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Contribution to the Wooden-Frame Wall Assemblies Airtightness Tests : a Three-scale Laboratory Study

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Abstract

Poor airtightness in buildings can lead to an over-consumption of energy and to many issues such as moisture damage and poor indoor climate. The wooden frame constructions are particularly subject to air leakages and further knowledge in this field is needed to meet the regulation requirements tightened by the development of low-energy and passive houses.

This paper focuses on a three-scale experimental study carried out in laboratories to quantify the impact of a number of construction details on wooden-frame wall airtightness. For this purpose we built two original experimental setups and we used a third existing one. Each of them enables to carry out pressurization tests at a different scale. The results put all together give quantitative information for more accurate building scale simulations. It also gives a number of recommendations for a better workmanship on the building site to enhance the airtightness.

It has been found in particular that the density of the insulation material is significant since a soft glass wool can have an air permeability three times higher than a rigid one with the same thermal performances. Moreover it has been pointed out that the bounding between the gypsum board and the insulation has a significant impact on the resulting pressure-flow law, and to ensure no air gap the whole interface should be glued. Finally at wall scale we have found that the sealing of the gypsum boards and the vapour barrier against the bottom wall plate is not very significant as long as the exterior side is sealed correctly. On the other hand a proper sealing on both sides of a window is required because of the air gaps along it.

Keywords - Airtightness, laboratory study, pressure-flow law, wooden frame

1. Introduction

Poor airtightness in buildings can lead to an over-consumption of energy and to many issues such as moisture damage and poor indoor climate. The wooden frame constructions are particularly subject to air leakages and further knowledge in this field is needed to meet the regulation requirements tightened by the development of low-energy and passive houses.

The most common experimental technique to characterize the airtightness is the pressurization test. A pressure difference ΔP (Pa) is applied between the two sides of the tested building component and the resulting volumetric air flow Q (m^3/h) is measured [1]:

$$Q = C.\Delta P^n \qquad (1)$$

With:

- C ($m^3/(hPa^n)$):leakage coefficient characterizing the air permeability
- n (-): flow exponent ranging from 0.5 (turbulent) to 1 (laminar)

This test is carried out in situ to measure the air permeability of a building envelope, usually using a blower door. The ventilation openings are sealed and the fan of the blower door depressurizes the house, exaggerating the building's air leaks. The usual range applied to get the pressure – flow law (1) is from -10 Pa to -100 Pa [2] and n is normally found to be in the vicinity of 0.65 [3]. It reflects a combination of turbulent flows obtained with large leaks such as gaps below doors, and laminar ones such as a flow through a porous insulation material.

These in situ tests are useful to measure or verify the performance of the building envelope [4], [5] and [6]. However laboratory tests with specific experimental setups are required if one wants to measure the performance of a single building component [7], a given wall assembly [8], or specific construction details such as window–wall interface in cavity brick walls [9], structural floors [10], or joints between the basement and the wood-frame wall [11].

As a contribution to quantifying the impact of workmanship on wooden-frame wall airtightness, this paper presents the results of a three-scale experimental study carried out on two new experimental setups and an existing one. First the experimental facilities are described, then the experiments are presented and their results are discussed. We measured the air permeability of glass wool depending on its compression. Then we studied the impact of the way different elements are assembles in a wall.

2. Experimental setups

Small scale – SAPI box

We have contructed a small experimental bench: SAPI box (Small Air Path Investigation box) to characterize the permeability of insulation materials or very simple wall assemblies, as shown in Fig. 1. The inside dimensions are 300 (length) x 150 x 150 mm. The air input can be connected to the compressed air network. A first frame is placed 100 mm downstream to install the studied building component with a 150 mm square-section, and a thickness up to 200 mm. A second frame can be placed downstream to maintain the component at a constant compression. The box is airtight at the working pressures (under 5000 Pa). The airtightness between the tested component and the box walls is ensured by self-adhesive tape on the edges of its downstream side.

The flowrate is measured before entering the SAPI box with a mass flow meter (Brooks 5863S). The relative pressure is measured in the upstream part of the box with respect to atmospheric pressure by a piezoelectric pressure sensor (Kobold SEN-323).

The objective of this box is to obtain quick results for a comparison of different elements with good repetability, but the absolute precision is limited. The small dimensions of the box compared to the potential high air velocity do not guarantee a homogeneity of the pressure conditions along the upstream side of the tested building component. Moreover, the two frames reduce the inlet and outlet cross sectional area for the airflow to a 110 mm square-section. However, the air may flow through a larger section inside the building component (up to 150 x 150 mm), which would make air permeability measurements less precise with this experimental set-up.

Intermediate scale – APIE box

The second facility: APIE box (Air Path In Envelopes box) was built to investigate the air path inside 2m high and 0.7m wide wall assemblies, characterize the impact of the infiltrations on the temperature and humidity fields inside the wall, and to measure its air permeability [12]. As shown in Fig. 1, the experimental setup is divided into three major parts: a fixed box in the center to install the studied wall assembly and two symmetrical movable boxes on each side with a 90 cm diameter air inlet and outlet. It was sized with CFD simulations to ensure a good homogeneity in the pressure field near the tested wall. The airtightness of the box has been verified up to 200 Pa by placing an airtight gypsum board in place of the tested building component. The mass flow meter (Eldridge 9724MPNH) and the pressure sensor (BTEL5002) used are adapted for lower ranges.

Big scale – AEV test bench

In order to test wall assemblies at a bigger scale (up to 10 m x 5.5 m), we used the existing AEV (a French acronym standing for "Air, Water, Wind") test bench at the CSTB, Scientific and Technical Centre for Building, in Grenoble. It enables to test the wind resistance, the air permeability and the waterproof performance of real-scale building components such as house gates, garage doors, cladding, or in our case a wooden frame wall assembly.

When used for air permeability tests only, this bench has the same principle as the two smaller scale experimental set-ups presented above. A pressurizing/depressurizing ventilation system is capable of generating up to 8 000 Pa of pressure difference between the two sides of the tested building component, and a flow meter measures the induced air leakage rate. A perfect sealing is required between the test frame and both the test wall and the tested building component.

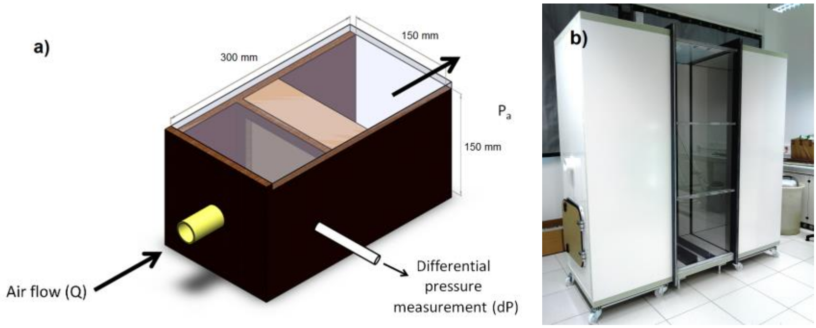

Fig. 1 Small (a - SAPI box) and Intermediate (b – APIE box) scale setups

Verification of the experimental results reliability

We have constructed the SAPI and APIE boxes for this study and further investigation on the air path in wooden frame assemblies. In order to verify the reliability of the results, we used glass wool permeability tests similar to the ones presented in the next section, and we compare the results with a reference value obtained with a permeameter ($6.41.10^{-10}$ m²).

The permeability measured with the APIE box is extremely close to the reference one, with a relative error of 0.43%. The SAPI box gives a higher relative error of 11%, but as mentioned before this box aims at producing relative results rather than very accurate absolute values.

We have also carried out a pressurization test with the APIE box on a gypsum wall with a 20 mm diameter hole, and find a good agreement with a previous study from the LEPTIAB and EDF R&D laboratories [13].

3. Impact of the glass wool compression on the air permeability

At our working pressure the flow in the porous medium is laminar (Reynolds <10^{-2}) which means it can be described by the Darcy's law:

$$Q = - k/\mu.\nabla P \tag{2}$$

With:

- k: intrinsic permeability of the medium (m²)
- μ: dynamic viscosity (Pa/s). The value for the air at 25°C is approximately 1.85e-5 Pa/s (μ = ν/ρ)
- L: the length over which the pressure drop ΔP takes place (m). In this experiment the thickness of the glass wool layers was 60 mm.

By combining (1) and (2) we can calculate the permeability of the tested insulation material with A the cross-sectional area to flow (m²):

$$k = C.\mu.L / A \tag{3}$$

We tested with the APIE box the air permeability of two types of glass wool with similar thermal conductivity (around 0.035 W/m/K) but a different density. The LPGW (low permeability glass wool) is rigid and originally attached to a gypsum board (Calibel® panel). Its averaged density taken on 4 samples is experimentally measured to be 51.6 kg/m^3. The HPGW (high permeability glass wool) is lighter and usually used for the roofing insulation. Its averaged density, also measured on 4 samples, is 15.7 kg/m^3. It is not rigid and can easily be compressed.

We have also tested the impact of the compression level on the air permeability for 2 layers of HPGW. The resulting pressure – flow laws are shown in Fig. 2, and the corresponding permeability coefficients are presented in Table 1. L_0 represents the thickness of the material as recommended by manufacturer. The uncertainties are given by the flow meter and pressure sensor characteristics.

Table 1. Density and air permeability of the two glass wool materials

	L (cm)	Compression ratio L_0/L	Apparent density(kg/m^3)	k (m²)
LPGW	6	100%	51.6	$6.41.10^{-10}$
HPGW	6	100%	15.7	$1.69.10^{-9}$
	11	92%	17.1	$1.45.10^{-9}$
	9	75%	21.0	$1.12.10^{-9}$
	7	58%	27.1	$8.15.10^{-10}$

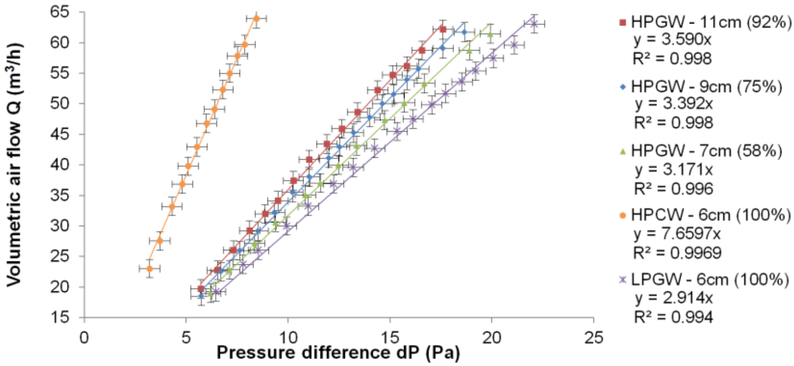

Fig. 2 Permeability of the HPGW at several compression ratio and of the LPGW

These results show that the choice between two insulation materials, even with similar thermal properties, can have a significant impact on the airtightness since the air permeability is three times smaller for the LPGW than the HPGW. Moreover, in case of soft glass wool, the air permeability is proportional to its compression ratio L_0/L, with a permeability coefficient divided by 2 when the compression ratio decreases from 100% to 58%.

4. Impact of the bounding between the wall assembly materials

The bounding between the layers may also significantly impact air permeability of a wall assembly. A simple wall assembly has been implemented in the SAPI box to quantify the impact of this parameter. The first layer is a plastic-coated cardboard (PCC) with a 20 mm diameter centered hole, and the second layer is the HPGW material. The tests are carried out with a sealing (adhesive tape) preventing the air to pass between the glass wool and the box walls and with a 2nd frame (downstream) to maintain the glass wool at a constant compression ratio of 70%. The pressure difference ranges in this study are much higher than those encountered in-situ, but this was necessary to maintain good air flow measurement accuracy despite the low permeability. The results are presented in Fig. 3.

One test is carried out with the two materials glued on their whole interface surface. This results in an almost linear trendline with a flow exponent n that equals to 0.982. The fact that it is slightly under 1 can be explained by a reduced cross-sectional area across the hole in the PCC, inducing higher velocities and a possible local turbulent flow.

The same test with only a circle of glue around the air inlet gives slightly different results. The leakage coefficient C is lower, which means there is probably a small air gap between the two layers: even if the air enters the insulation by a 20 mm diameter section, it can partially exit it after the glue circle and disperse in the air gap to re-enter with a larger cross-sectional area. This phenomenon reduces the risk of local high velocity and therefore the flow exponent reflects a laminar flow.

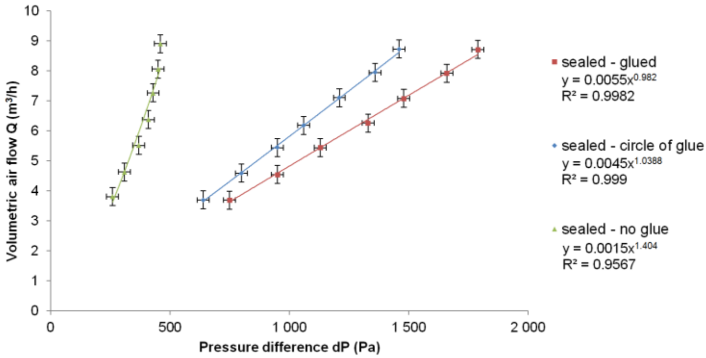

Fig. 3 Impact of the sealing and the bounding between a plastic-coated cardboard with a 20 mm diameter centered hole and a 4 cm layer of HPGW

When there is no glue between the PCC and the HPGW, there is naturally an air gap appearing between the two components. The flow exponent is above 1 (n=1.404), which is not physically possible. As explained in the introduction, this parameter varies from 1 for a completely laminar flow to 0.5 for a completely turbulent flow. The only explanation is therefore that the wall assembly has been transformed during the pressurization test, with probably an increasing thickness of the air gap between the two materials.

As a conclusion, the bounding between the wall assembly layers has a significant impact on its air permeability, and to ensure no air gap the whole surface should be glued.

5. Tests on a real wooden frame wall assembly

The air permeability of a real wooden frame wall assembly was also measured on the AEV test bench, in accordance with EN 1026. It is 5 m long and 2.5 m high, and is made of a 15 mm thick gypsum board (GB), a vapor barrier (VB), two 80 mm thick wood fiber layers and a 10 mm thick MFP board.

First the wall assembly is tested with no sealing between the gypsum boards, no sealing of the vapour barrier against the bottom wall plate, and no window (Fig 4.a). Then we used aluminum foil tape to seal the gypsum boards (Fig 4.b) and later we sealed the VB with the bottom wall plate on the interior side. Finally, we added a triple glazed window and studied the impact on the air permeability depending on its sealing (Fig 4.c).

The resulting pressure-flow laws are presented in Fig. 5. The measurement uncertainties are calculated considering that they follow a power law (equation (1)), and using the deviation from this model.

The successive GB and VB sealing decrease on average the wall air permeability of respectively 10% and 7%, which is not very significant compared to the slot length covered (respectively 19 m and 5 m). It can be explained by the good sealing on the exterior side of the wall (MFP with sealed junctions) which prevents high leakages regardless of the sealing on the interior side. For the last case the flow exponent reached 0.91, reflecting a mostly laminar flow through porous insulation material or very small openings.

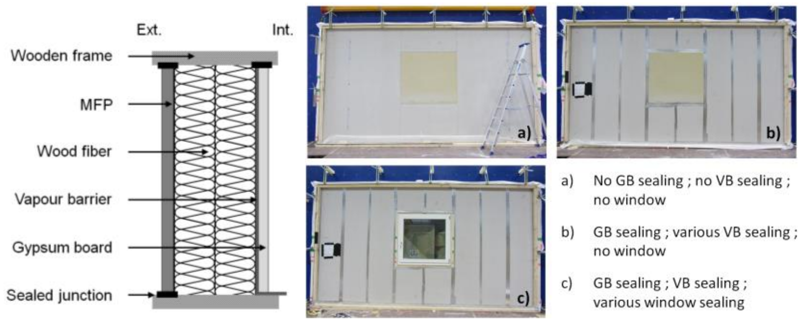

Fig. 4 Steps of the wooden frame wall assembly air permeability tests on the AEV bench

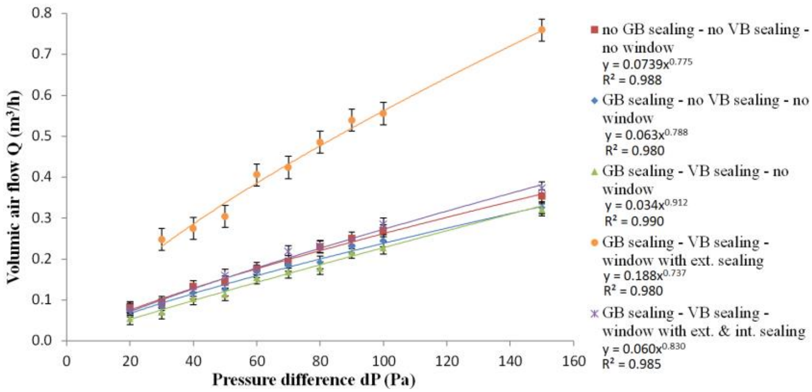

Fig. 5 Impact of sealing levels on the air permeability of a wooden-frame wall assembly

On the other hand the addition of a window creates inevitably air gaps around it (4.8 m gap), which are direct air paths. As a result when the window is sealed only from the exterior side (with polyurethane putty), the air infiltration flow is more than doubled compared to the wall without window. The flow exponent decreases to 0.74, which means that the air is passing through larger openings. When sealed on both sides, the impact of the window on the air permeability is much less significant, with measured air flows similar to the first test.

6. Conclusion

The building airtightness is a rising concern to meet the regulation requirements tightened by the development of low-energy and passive houses. That challenge needs to be addressed by academic studies, including laboratory experiments, on the building components air permeability, the performance of simple wall assemblies and the impact of the workmanship.

For this purpose we built two original experimental setups and we used a third existing one. Each of them enables to carry out pressurization tests at a different scale. The SAPI box is convenient to get quickly relative results on 15 cm x 15 cm building materials and elementary components. The APIE box has bigger dimensions (2 m x 0.7 m) which decrease the error sources. We have verified the reliability of the measurements by comparison with a permeameter test and a literature study. In addition normalized tests on the AEV bench were used.

The tests carried out on these three experimental setups contribute to quantifying the impact of workmanship on wooden-frame wall airtightness. It has been found that the choice of the insulation material can have a significant impact since the tested soft glass wool had a three times higher air permeability than a rigid one with the same thermal performances. The permeability seems also to be proportional to its compression ratio.

Moreover we have pointed out that whether or not the gypsum board and the insulation are glued together has a significant impact on the resulting pressure-flow law, and to ensure no air gap the whole surface should be glued.

Finally, the tests carried out on a real wooden frame wall assembly showed that when the sealing is properly achieved on one side of the wall, the impact of an airtightness defect on the other side is not very significant. The addition of aluminum foil tape to seal the gypsum boards and the sealing of the vapour barrier against the bottom wall plate were found to have both an impact on the air leakage flow under 10%. On the other hand we have shown that a proper sealing on both sides of a window is required. In our configuration the addition of a window with only the exterior sealing has more than doubled the air leakages, whereas a both side sealed window had an impact under 20%. This brings to the conclusion that when air gaps are involved, providing a direct path for the air, a good sealing on both sides of the wall is required, but otherwise an airtight defect on one side has not a very significant impact on the global wall assembly air permeability. These experimental results obtained at a real scale could be used in models by expressing the permeability reduction by meter of sealed gap. However this is not straightforward since the flow exponent is also impacted by the change of air path, and the relative decrease in permeability is therefore dependent on the pressure difference.

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