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The Effect of Repeated Moisture Cycles on the Air Tightness of Traditional Clamped Vapour Barrier Joints

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In this study it has been investigated whether and to what extent, repeated moisture cycles affect the air leakage through clamped overlap joints in the vapour barrier layer. Use of clamped joints is a traditional way to make airtight joints in the wind- and vapour barrier used in wood frame walls in Norway and other countries. A laboratory test has been carried out, with a total of 63 pressure tests, being carried out on 9 test samples, consisting of overlap joints of 0.15 mm polyethylene film clamped between a wooden batten and stud. Each sample was tested seven times after repeated drying and humidification, where the moisture values of the sub-cycles were chosen to represent the annual variations of indoor relative humidity.

The laboratory test materials were mounted with machine nails with various center spacing (150 mm, 300 mm and 450 mm). The overlap joints of the vapour barrier were in the end of the test sealed with adhesive tape, revealing to what extent this over a longer period of time will be beneficial.

The results showed that the first moisture cycle (drying) resulted in significant increase of air leakage for all the sample variants. Throughout the moisture cycles, a further strong leakage development for center spacing 450 mm was observed, which was less for 300 mm, and non-existent for 150 mm. The gain of using structural adhesive tape was found to largely depend on the level of perforation resulting from the nails and their center distance. Adhesive tape on the joints resulted in the greatest reduction in leakage numbers where the center distance between the nails was high, i.e. the reduction was 58% for center distance 450 mm. However, with shorter center distance the use of tape only decreased the air leakage between 22-39%, revealing the fact that a large part of the joint leakage is through the nail perforations.

Keywords: vapour barrier, air tightness, clamped joint, building envelope.

Introduction

Air leakages through building envelopes lead to higher energy consumption, may result in moisture accumulation problems in the building envelope, and it may also affect the indoor air quality (Airaksinen et al. 2003, Janssens and Hens 2003, Relander et al. 2012, Tuominen et al. 2014, Kalamees et al. 2017). The requirements regarding reduced energy demand in buildings are continuously tightened and by 2020 all new buildings in Norway are required to be almost zero energy buildings (EPBD 2016, TEK17 2017). Therefore, the requirements for airtightness in the Norwegian building regulations were strengthened in 2017, from 2.5 air changes per hour at 50 Pa (volume normalized) for residential buildings and 1.5 for other buildings, to 0.6 for all buildings (TEK17 2017).

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The airtightness of the building envelope is achieved through the durability and connectivity of the air barrier to other building components (Kalamees et al. 2017). Typical building envelope constructions, both in Norway and other countries, use clamped joints as a traditional way to attain airtight joints in the wind- and vapour barrier layer. The airtightness of clamped joints depends on several parameters including geometry of the wooden batten, type of fixing and center to center distance of the fixings. Some of these parameters have already been investigated in several laboratory studies summarized and discussed in (Gullbrekken et al., 2012a; Gullbrekken et al., 2012b). They found that nails account for higher air leakage rates than screws. Wetting and drying cycles (imitating the yearly relative humidity variations) resulted in higher air leakages due to shrinking and swelling of the wooden battens. In addition, the center to center distance of 600 mm between fixings generally resulted in higher air leakage rates compared to shorter center to center distances such as 300 mm and 150 mm.

However, the effect of several years of cyclic shrinking and swelling of wood materials used in clamped joints and their influence on the airtightness of the building envelope, have not yet been investigated. The aim of this study is to investigate how the airtightness of clamped vapour barrier joints are affected by several drying and wetting cycles caused by moisture variations in indoor environment. The durability of the joint is presumably unaffected by material degradation, but the function is affected by the shrinking and swelling of the wooden materials.

Methods

General

The general concept of the laboratory test was to expose clamped vapour barrier joints to several repeated cycles of drying and wetting. This was done to simulate the yearly shrinking and swelling of the wood close to the joint, which again is expected to influence negatively on the air tightness of the joint. A short description of the chosen procedure is given in the following:

1. Different test samples of clamped vapour barrier joints were made.
2. The test samples were wetted to a “high” wooden moisture content (typical summer condition).
3. The test samples were mounted on a test box and air leakage of the samples were measured.
4. The test samples were dried to a “low” wooden moisture content (typical winter condition).
5. The test samples were again mounted on a test box and air leakage of the samples were measured.
6. Pt 2-5 were repeated three times, simulating 2,5 years starting with summer condition and ending in a winter condition. This gave six air leakage tests for each test sample.
7. To see the effect of taping of joints, the joints were taped and a final air leakage test were made.

To assess the practical implications of the measured air leakages, the resulting air change rate at 50 Pa was estimated for two different case buildings, see chapter “*Numerical estimation for case buildings*”.

Material and test samples

A typical clamped vapour barrier joint in wood frame walls are made by nailing or screwing a wooden batten to the wooden stud with the overlap vapour barrier joint in between. The battens were chosen with dimension 36 x 48 mm (width x thickness). In Norwegian building tradition it is normally recommended to use batten thickness between 11-36 mm to clamp the overlap vapour- and wind barrier joints. For thicker battens the potential to get a gap between the batten and stud due to the yearly shrinking of the batten is higher, and thereby giving a reduced pressure on the overlap joint. The reason for chosing a batten with thickness of 48 mm is that it has become usual in Norway recent years to mount 50 mm mineral wool (and using 48 mm battens) on the internal side of the vapour barrier. This makes it possible to mount for instance electric cables in this layer without perforating the vapour barrier. To fix the battens machine nails with dimension 3,2 x 90 mm were used. Three different center to center (“cc”) distances of the nails were used; 150, 300 and 450 mm. The battens were nailed to a stud with dimension 36 x 98 mm. The reduced stud

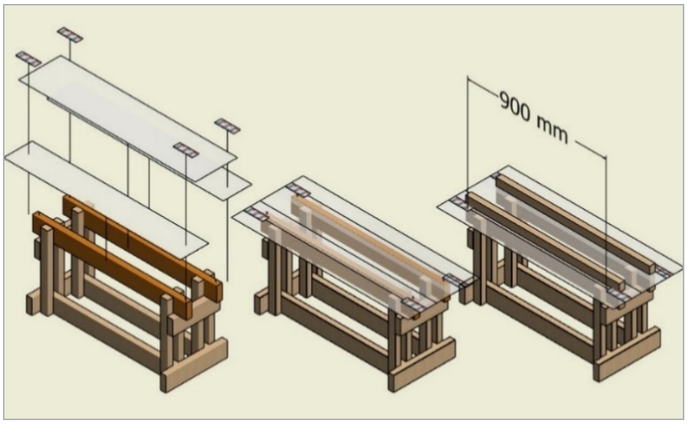

Fig. 1

Assembly of the test samples. Two 1000 mm studs are placed in a mounting rack. Then the PE-foil is mounted before the 1000 mm long batten is nailed to the stud. The joint ends was taped to avoid unintentional air leakage, so the joint length was a little bit shorter than the stud/batten (900 mm)

dimension (normal thickness is 148 mm or thicker) is assumed not to have any effect on the differential movements between stud, batten and nail. Both battens and studs consisted of Norway Spruce class C24.

Each test sample consisted of two joints each 900 mm long, see Fig. 1, i.e. total length 1,8 m per sample. Three samples for each center to center distance (150, 300 and 450 mm) were produced, i.e. a total of 9 samples were made. The nail gun pressure was set to give a surface immersion for the nail head of approximately 1-2 mm.

Wetting and drying procedure

The intention of the drying and wetting procedure described in chapter "*Material and test samples*" was to simulate the yearly moisture cycles that the wood close to the vapour barrier joint (wooden batten and inner half of wooden stud) experiences. Simulations of the hygrothermal conditions in a south facing wood frame wall were conducted with WUFI-2D (Künzel 1995). The wood frame wall had the following layers from inside; 13 mm gypsum board, 48 mm mineral wool/48 x 48 mm wooden batten, 0,15 mm polyethylene foil, 198 mm mineral wool/198 x 48 mm wooden stud, 13 mm gypsum board, 25 mm ventilated air layer and 18 mm wooden cladding. As external climate the Moisture Design Reference Year (MDRY) for Gardermoen was chosen, a weather station close to Oslo in the south of Norway. As internal climate a moisture excess of 4 g/m3 in the heating season (outdoor temperature below + 5 °C) was chosen based on findings of Geving and Holme (2012), with linear transition to 1,5 g/m3 at external temperatures above 15 °C.

After the first period of stabilization, the simulations showed that the moisture content will oscillate between 7.8 and 12.7 weight% for the inner half of the wood stud and between 9 and 14,2 weight% for the wooden batten. On the basis of these results, the target values for the experimental setup were chosen to 7 weight% (winter condition) and 14 weight% (summer condition).

Drying and wetting were performed in an oven at 70 °C to speed up the process. The wetting was performed by installing the samples and a specific amount of water in a sealed air and water vapour tight box positioned inside the oven, see Fig. 2. The temperature stratification inside the box was controlled

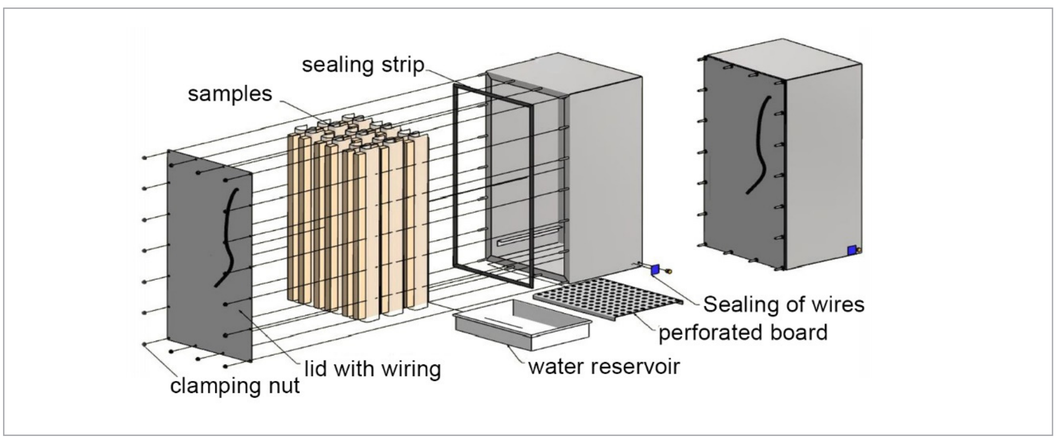

Fig. 2

Set up of test box for the wetting procedure. The box was then placed in the oven by thermocouples. During the drying and wetting, the wood moisture content was controlled by measuring the electrical resistance between two electrodes positioned in two of the wood samples. In addition all the samples were weighed before the different airtightness measurements. Each wetting and drying cycle lasted in average 145 and 115 hours respectively. Finally, the dry weight of the samples were measured by dryng in the oven at 110 °C. By extracting the weight of the polyethylene foil, tape and nails the average moisture content of the wood could be calculated for every part of the test cycle.

Air leakage testing

The resistance to penetration of air through pinched joints in the vapour barrier was tested in accordance with EN 12114 (EN12114 2000). The air leakage was measured at a pressure difference of 20, 30, 50, 70 and 90 Pa. By linear interpolation of the measurement values the air leakage at 50 Pa pressure difference was calculated. The airtight box used for the moistening of the samples was also used for the air leakage measurements. The PE-foil of the samples was positioned between a sealing gasket on the airtight box and a sealing gasket on a wooden frame fixed with bolts with a specific momentum, see Fig. 3. The airtightness of the airtight box including the gaskets was accounted for by measuring the air leakage at 50 Pa pressure difference with an airtight polyethylene foil (no joints) as a sample. This was done after each of the different test sequences. The leakage values ranged from 0,17 to 3,65 litre/h at 50 Pa, which was subtracted from the previous ordinary air leakage test.

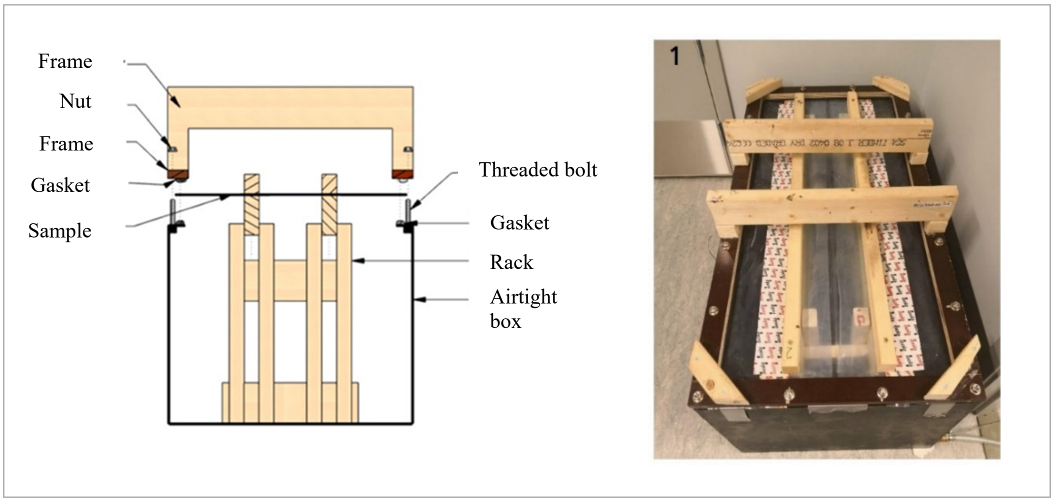

Fig. 3

Assembly of the sample to the airtight box for air lekage testing. To the right is shown the final testing with taped joints

At the end of the test (after the last drying) the overlap joint was taped without demounting the sample or the wooden batten. The top overlap of the polyethylene foil was portruding approx. 2 cm to the side of the batten, allowing the joint to be sealed with a special polyethylene tape (45 mm wide).

Numerical estimation for case buildings

In order to evaluate the practical implications of the measured air leakages two case buildings has been investigated; a single family house and an office building with heated area/volume of respectively 140 m^2/336 m^3 and 12870 m^2/46191 m^3. The resulting air change rate for the two case buildings has been estimated by use of the results from the air leakage measurements. The estimated air change rate only included leakages through the joints in the vapour barrier. This means that the air leakage resistance from other material layers such as interior cladding and wind barrier are not accounted for. In order to calculate joint lengths in the two case houses some assumptions and simplifications have been made:

- All the air leakages in the buildings is through the clamped joints in the vapour barrier (no leakages through the roof).

- PE-foil with a length of 15 m and a width of 2,6 m.
- Clamped joints at bottom and head sills, corners and around the windows

This gave a total clamped joint length for the single family house and the office building of respectively 320 m and 5052 m.

Results and discussion

Experimental study

The real moisture content of the wooden part of the test samples are shown in **Fig. 4**. As the figure shows the high level (summer condition) varies between 11,9 to 14,7 weight%, with an average of 13,3 weight%. The low level (winter condition) varies between 5,7 to 6,5 weight%, with an average of 6,0 weight%. This is considered reasonable close to the target values for the experimental setup (14 and 7 weight%).

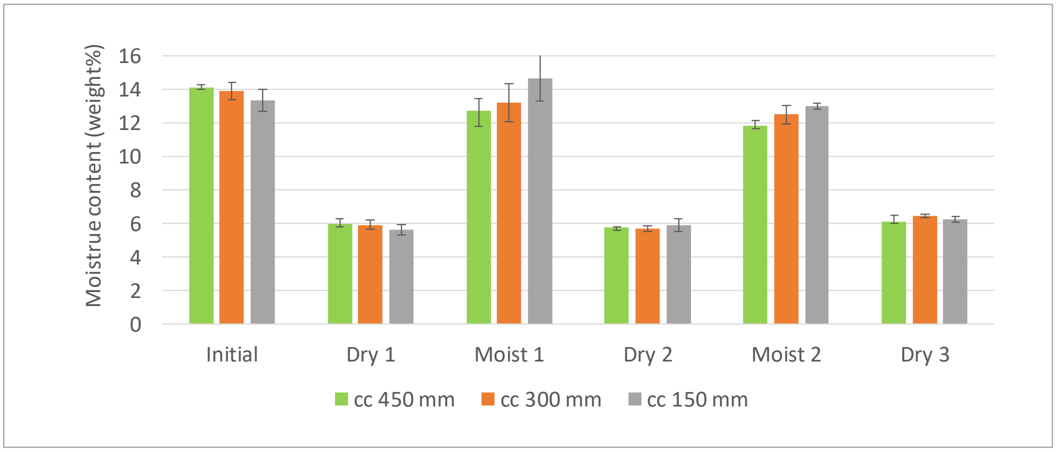

Fig. 4
Moisture content (including standard deviation) of wooden samples during the test cycle measured by drying and weighing

The measured air leakage through the different vapour barrier joints are shown in **Fig. 5**. All the measurements show that initially before any drying the joints are very airtight, between 0,9 to 4,5 litre/hm, with cc 450 mm nail distance giving the higher value. After the first cycle of drying the air leakage is increasing to between 32 to 40 litre/hm. This is caused by the shrinking of the wooden batten and stud when going from a moisture content of approximately 14 weight% to 6 weight%. The shrinkage is causing an increased air gap between the batten and stud where air leakage can occur, see **Fig. 6**. After the first wetting cycle up to approximately 13 weight% the air leakage is reduced again, however to a somewhat higher level than the initial air leakage.

For the remaining drying and wetting cycles we observe that for the samples with cc 450 mm the air leakage is increasing dramatically for each cycle, especially after each period of drying. The air leakage after the second drying cycle has increased 97% compared to the air leakage after the first drying cycle. Between the second and third drying cycle the increase in air leakage is 45 %. For cc 150 mm and cc 300 mm we do however not see the same effect, i.e. the air leakage is approximately the same after each drying period. This indicate that a center to center distance between the nails of up to approximately 300 mm may be acceptable, but the clamping effect may not be durable for repeated yearly moisture cycles for center to center distances above 300 mm. It should however be noted that the current study only included 2,5 yearly cycles, while we would expect the life cycle of the building to give at least 50 yearly cycles. This could lead to increased air leakage also for cc 150 mm and cc 300 mm. We do for instance observe a small increase in air leakage between the first and second drying cycle (20% increase) for cc 300 mm.

The effect of shrinkage and swelling on the air leakage is obviously also dependant on the thickness of the wooden batten, which is thicker than the recommended maximum thickness for battens used for clamping vapour barrier joints (approximately 36 mm according to Norwegian tradition). A thick batten will in total have a larger shrinkage/swelling compared to a thinner batten, meaning that the potential for creating an air gap like shown in **Fig. 6** is larger. Other parameters that may affect the shrinkage (given the variation in yearly moisture content is the same) is the length of the nail and the design of the nail (surface texture etc).

The effect of taping the overlap joint is relatively strong, reducing the air leakage with 58%, 39% and 22% for the cc 450 mm, cc 300 mm and cc 150 mm respectively. One could have expected that the taping should have reduced the air leakage close to the initial level before the first drying cycle, however this is far from happening. One possible explanation is that a large part of the air leakage during dry conditions is through the fixing holes of the nails through the vapour barrier. This is anyway an interesting finding even for cases when all the joints are taped, since there will always be a number of holes through the vapour barrier from the nails or screws. The configuration of fixing method when using wooden battens at the interior side of the vapour barrier may therefore be of interest even when taping of joints are used.

Numerical estimation for case buildings

The estimated air leakage at 50 Pa for the two case building is shown in **Fig. 7**, based on the initial leakage, after the third drying cycle and after taping of the joint. In general we see much lower air change rate for the office building than the single family house. This is as expected since the office building have a much lower ratio between area of exterior walls and building volume, than the single-family house.

If we compare with the maximum air leakage requirement of 0,6 1/h at 50 Pa, we find that the leakage through the clamped joints (after the third drying) only accounts for between 6-15% (single family house) and 0,7-1,7% (office bulding) of the air leakage requirement. If we omit the results for the 450 mm nail distance, the air leakage accounts for between 6-8% (single family house) and 0,7-0,9%

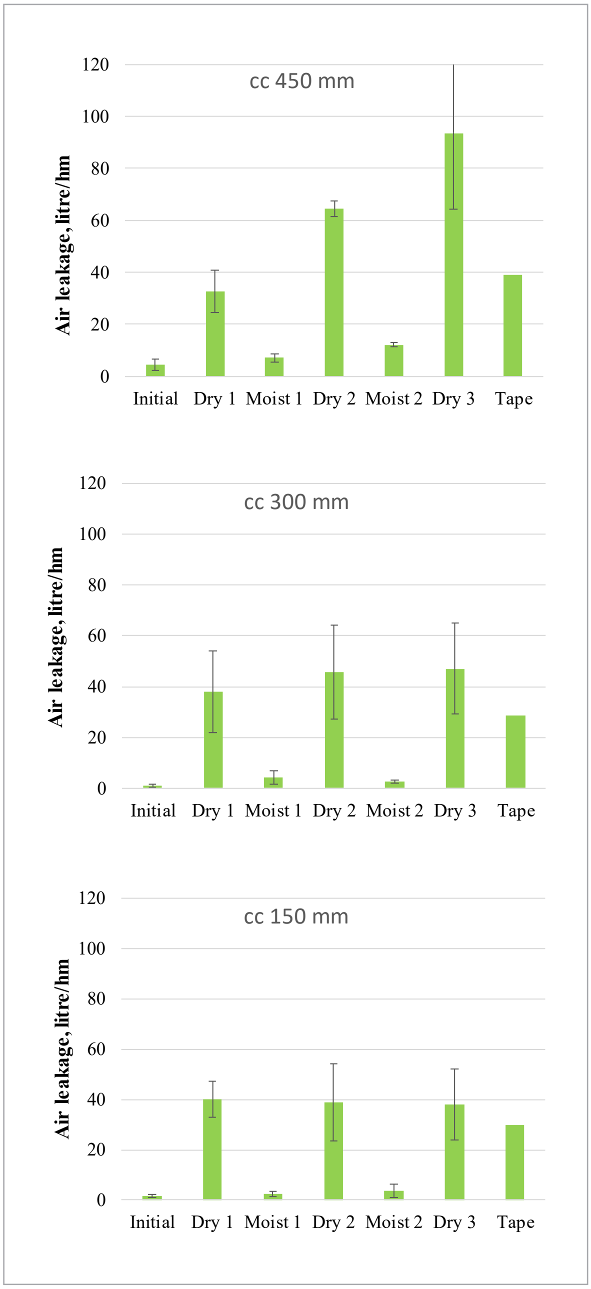

Fig. 5

Average air leakage (including standard deviation) through the different samples during the drying and wetting cycles. The results are given per meter joint for the three different center to center distances of the nails; 150, 300 and 450 mm

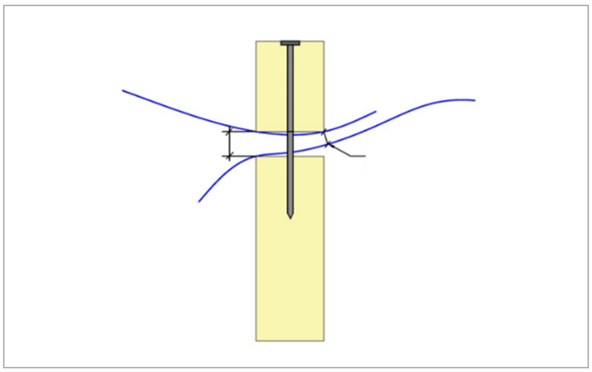

Fig. 6

Shrinkage of the wooden batten and stud reduces the clamping effect by creating an air gap where air might leak

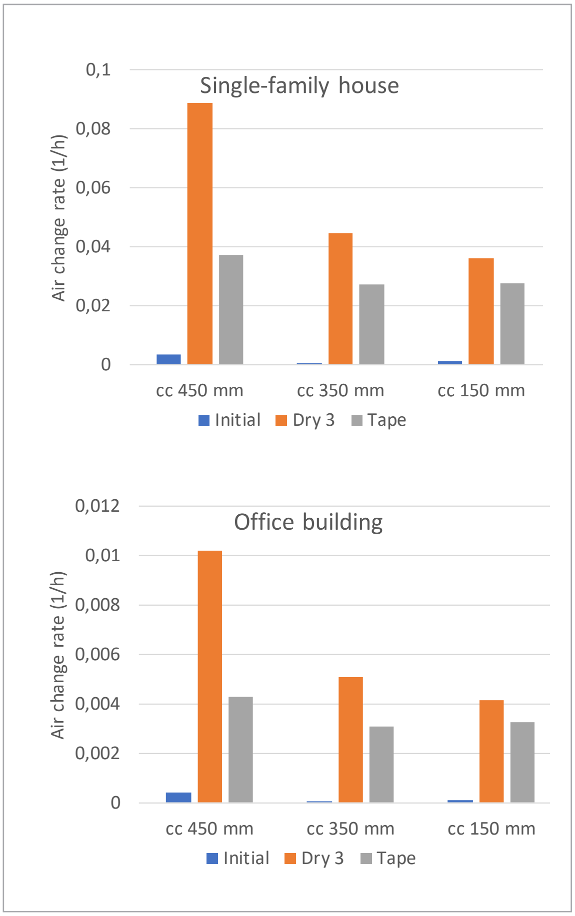

Fig. 7

Estimated air leakage at 50 Pa (normalized by volume) for the single-family house and office building. It is asumed there is no other leakage path than the clamped vapour barrier joints in the walls, see details in chapter "*Numerical estimation for case buildings*"

(office building) of the passive house requirement. This means that if the target value for airtightness for example is close to 0,6 1/h, the leakage through the clamped joints will not be critical in regard to reaching this goal. This especially applies for larger buildings with a low ratio between wall area and volume. If however the target value is closer to 0,2 1/h, the air leakage through the clamped joints is of growing relative importance, especially for smaller houses.

From **Fig. 7** we also see that the relative improvement of taping the joint compared to an ordinary clamped joint is not big, especially for the larger building. The latest years, especially for passive houses projects in Norway, we have seen air leakage numbers at 50 Pa measured down to 0,1 - 0,2 1/h. These projects typically have extensive use of tape products at the vapour and wind barrier joints. The results of this study rise the question whether all this use of expensive tape products at the overlap joints are necessary, at least when a wooden battens anyway will be used at the interior side of the vapour barrier.

Conclusions

This study has investigated whether and to what extent, repeated moisture cycles affect the air leakage through clamped overlaps in the vapour barrier layer. The results showed that the first drying cycle (from summer to winter conditions) resulted in significant increase of air leakage for all the sample variants. Throughout the moisture cycles, a further strong leakage development for center to center nail spacing 450 mm was observed, which was less for 300 mm, and non-existent for 150 mm. The gain of using structural adhesive tape was found to largely depend on the level of perforation resulting from the nails and their center distance. Adhesive tape on the joints resulted in the greatest reduction in leakage numbers where the center distance between the nails was high, i.e. the reduction was 58% for center distance 450 mm. However, with shorter center distance the use of tape only decreased the air leakage between 22-39%, revealing the fact that a large part of the joint leakage is through the nail perforations.

An estimation of the relative importance of air leakage through this type of overlap joints were made for a small and large type of building. The relative importance was not found to be big, since the estimated total air leakage through the overlap joints at 50 Pa accounts only for between 6-8% (single family house) and 0,7-0,9% (office building) of the passive house requirement.

The results also showed that although there is a positive effect of taping the overlap joint, the effect seems to be reduced by air leakages through the fixing holes of the nails through the vapour barrier.

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