperatures below zero as in room temperatures. One product had a significant increase in the water vapor resistance (+40 %), meaning that the potential mass of water vapor that goes through the roofing underlay in cold temperatures is decreased. One product had a severe decrease in water vapor diffusion resistance in cold temperatures (-85 %). The total flow of water vapor diffusion through the samples is depending on the water vapor resistance of the product (s_d-value) and the water vapor pressure difference through the samples. The water vapor pressure differences across the samples are lower in sub-zero temperatures, thus the total water vapor flow through the samples is lower in sub-zero temperatures.

To avoid rime/ice on roofing underlays both s_d-value of the roofing underlay and a low level of build in moisture in the structure is important. The risk of rime/ice underneath the roofing underlay can be further reduced by having an air tight structure, and having a roofing underlay with the ability to store compensated water without letting the water fall down from its surface.

Background

Thermal insulated pitched wooden roof structures are a common type of roof structure in large parts of the world. These structures, just like e.g. wooden wall structures, needs a ventilated space between the cladding/roof cover and wind barrier/roofing underlay. This space transports heat and moisture away from the structure, and thereby preventing moisture to be stored in the structure.

Roof structures with water vapor roofing underlays have to be ventilated by use of two ventilated air gaps. In the 1990`s a new product group and type of roof structures were introduced, making it possible to include only one ventilated space in wooden roof structures. The vapor open roofing underlays water tight, but vapor open. This means that water vapor can be transported through the material, but water (precipitation) will not penetrate the product.

In wooden roof structures water vapor can be accumulated close to the interior side of the roofing underlay as water due to several conditions and circumstances. In Nordic climates the temperature inside a house is almost always higher then the outdoor temperature. In a roof structure, this will lead to a low relative humidity in the air close to the vapor barrier, where the temperature is high. Close to the roofing underlay, the temperature is close to the outdoor temperature, and the relative humidity will increase. In Passive Houses the temperature is lower than in houses built according to the building regulation, due to the high amount of thermal insulation. The level of humidity is dependent on among others the amount of build-in moisture in the wooden roof structure (rafters), the amount of air leakages of internal (humid) air entering the roof structure and the level of ventilation of the air space between the roofing underlay and the roof cover. The amount of build-in moisture is especially dependent on the weather conditions when the roof structure was constructed and the total amount of wood in the roof structure.

Vapor open roofing underlay`s mounted according to the acknowledged guidelines in Norway have in the past cold winters experienced problems with time/ice on the interior side of the products. When the temperature is below zero, diffusion of water vapor leads to accumulation of rime/ice on the underside of the roofing underlay, see example in Figure 1.

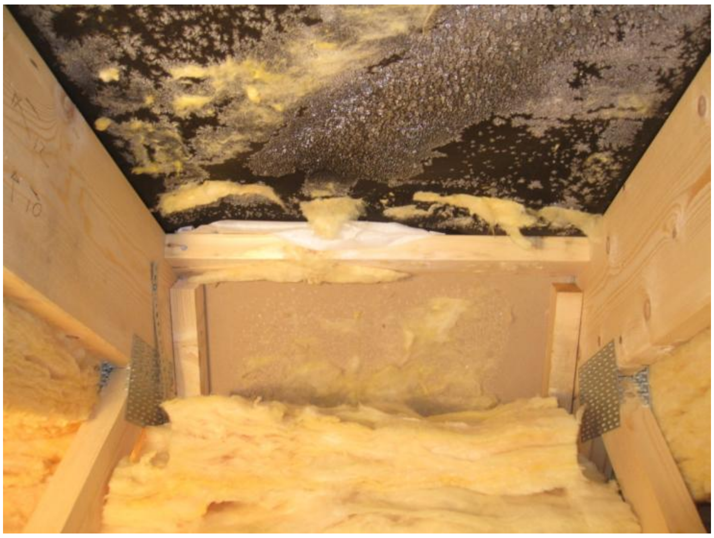

Figure 1 Example of a roofing underlay with ice on the interior side

This can, when the outdoor temperature quickly rises above zero degrees Celsius, lead to dripping of melt water from the roofing underlay, experienced as a water leakage through the ceiling, window posts etc. for users of the building. This water can cause short-and long term damages to the building elements such as window frames, ceiling plates, gypsum boards in both walls and roofs etc.

Method

To investigate the water vapor resistance in vapor open roofing underlay`s in temperatures below zero, with potential for rime/ice on the underside of the products , an extensive laboratory experiment was conducted in 2010-2011 at SINTEF Building and Infrastructure, Trondheim, Norway. The experiment was a collaboration between seven companies producing vapor open roofing underlays and SINTEF Building and Infrastructure. The purpose of the experiment was to investigate if and how the vapor resistance of the material changes when rime/ice is formed on the interior side of the product.

The experiment was going to simulate winter conditions in thermal insulated wooden roof structures with a high level of build in moisture. Ten vapor open roofing underlay`s was tested in an advanced and further developed version of the cup-method described in NS-EN ISO 12572. Each underlay represented the top lid of a plastic box that contained 200 mm insulation with water in the bottom. The water in the bottom of the box was held at a constant temperature of +23 ° C. The temperature on the outside of the box was -4 ° C when testing in sub-zero conditions. The respectively s_d-values was calculated by registering the weight loss for each product as the experiment progressed. In addition, the condensation uptake for each product was measured, using an additional box with removable lids made of the respective roofing underlays. The apparatus is shown in Figure 2.

Figure 2 Overview of the experiment apparatus in the laboratory

Each product replaced the original lids on two separate boxes. Boxes closest to the left row in Picture 1 were used to measure the water vapor diffusion resistance, and the lid was sealed with butyl tape. Sensors for measuring the relative humidity were mounted inside the box, close to the interior side of the roofing underlay. Two sensors were also mounted inside the room, tracking the temperature and relative humidity in the room. Thermo elements were mounted on both exterior and interior side of the roofing underlays, and were detached at each weighing of the boxes. The boxes in the row to the right on Picture 1 have a detachable lid, making it possible to investigate how much rime/ice that was attached to the specimen. The complete set-up is shown as a vertical section of the apparatus in Figure 3.

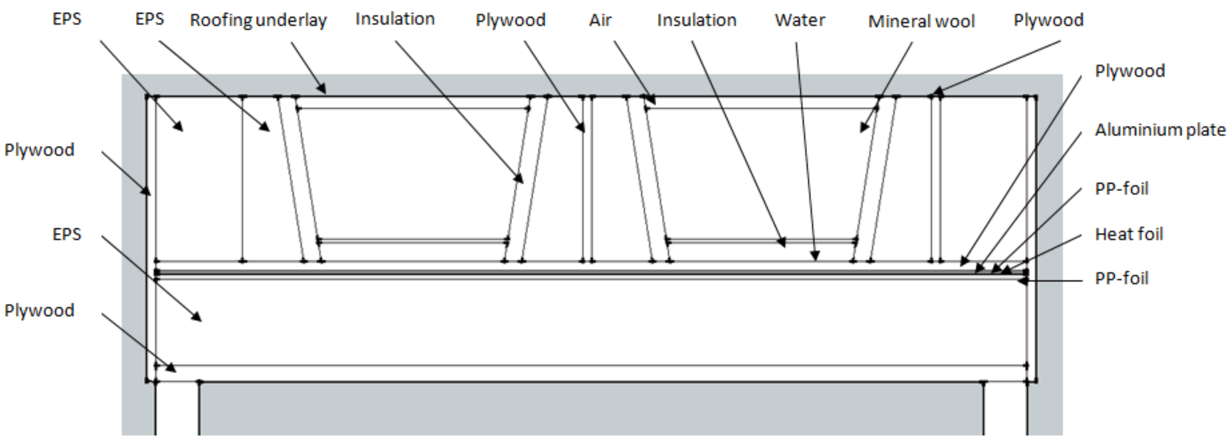

Figure 3 Vertical section of the apparatus

Products participating in the experiment

Seven companies' producing combined roofing underlays and wind barriers participated in the experiment, with a total of 10 products. Table 1 shows the main characteristics of the participating products.

Table 1 Overview of the ten vapor open roofing underlays included in the experiment

ID	Type of product	Material	Thickness mm	Basis weight g/m²
A	Board product	Wood fiber	32,0	2900
B	Roll product	Spun bonded PE-fibers and PP, with felt	1,3	320
C	Roll product	Spun bonded PE-fibers	0,6	195
D	Roll product	PU and PP, with cloth made of PP	1,2	300
E	Cardboard	Laminated paper	2,1	1400
F	Roll product	PP and PE	0,7	160
G	Roll product	PP	0,8	195
H	Roll product	PP and PE	0,8	140
I	Board product	Wood fiber	20,5	4800
J	Roll product	PP	0,8	210

PE = Polyethylene
PP = Polypropylene
PU = Polyurethane

Results and discussion

The results from the experiment are shown in Figure 4-6. After each table the results are explained and discussed. The vapor diffusion resistance is presented as the s_d-value. As a comparison, the recommended limit for the s_d-value for vapor open roofing underlays according to SINTEF Building and Infrastructure guidelines is s_d-value < 0,5 m.

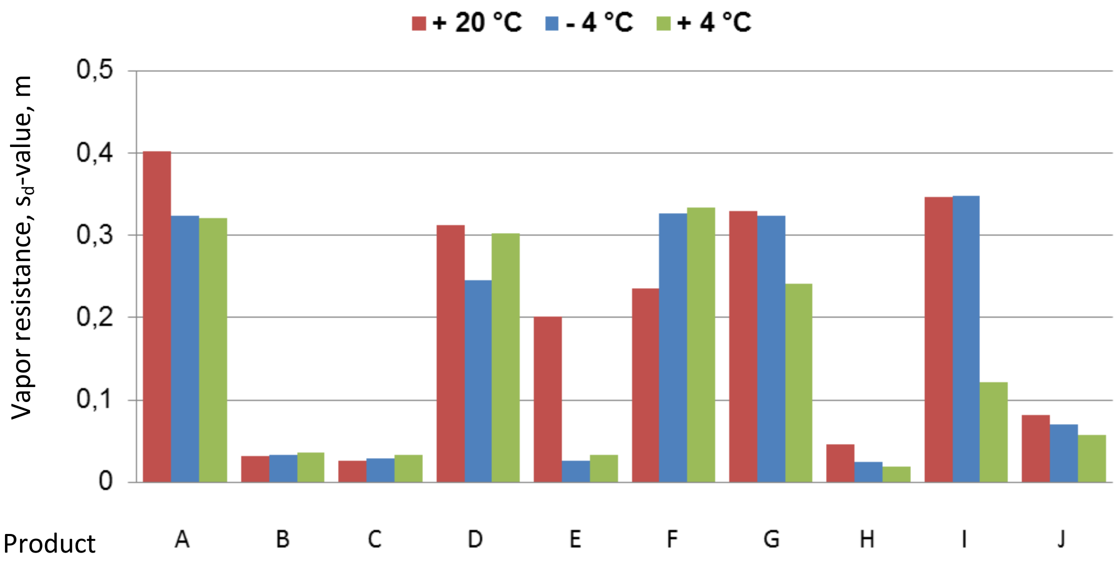

Figure 4 The s_d-value of the ten roofing underlays at three different temperature conditions

The results show that six of the ten roofing underlays have approximately the same vapor resistance in temperatures below zero as in room temperatures. Product F had a significant increase in the vapor resistance (+40 %), which is an increase in the s_d-value of +0,10 m. Product E had a severe decrease in water vapor diffusion resistance in cold temperatures (-85 %), which is an decrease in the s_d-value of -0,18 m. The decrease is due most likely to the increase in moisture content in the product. It is a well known fact that wood and wood based products gets more open for vapor diffusion when the moisture content increases. This is also the case with Product A that has a decrease in the s_d-value of -20 % in cold conditions. The last roofing underlay with changes in the vapor resistance is Product D (- 19 %).

Due to the fact that no samples were dried out before the outdoor temperature was changed the results are presented in the same order as the experiment was conducted. The total moisture content increased during the experiment period for most of the products, see Figure 5 and 6.

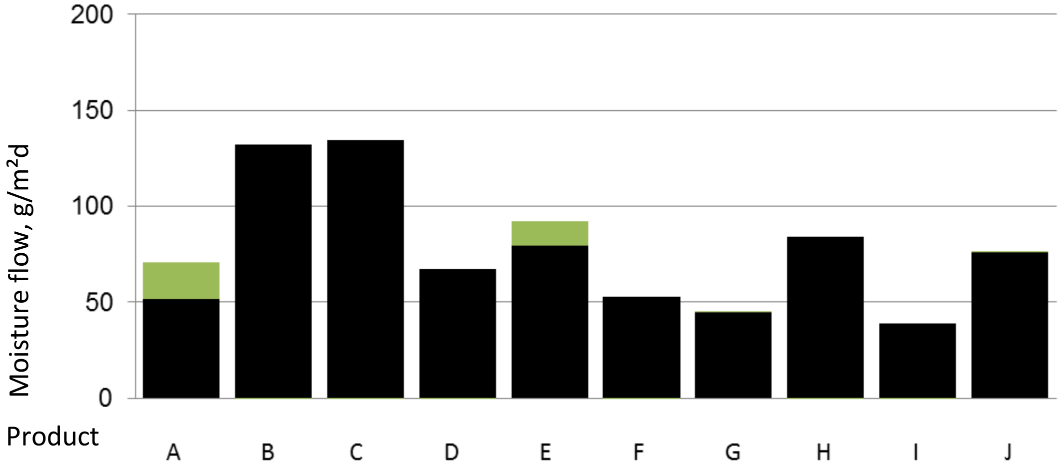

Figure 5 The total moisture transport (black column) and moisture uptake (green column) at outdoor temperature +20 °C. The horizontal ax represents the different roofing underlays, while the vertical ax represents the moisture flow [g/m²d]

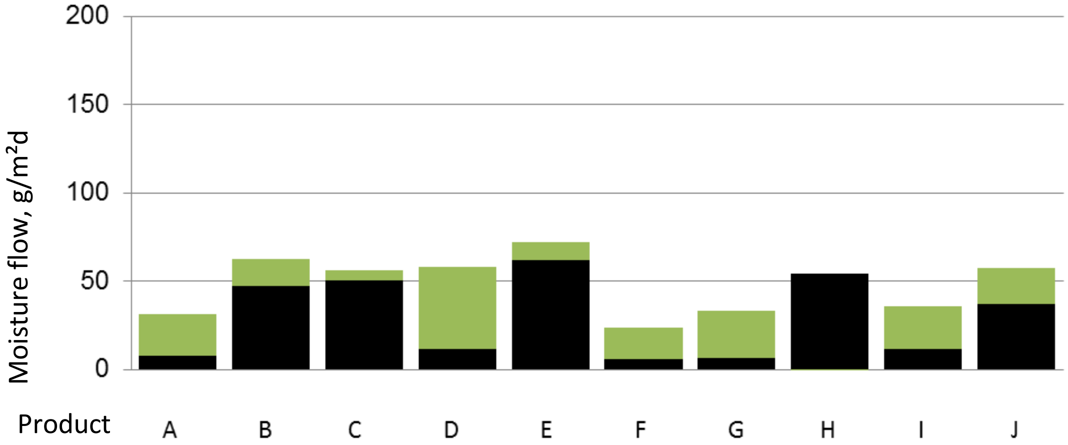

Figure 6 The total moisture transport (black column) and moisture uptake (green column) at outdoor temperature -4 °C. The horizontal ax represents the different roofing underlays, while the vertical ax represents the moisture flow [g/m²d]

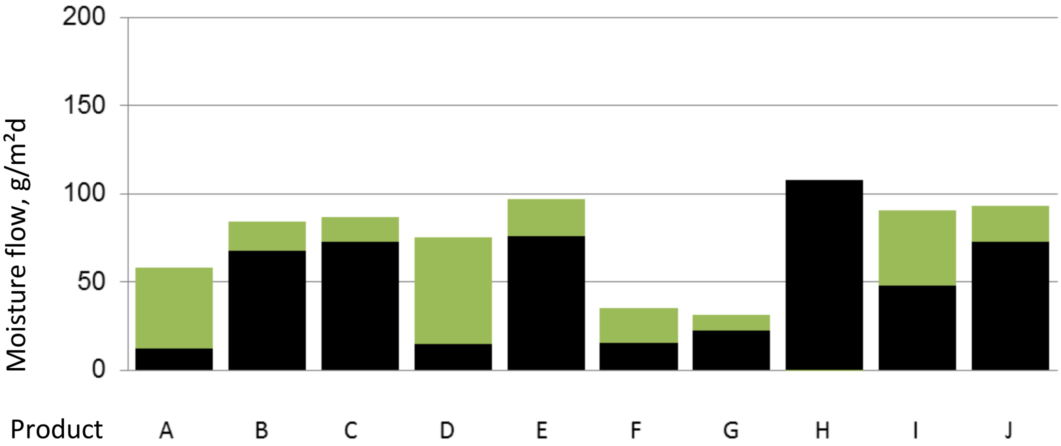

Figure 7 The total moisture transport (black column) and moisture uptake (green column) at outdoor temperature +4 °C. The horizontal ax represents the different roofing underlays, while the vertical ax represents the moisture flow [g/m²d]

The moisture flow (moisture transport + moisture uptake) is highest at +20 °C. In winter conditions the moisture uptake is the main part of the moisture flow for several products. Even if the s_d-value in sub-zero temperatures is approximately the same at +20 °C, the total amount of water vapor that is diffusing thorough the material at -4 °C is remarkably lower. This is due to the fact that the moisture transport via diffusion through the material is dependent on the s_d-value of the product and the water vapor pressure difference through the samples. The water vapor pressure differences across the samples are lower in sub-zero temperatures, thus the total water vapor flow through the samples will be lower in sub-zero temperatures.

The moisture uptake presented in Figure 6 froze to ice due to the low temperature on the exterior side of the roofing underlays. Examples of roofing underlays with ice on the interior side are shown in Figure 8-17.

Figure 8 Ice crystals underneath product A2M

Figure 9 Ice crystals/rime underneath product B4M

Figure 10 Ice crystals underneath product C6M

Figure 11 Rime underneath product D8M

Figure 12 The underside of product E10M had no rime/ice

Figure 13 Ice crystals/rime underneath product F2M

Figure 14 Ice crystals/rime underneath product G4M

Figure 15 Ice crystals/rime underneath product H6M

Figure 16 The underside of product I8M had no rime/ice

Figure 17 Ice crystals/rime underneath product J10M

The differences in the water vapor transport properties gets more obvious in low temperatures. Especially for winter conditions, the most vapor open roofing underlays (Products B, C, E, H and J) give a substantial faster removal of water vapor then the other products (A, D, F, G and I).

A high moisture uptake can be an advantage if the stored moisture underneath the product later on is transported through the roofing underlay and ventilated away from the roof structure. This can compensate for a relatively low moisture transport. It is crucial that the water is completely dried out before the temperature rises to a level that makes the growth of mold possible.

The moisture transport is approximately twice as high at +4 °C as for -4 °C. This is explained by the increased temperature, witch leads to a higher vapor pressure difference through the products. The vapor pressure difference at +4 °C is approximately the twice as at -4 °C.

Conclusion

The experiment shows that the investigated roofing underlays are open for water vapor diffusion also at sub-zero degrees. None of the investigated products got "vapor tight" by rime or ice.

Most of the products were approximately as vapor open in sub-zero degrees as + 20 °C. Only one product had a remarkably increase in the s_d-value at sub-zero temperatures, while three products had a remarkably decrease in the s_d-value.

Even if the s_d-value for most of the roofing underlays is approximately the same at sub-zero degrees as at + 20 °C the water vapor transport is remarkably lower at sub-zero temperatures. This applies especially for the products with the highest s_d-value: A, D, F, G and I. This reduction of transportation of water vapor is caused by the reduction in force, i.e. the water vapor pressure difference, is much lower when the temperature at the roofing underlay is low.

The relative difference between the water vapor diffusion transport to the most vapor open products and the other products is higher at sub-zero temperatures compared to summer values.

The differences in the water vapor transport properties gets more obvious in low temperatures. Especially in winter conditions, the most vapor open roofing underlays (Products B, C, E, H and J) gives a substantial faster removal of water vapor then the other products (A, D, F, G and I).

The results show that to avoid condensation on roofing underlays the most crucial property of the roofing underlay is a low water vapor diffusion resistance (s_d-value). The capability to temporarily store moisture on the interior side of the roofing underlay can contribute to prevent dripping problems and a wet structure in a critical drying out phase in winter time. The capability to temporarily store water might compensate for a somewhat lower capability to transfer moisture. It is important though, that the stored moisture is dried out before the temperature in the spring reaches above approximately +5 °C, preventing the possibility for mold growth to start.

The level of build in moisture in the structure is also important. The risk of ice underneath the roofing underlay can be further reduced by having an air tight structure, and having a roofing underlay with the ability to store water without letting it fall down from its surface.

The results and conclusions in this article are only valid for the product included in the experiments and can not automatically be transferred to other roofing underlay products.