Durability of traditional clamped joints in the vapour barrier layer: Experimental and numerical analysis

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Abstract

Clamped joints of wood frame buildings are a traditional way in Norway to attain airtight joints for the air and vapour barrier. Numerous defects registered in the SINTEF Building Defects Archive related to air leakage through the vapour barrier, on one hand, and stricter requirements for reduced energy consumption, on the other hand, questions today's efficacy of these type of joints. This study investigates the durability of clamped joints by studying how the airtightness is affected by several drying and wetting cycles. Experimental work is carried out to measure air leakage, that in turn, are used to evaluate their impact on the airtightness of two different constructions by numerical estimations. Results show that the air leakage rates are increased significantly due to transient climatic conditions. Clamped joints may no longer provide airtight building envelopes given the stricter requirements for energy consumption and implications of climate change. A more promising and robust alternative is the use of self-adhesive tapes.

Keywords: airtightness, air leakage, wood, clamped joints, building envelope, durability

1. Introduction

Air leakage and air infiltration through the building envelopes have a significant effect on the buildings' energy performance and its indoor environment. Air leakage leads to higher energy consumption, may result in moisture accumulation problems in the building envelope, and it may also affect the indoor air quality (Airaksinen, Pasanen et al. 2003; Janssens and Hens 2003; Relander, Holøs et al. 2012; Tuominen, Holopainen et al. 2014; Kalamees, Alev et al. 2017). Consequently, airtight building solutions are crucial features that help ensure achieving energy efficient buildings, avoid moisture problems during the building life cycle, meeting the increasingly stricter performance requirements for reduced energy consumption of homes in Norway.

The requirements regarding reduced energy demand in buildings are continuously being 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 Norwegian building regulations were strengthened in 2017, from 2.5 air changes per hour for residential buildings and 1.5 for other buildings to, 0.6 for all buildings (TEK17 2017). Relander et al. (Relander, Holøs et al. 2012) have shown that improving the airtightness of a residential building from the previous requirement to the present one can save approximately 20 kWh/m^2 per year, which corresponds to more than 10% of the average total energy consumption of a Norwegian household ((SSB) 2014). Considering this, the energy efficiency of buildings can only be assured when the building envelope provides sufficient airtightness.

The airtightness of the building envelope is achieved through the durability and connectivity of the air barrier to other building components (Kalamees, Alev 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 air- and vapour barrier. Nevertheless, a considerable number of building defects registered in the SINTEF Building Defects Archive are related to air leakage through the vapour barrier caused by convection. Considering these sources of building defects, it has been revealed that moisture is the cause of 76 % of total building defect cases. Moisture from indoor air, including air leakage through the vapour barrier, amounts to 15 % of the total number of building defect cases. On the other hand, by additionally considering the more demanding requirements for lowering the energy consumption in buildings, it is therefore questionable whether this traditional method provides sufficient airtightness.

The airtightness of clamped joints depends on several parameters including the geometry of the tile batten, type of fixing and its center to center distance. Some of these parameters have already been investigated in several laboratory studies (Sagen, 2003; Bergby, 2011; Selmer, 2013) and the results are summarized and discussed in (Gullbrekken et al., 2012a; Gullbrekken et al., 2012b). Sagen (2003) carried out laboratory studies to investigate different types of fasteners of clamped joints in the air barrier. It was found that the use of nails account for higher air leakage rates than screws. Wetting and drying cycles resulted in higher air leakage due to shrinking and swelling of the wooden battens. Shrinkage and swelling are caused by natural yearly variations in relative humidity of the indoor air of Norwegian homes (Geving and Holme 2012). Bergby (2011) extended the previous laboratory measurements by investigating different center to center distance between battens. It was confirmed that screws as fasteners provided better airtightness than nails. In addition, the center to center distance of 600 mm generally resulted in higher air leakage rates compared to shorter center to center distances such as 300 mm and 150 mm.

Besides the geometrical parameters, the airtightness of clamped joints is also affected by the prevailing microclimate and its impact. However, the effect 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 was to investigate the durability of clamped joints by studying how the airtightness is affected by several drying and wetting cycles caused by moisture variations in the 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 batten. The cyclic dimensional changes occurring due to variations in relative humidity are assumed to affect the clamping effect over time. Furthermore, determining which design accounts for the best airtightness, and the effect of applying adhesive tape were also investigated. Finally, a rough calculation of the effects on the overall leakages rates was conducted. the materials investigated and the experimental set-ups are presented in Section 2. In section 3 results of experimental investigations are given and discusses; the results were further used as input for numerical estimations. Finally, conclusions are drawn in section 4.

2. Materials and methods

1.1. Experimental setup

The cycling of the moisture level in the wooden battens was performed by placing the samples in a sealed steel cabinet with a water reservoir at the bottom. The cabinet was again placed in a climate chamber at a temperature of 70 ^{o}C.

To determine the moisture variations occurring in the batten on the inside of the vapour barrier, and therefore the shrinking and swelling of the wood materials, simulations in WUFI-2D have been firstly conducted (Kunzel, H. M., 1995). WUFI, a software developed by the Fraunhofer Institute of Buildings physics, simulates hygrothermal conditions in building parts under transient climatic conditions. In this study, a south-facing external timber frame construction was chosen. The geographic location was Gardermoen, a weather station near Oslo in the south of Norway. The climatic data included in WUFI is based on MDRY (Moisture Design Reference Year). There are several possibilities to define the internal moisture development as a function of external temperature (moisture load), further defined as the difference between the moisture content of the indoor and outdoor air. Based on the findings of Geving & Holme (2012), the moisture development was defined as "medium", corresponding to an internal moisture access of 4 g/m³ in the heating season with a linear transition to 1.5 g/m³ at external temperatures above 15 °C. The results from these simulations, which were conducted over a period of 5 years, showed that the moisture content in the construction stabilizes after approximately six months and will afterwards oscillate between 7.8 % (weight) and 12.7 % for the inner half of the wood stud and between 9 % (weight) and 14,2 % for the wooden batten. On the basis of these results, the target values for the experimental setup were chosen as 7 % (weight) as the dry threshold and 14 % as the wet threshold value for the batten moisture content.

The samples chosen were Norway spruce studs, class C24 with chamfered edges. To limit the wetting and drying time of the studs a reduced dimension of 36 x 98 mm was used. The reduced stud dimension and therewith the reduced penetration depth of the screws was assumed not to have any effects on the movements of stud and screws due to moisture variations. The battens were 36 x 48 mm (with x depth). The length of the samples was limited to the inner height of the steel cabinet that again was limited to the available space in the climate chamber. Thus, the samples length was 1000 mm. For the vapour barrier, a commonly used PE foil with a thickness of 0.15 mm was used. Each sample included two vertical joints with a total length of 1.8 m per sample (see **Error! Reference source not found.**).

Three samples of each configuration were tested. Table 1 gives an overview of the samples and parameters. The samples were placed vertically in the test cabinet, which was sealed and then again put in the climate chamber (see **Error! Reference source not found.**). The measurements included three drying and wetting cycles and are presented by chronological order in **Error! Reference source not found.**. In addition, the last test included sealing the clamped joint of all the samples by applying adhesive tape to investigate the use of adhesive products on the airtightness of the joints. As such, the airtightness of each sample was tested seven times.

Drying and wetting of the samples were performed in an oven at 70 °C. 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. The temperature stratification inside the box was controlled 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. All the samples were weighed before undertaking the different airtightness measurements. Finally, the moisture content of each measurement was calculated by measuring the dry weight of samples after these were placed in the oven at 110 °C.

The resistance to penetration of air through pinched joints in the vapour barrier was tested when the measured wood moisture content was close to the target values of 7 and 14%. The samples were removed from the oven and air leakage through the clamped joint was then measured as quickly as possible in laboratory conditions of 22°C ±2°C and 20 % RH ± 10%. The air leakage was measured in accordance to EN 12114 (EN12114 2000). The air leakage was measured at a pressure difference of 20, 30, 50, 70 and 90 Pa. The air leakage at 50 Pa pressure difference was calculated by linear interpolation of the measured values. 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 clapping force (see **Error! Reference source not found.**). The airtightness of the airtight box was accounted for by measuring the air leakage at 50 Pa pressure difference with an airtight PE-foil as a sample. This was done prior to the different test sequences.

2.2. Methods numerical estimations

To evaluate the practical implications of the measured air leakages two test buildings were investigated. The resulting air change rate has been estimated by applying the results of air leakage as retrieved from the experimental measurements. The estimated air change rate only included leakages through the vapour barrier.

To calculate joint lengths in the two case houses some assumptions and simplifications were made:

- All air leakage in the buildings were through the clamped joints in the vapour barrier (no leakages through the roof).
- PE-foil has a length of 15 m and a width of 2,6 m.
- Clamped joints were assumed at the bottom and head sills, corners and around the windows.

Some important information about the two case buildings are given in Table 2.

3. Results and discussion

3.1. Results from experimental studies

The results of the experimental measurements, provided in Figure 5, show that the initial test of the samples using the traditional methods are very airtight. By drying the samples to approximately 6 % (weight), an increase of the air leakage was observed. This is caused due to the shrinking of the batten and the stud while the distance between the batten and the stud is fixed by the screws. Hence, the shrinkage causes an increased air gap between the batten and the stud where air can leak, as shown in **Error! Reference source not found.**. By moistening the samples to a moisture level of approximately 14 %, the air leakage of the samples w lowered. This is caused by the swelling of the batten and stud which decreased the air gap between the batten and the stud and thereby reduced the air leakage.

The measurements indicated that the air leakage through the clamped joints increased during the drying and wetting cycles. This effect can be explained by the movements caused by the shrinkage and swelling of the wood material which causes an increased stress on the joint of the screw and wood. This effect is, as expected, dependent on the design of the screw. The length of the screw, thickness and design of the thread will all affect the fastening capacity of the screw and wood material. This could be a suggested topic of a future study. It is likely that further wetting and drying cycles would further increase the air leakage through the clamped joints. The current study included only three cycles, whereas the number of dying and wetting cycles during the life cycle of a building could be presumed to exceed three cycles. Hence, there are still uncertainties concerning the long-term durability of these type of clamped joints.

Even when applying adhesive tape to ensure airtight sealing, air leakage to some degree was still measured. One possible explanation of air leakage through the taped joint can be that air leakage occurs through the fastening fixing holes that perforate through the vapour barrier, as shown in **Error! Reference source not found.**. Nevertheless, the application of adhesive tapes lowered the air leakage to some extent. A similar conclusion was drawn by Kreigeret al. (2015) and Kalamees et al. (2017), where it was suggested that self-adhesive products may be a more promising and robust solution to guarantee the airtightness of the building. Indeed, adhesive tapes are: a) easy to apply, especially in renovations projects; b) they are cost-efficient; and, unlike other connecting measures, c) they do not make holes and thus, offer fewer opportunities for air leakage. However, considering that such solutions have been applied only during the past decades, there is still little knowledge of the availability of adhesive tape products (Bracke, Van Den Bossche et al. 2014); especially, regarding their durability, expected service life and evaluation and test methods. First, the service life of a building or structure is often presumed to be 60 years (15686-1 2011). For building parts and components, the expected service life varies depending on how accessible the respective building part is for maintenance and replacement. Hence, the failure of these products is not easily observable, and the repair or replacement is normally not technically nor economically feasible. Second, there exists no up to date evaluation methods, guidelines or standards that can be used to help verify the durability of adhesive joints when applied to vapour barrier system. Consequently, more research is required to acquire knowledge and develop standards and guidelines regarding the long-term performance and durability of adhesive solutions to achieve airtightness over the expected service life of a building.

3.2. Results from numerical estimations

Error! Reference source not found. and **Error! Reference source not found.** show the estimated air change rate of the two case buildings based on the measurements of the initial air leakage, after the third dry out, and after taping the joints using the assumptions in the previously described in Section 2.1. Note that the results assume no air leakage through the roof, floor, penetrations, and connections between building parts. The code for the samples is explained as follows e.g. 450 is the center to center distance between the fasteners in mm, correspondingly. The results generally indicate lower air change rates for the office building compared to the single-family home. One explanation is a different relation between the area of exterior walls and volume for the two buildings. Screws with a centre to centre distance of 450 mm provided the largest calculated contribution to the air change rate. However, the estimated air change rates at 50 Pa pressure difference through the joints of the vapour barrier has a minor contribution compared to the requirements in the Norwegian building regulations. The measured air change rate at 50 Pa pressure difference of a specific building consists of several other air leakage sources among them air leakage through other building parts such as the roof, window and floor as well as penetrations through the roof and wall assemblies. As further stated, there are uncertainties concerning the long-term durability of these clamped joints. Previous research shows that an airtight vapour barrier is important in avoiding condensation problems in roofs (Janssens, A., Hens H. 2003). Further, Aho et al. (2008) state that an airtight building envelope, and hence the use of a vapour barrier, is an essential element of the envelope assembly to avoid local moisture accumulation that in turn can cause moisture problems such as the formation of surface mould or decay of timber structures.

4. Conclusions and further work

In this study experimental measurements and numerical estimations were carried out to investigate the effect of cyclic drying and wetting conditions on clamped joints of wood frame constructions. The impact of cyclic drying and wetting of these joints on the airtightness of two case buildings was also investigated. Experimental results showed the airtightness of clamped jointswas reduced due to the cyclic conditionings. However, there still remain uncertainties concerning the long-term durability of these clamped joints. A more promising and robust alternative solution to render the building envelope airtight could be the application of self-adhesive tapes. More research is required to acquire knowledge and develop standards regarding the long-term performance and durability of self-adhesive tapes to achieve the required airtightness over the expected service life of buildings in Norway.

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List of Tables

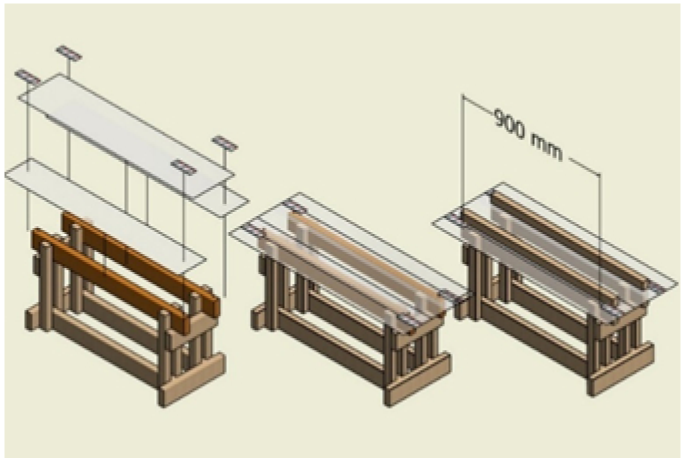
Table 1 Overview over samples and their configuration

Sample	Stud (width x depth x length) [mm]	Batten width x depth [mm]	Center distance [mm]	Screws/Fastening[1]	Number of samples
SK450	36 x 98 x 1000	36 x 48	450	Wood screw, 6.0 x 120	3
SK300	36 x 98 x 1000	36 x 48	300	Wood screw, 6.0 x 120	3
SK150	36 x 98 x 1000	36 x 48	150	Wood screw, 6.0 x 120	3

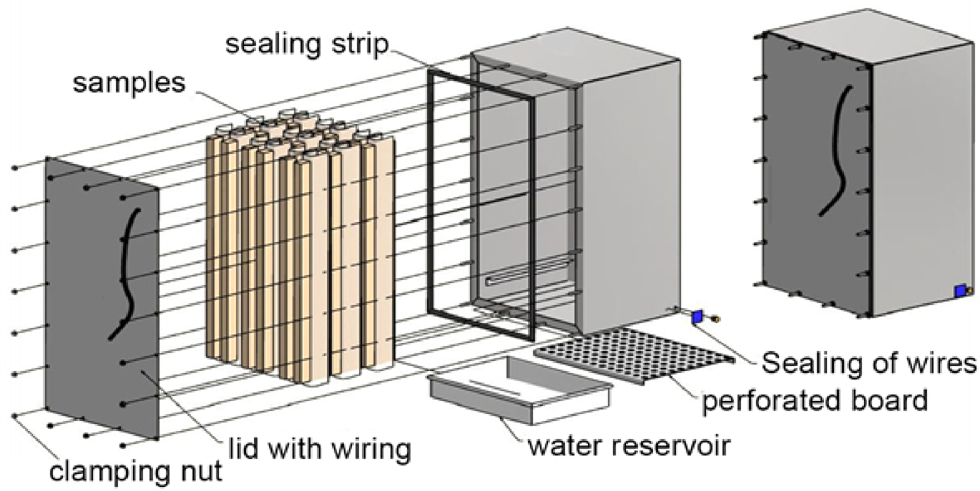
[1] The screwing pressure was set to and immersion of approx. 1-2 mm

Table 2. Input data for the calculations of the case buildings.

	Single family house	Office building
Heated area [m²]	140	12870
Heated volume [m³]	336	46191
Total clamped joint length [m]	320	5052

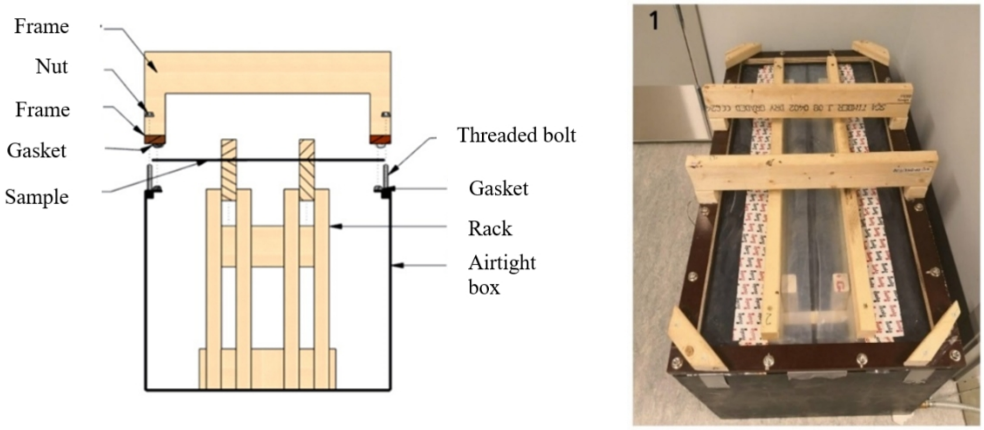


Mounting of the test samples.

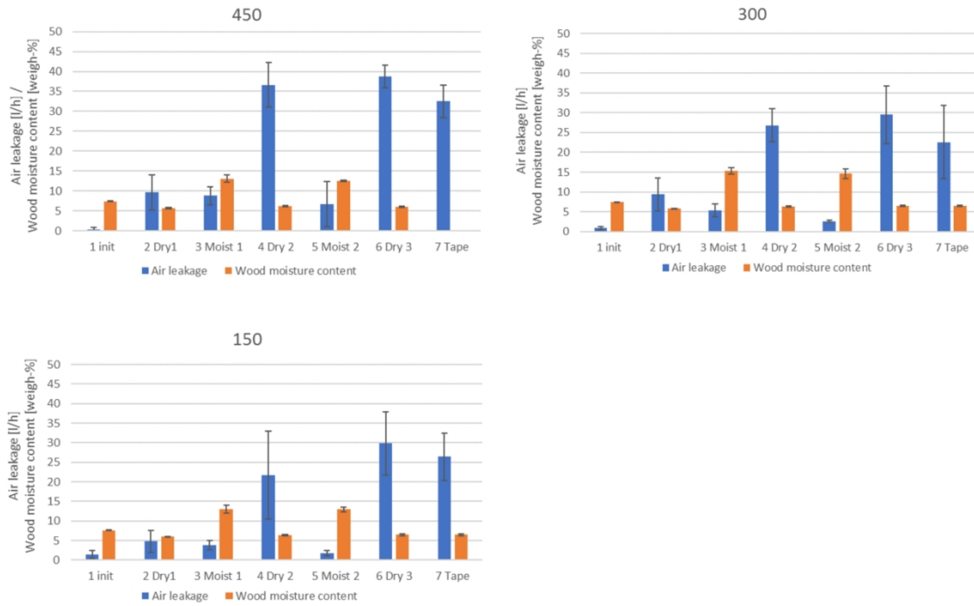


Configuration of the experimental setup.

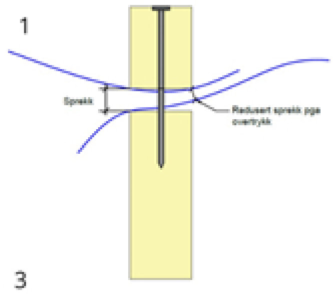
Test cycles sequence.



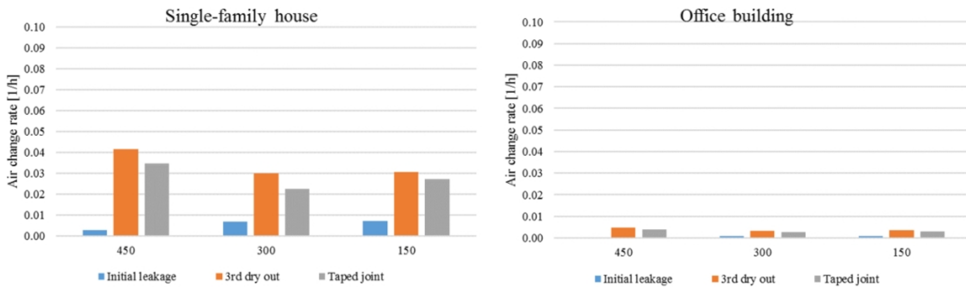
Fixing of the different samples to the airtight box.



Air leakage through the different samples before and after drying and moistening. The code e.g." 450" means the centre to centre distance of the fasteners in mm.



Shrinkage of the batten and the stud reduces the clamping effect leaving a air gap between the batten and the stud.



Estimation of air change rate of the single-family house and office building using assumptions in the presented in section 2.