Assessment of the durability of airtightness products in laboratory controlled conditions: development and presentation of the experimental protocol.

Andrés Litvak [1*], Fabien Allègre [2], Bassam Moujalled [3], and Valérie Leprince [4]

1 Cerema, DAIT/GBAT
rue Pierre Ramond - Caupian
33166 Saint Médard en Jalles cedex, FRANCE
**Corresponding author: andres.litvak@cerema.fr*

2 RESCOLL
8, allée Geoffroy Saint Hilaire CS 30021
33615 PESSAC cedex, FRANCE

3 Cerema, Project-team BPE
46 Rue St Theobald – BP128
38081 L'Isle d'Abeau, France

4 PLEIAQ
84 C Av de la Libération
69330 Meyzieu, France

ABSTRACT

The airtightness of new buildings has significantly improved in the last two decades thanks to building energy performance regulations. However, until now, low knowledge is available about the evolution of buildings' envelope airtightness. This work deals with the durability of buildings airtightness, and focuses on ways to better characterize it. This study is part of the French research project "Durabilitair" (2016-2019) that aims at improving our knowledge on the variation of buildings envelope airtightness through onsite measurement and accelerated ageing in laboratory-controlled conditions. During a past AIVC conference, a publication of the Durabilit'air project has presented and discussed the state of the art on characterizing buildings' airtightness durability. Final results from the Durabilitair mid-term and long-term time scales field measurement campaigns are presented in a companion paper of this conference.

This paper focuses on the assessment of the durability of airtightness products in controlled conditions through the development of a laboratory experimental protocol for characterizing the accelerated ageing of building airtightness assembled products. The overall objective is to define and develop an experimental protocol capable of testing and quantifying the airtightness evolution of assembled airtightness products samples and comparing the relative ageing of the samples.

The state-of-the-art showed that there is no standardised protocol to characterise in laboratory-controlled conditions the durability of product assemblies regarding airtightness performance. As a matter of fact, due to the diversity of airtightness products, it is difficult – and even, perhaps impossible – to define an accelerated ageing universal protocol that would be equivalent to a known amount of years of natural ageing. From the light of the state of the art results, we defined the exposure conditions of a relative ageing test, through thermal, humidity and pressure variation cycles. We developed a 1 m^3 environmental chamber and exposed three different 1 m^2 samples of assembled products to the defined exposure conditions cycles.

The tested samples represent three different treatments of airtightness of the joints between windows and walls: 1) impregnated foam; 2) sealant with backing foam and 3) adhesive and membrane complex. During each exposure cycle, we have measured the evolution of the airtightness of the sample.

The ageing tests of the samples 2 and 3 showed a significant degradation of the airtightness performance after the ageing cycle, whereas air permeability of sample 1 could not be assessed by our experimental protocol. The choice of the samples and the experimental conditions are described and discussed. We conclude that modifying the duration and the characteristics of the exposure cycles (humidity, temperature and pressure) would certainly allow more differentiating results in future works.

KEYWORDS

Airtightness, laboratory measurements, accelerated ageing, durability

1 INTRODUCTION

1.1 Context

Understanding buildings' airtightness governing factors has become a major concern for professionals from the building sector. Significant progress have been achieved, mainly due to mandatory requirements in many countries, as a consequence of Europe's ambition to generalize nearly zero energy buildings by the end of 2020. Nevertheless, we still lack of expertise today about the durability of airtightness products, at mid- and long- term scales.

As a matter of fact, this subject remains very complex, since it covers in the meantime (i) the modelling of the mechanisms of building's and products' loads and deformations; (ii) the accelerated ageing in laboratory controlled conditions and (iii) the performance characterization from field measurements results.

1.2 Objectives

In this paper, we present the results of this second objective, that has been studied as part of the French multi-partner 2016-2019 research project Durabilitair (www.durabilitair.com). We aim at assessing the durability of airtightness products in controlled conditions for characterizing the accelerated ageing of building airtightness assembled products. The overall objective is to define and develop an experimental protocol capable of testing and quantifying the airtightness evolution of assembled airtightness products samples and comparing the relative ageing of the samples.

Final results from the Durabilitair mid-term and long-term time scales field measurement campaigns are presented in a companion paper of this conference (Moujalled, Berthault, Litvak, Leprince & Francés, 2019). An earlier publication presented and discussed the state of the art on characterizing buildings' airtightness durability (Leprince, Moujalled & Litvak, 2017). In the light of analysis of on artificial ageing in laboratory conditions, we defined an experimental methodology and selected three samples of assembled airtightness products to be tested. The main objective of this research is to prove the technical feasibility of such an experiment, in order to develop a protocol for accelerated ageing and testing of airtightness assembled products.

2 METHODOLOGY

2.1 Results of the state of the art on artificial ageing in laboratory conditions

In a previous state of the art, we presented a summary of artificial ageing recent studies, in controlled laboratory conditions (Leprince, Moujalled & Litvak, 2017). In this review, we pointed the importance of well defining the sample to be tested (products assembly v/s product alone) and the ageing protocol conditions. Due to the diversity of airtightness products, we concluded that it is probably impossible to define an accelerated ageing universal protocol that would be equivalent to a known amount of years of natural ageing.

A study tested the durability of adhesives on exterior airtightness barriers (Langmans, Desta, Alderweireldt, & Roels, 2015). The adhesives were exposed to different cycles of temperature (2 weeks), temperature, humidity and gel (12 days) and high humidity (4 weeks). The study concluded that the increase in air permeability was limited. Another research tested both products properties alone and products assemblies implemented in a cell (Ylmén, Hansén , & Romild, 2014). No correlations were observed between the durability of the product alone and the durability of the assembly airtightness. The authors concluded that it is required to develop durability tests of the complete airtightness systems on full-scale set-up. Besides, the impact of solicitations under pressure, humidity and temperature variations was shown to be different depending on the kind of air barrier: plasters are sensitive to humidity and temperature while membranes are sensitive to pressure variation (Michaux, Mees, Nguyen, & Loncour, 2014). Therefore, if one wants to define a protocol that would apply to all kind of air barrier, all type of constraints shall be included in the protocol.

A research has tested products implemented at full-scale wall constructed on a steel frame of 3m x 3m (Antonsson, 2015). They applied heat treatment (60°C, 1 week) and pressure load (-150/+150 Pa) on the sample with a climatic chamber and a pressurisation device docked on the wall (not simultaneously). Two systems have been tested with this protocol and significant deviations were observed in the results. With the first system, a significant change in air leakage has been observed after the heat treatment, while with the second system very little change could be observed.

2.2 Modelling of the mechanisms of building's and products' loads and deformations

Few works have studied the modelling of the mechanisms of building's and products' loads and deformations. A study estimates that 60 to 75% of the pressure loads can reach the airtightness products (Ackermann, 2012). The study concluded that the durability of the air barrier should be tested by performing pressure / vacuum cycles and testing the maximum load. It proposes a test protocol representing 50 years of wind pressure cycle (the maximum load must be a wind that occurs once every 50 years). From the BRE digest, the study has therefore established the load cycles to be implemented according to the maximum load, as well as the simulation of the maximum loads. In this study, correlations were determined between artificial aging and natural aging according to standards. Nevertheless these correlations, based on the laws of Arrhenius are valid only for certain types of materials. For assemblies, the law of Arrhenius is difficult to use. Indeed, estimating thermal and humidity loads is more difficult and depends on the air barrier position. The following recommendations have been identified to address the risks of phase changes during accelerated aging tests in the laboratory:

- Differentiate hygroscopic materials from other non-hygroscopic materials because moisture can laminate the material
- Take into account the absolute humidity in 24h test cycles with absorption / desorption (hot humid, hot dry, cold environments, ...)
- Test products in accordance with the real life exposure conditions
- Do not exceed the glass transition temperature of the products (T ° of transition from the vitreous / solid state to the pasty / rubbery state). Example: PU foams: TV = 50 to 60 ° C
- Do not extrapolate the life of the tested products to accelerated aging (T ° and RH), unless the material is tested at constant T °, without change of state.

2.3 Main results

In the light of this works, we observed that the results of the aging tests vary from one study to another. One of the main reasons is that the protocol is not standardized. Nevertheless, the following general conclusions can be drawn:

- Implementation has a strong impact on durability
- Products do not have the same reaction under normal conditions as when they are subjected to extreme conditions (temperature, humidity or pressure);
- A standardized procedure for the aging of sealants is lacking to characterize products and especially assemblies regarding airtightness performance;
- The results of aging tests on products alone are not necessarily consistent with the aging observed when these products are put in situation;
- Product performance against conventional test procedures (peel, shear, etc.) does not necessarily correspond to their performance in terms of airtightness
- The aging strategy must be consistent with the loads of the products. The strategy may differ depending on the position of the air barrier.

3 DESCRIPTION OF THE EXPERIMENTAL PROTOCOL

Based on this analysis, we developed an experimental protocol for accelerated ageing of airtightness assembled products. The protocol definition consisted in :

1) developing an experimental chamber,
2) choosing the representative samples,
3) and defining the accelerated ageing conditions.

3.1 Environmental chamber

For our study, we developed a 1 m^3 environmental chamber to expose a 1 m^2 square sample of assembled airtightness products to weathering (thermal, hygrometric and pressure) controlled conditions. The environmental chamber is composed of three main parts:

- An accelerated weathering chamber (see A on figure below)
- A pressure test bench for differential pressure exposure and airtightness measurement (see B on figure below)
- A sample holder, between both enclosures (see C on figure below)

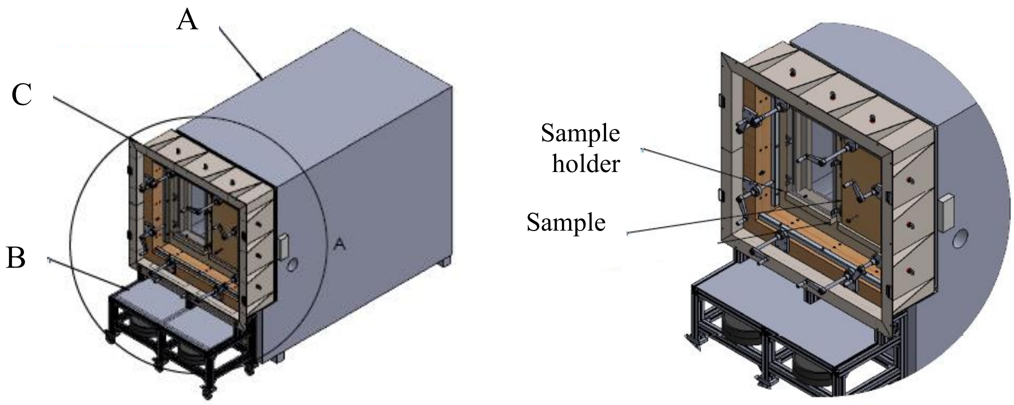


Figure 1 : Environmental chamber

The frame of the sample holder and the differential pressure bench constitute a single independent machine that allows to perform wind cycles and airtightness measurements between -250 Pa and + 250 Pa. We created a differential pressure on the sample by positive and negative pressurized air, with air mass flow controllers. Pressurization created the conditions for both the exposure (to wind exposure) and the airtightness measurement tests.

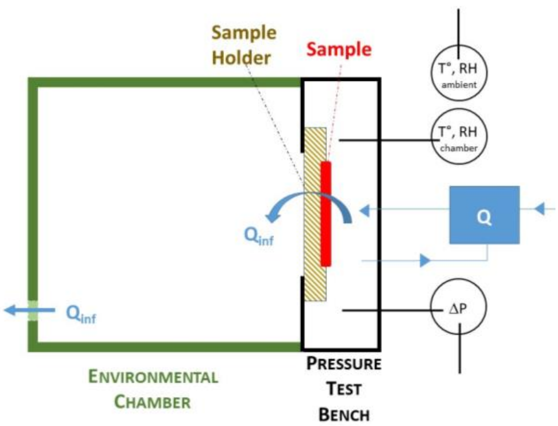


Figure 2a : global view with the pressure bench access panel closed by an aluminium plate

Figure 2b : the environmental chamber (the door was removed)

Figure 2c : the sample holder

We designed the technical specifications of the pressure test bench (see table 1) with the view to get the best compromise between a good signal stability and a fairly large usage range, in order to test the various implementation solutions and to maintain a control reactivity and a sufficient flow rate to carry out cycles with imposed frequency.

Table 1: technical specifications of the pressure test bench

Technical specifications	Values
Differential pressure measuring range	[-250 Pa , +250 Pa]
Steady state stability	± 2 Pa in [-250 Pa , +250 Pa]
Maximum setpoint	<30% (at 10 Pa) <5% (≤ -50 Pa and ≥50 Pa)
Maximum compensation capacity	30 lpm [0 , 250 Pa] 20 lpm [- 250 Pa , 0 Pa]
Pressure measurement precision	± 0.25% of measurement range
Airflow rate measurement range	[-50 lpm , 50 lpm]
Airflow rate measurement precision	± 0.6% of measurement range
Collected data	Differential pressure Airflow rate T°C/RH laboratory T°C environmental chamber Atm pressure laboratory
Acquisition data rate	5 Hz

Airtightness, repeatability and reproducibility tests were performed on the bench in 4 different configurations :

1) test i :with an aluminium airtight plate, closing the pressure bench,
2) test ii :with the aluminium plate, with a ϕ 2.5 mm round hole
3) test iii :with the aluminium plate, with a ϕ 4.0 mm round hole
4) test iv :with the aluminium plate, with the two holes (ϕ 2.5 mm and ϕ 4.0 mm)

Results confirmed the airtightness of the bench. The measured airtightness air flow rates were measured to be below the airflow rate measurement precision (0.18 lpm for positive pressure and 0.12 lpm for negative pressure). Inversely, airflow rate measurements as a function of pressure for the configuration n°ii-iii-iv (i.e., with holes), shown consistent results with the equivalent corresponding leakage area tests.

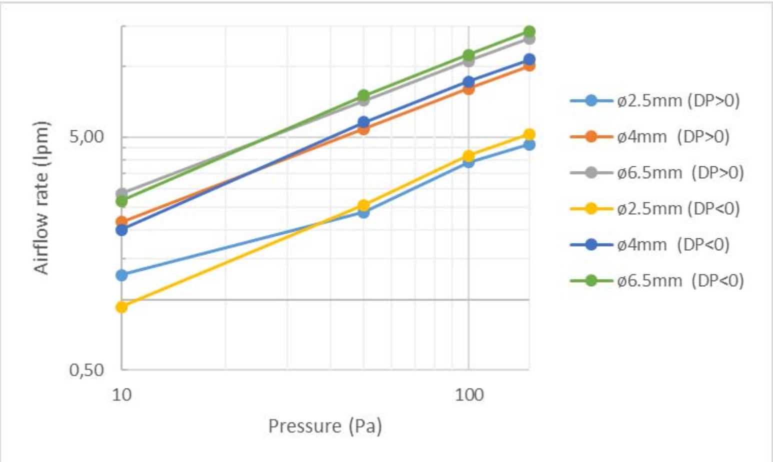
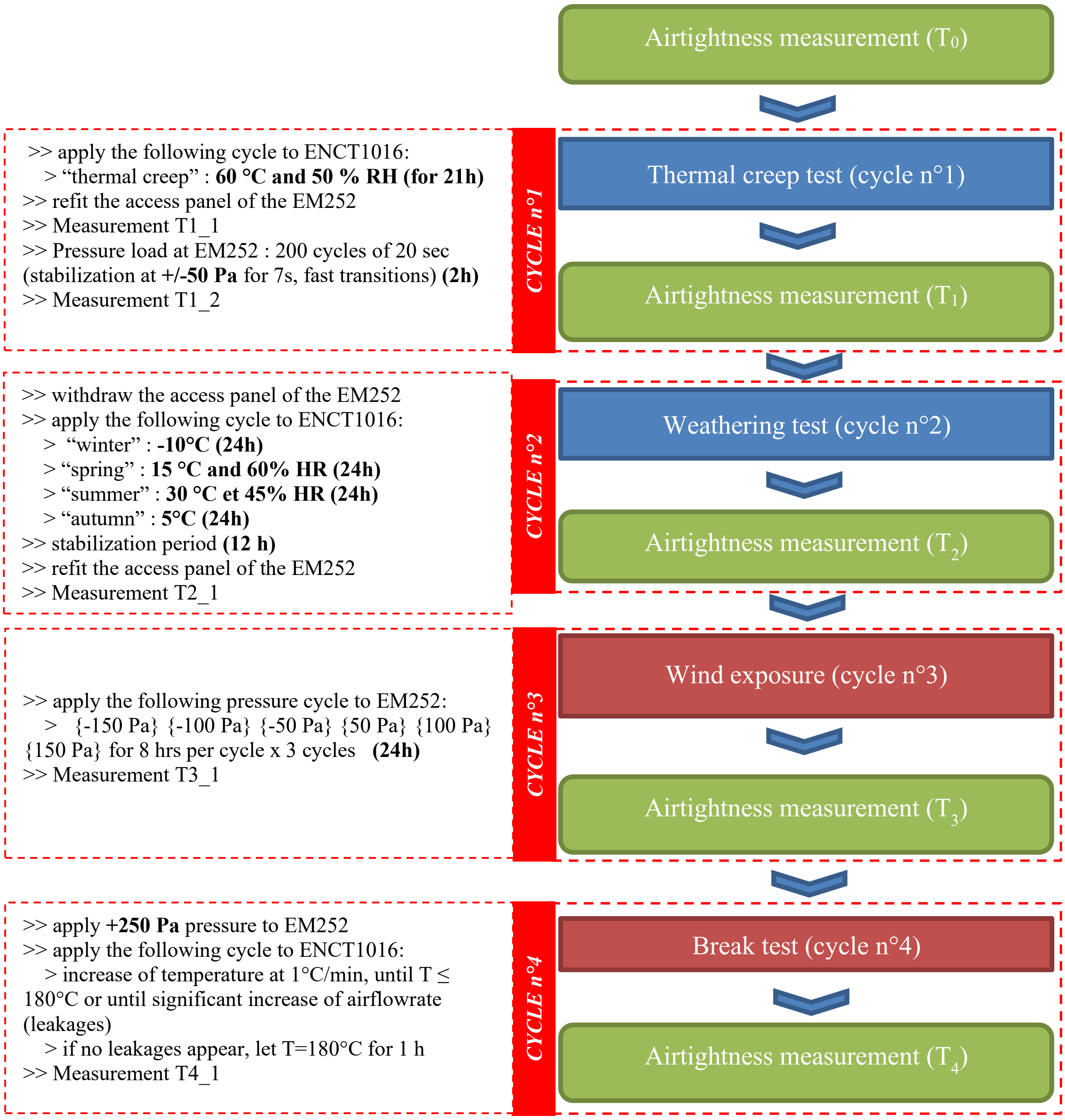


Figure 3 : air leakage flow rates across the aluminium plate (tests n°ii-iii-iv)

3.1 Exposure cycles and airtightness measurements

We defined a test as 4 successive cycles applied one after the other with intermediate measurements to control the evolution of airtightness between each cycle. We designed 4 weathering cycles, in order to accelerate the ageing of the samples :



Airtightness measurements were performed in order to determine the airflow rate Q as a function of pressure ΔP, according to the airflow rate and pressure law model, equation 1 :

$$Q = K\ \Delta P^{n} \quad (1)$$

where Q(lpm) is the airflowrate, ΔP(Pa) is the differential pressure and K(lpm.Pa^{-n}) and n(-) are the airflow coefficients.

For this work, we compared the measured airflow rates values at 0 Pa, ± 10 Pa, ± 50 Pa, ± 100 Pa and ± 150 Pa and represented the corresponding charted profiles (Q, ΔP).

For the pressure loads to be applied, we transposed Ackerman's protocol to France. The maximum wind measured in France in inhabited area is 150km/h which corresponds to 41m/s. According to ISO 15927-1:2003 "Hygrothermal performance of buildings – calculation and presentation of climatic data – part1: Monthly means of single meteorological elements", the on-site wind is:

$$vs = vr * Cr * Ct \tag{2}$$

with, vs (m/s) wind speed on site
vr (m/s) reference wind speed
Cr (-) roughness coefficient in Urban area below 16 m: CR(z)=0.24*ln(16/1)
Ct (-) topograhy coefficient Ct=0.9

Therefore a 41m/s wind represents a 24m/s wind on building site. If we consider that the maximum pressure coefficient on a façade is 0.5, this corresponds to a load of 173 Pa, according to the wind pressure equation. Now, if one considers Ackerman's assertion that 75% of the load is on the air barrier, that means that the maximum pressure to apply is 130 Pa. We transposed the BRE cycles digest, see table 2. One can note that these pressures correspond to the pressure ranges of an experimental protocol reported in our previous state of the art (Antonsson, 2015).

Table 2 : Range of the pressure test

Column Title	Number of cycles (positive and negative)	Percentage of the design pressure (%)	Corresponding pressure (Pa)
Sequence to be applied 5 times	1	90 %	117 Pa
	960	40 %	52 Pa
	60	60 %	78 Pa
	240	50 %	65 Pa
	5	80 %	104 Pa
	14	70 %	91 Pa
Last sequence	1	100 %	130 Pa

3.2 Samples

Three types of assembled products as treatments of airtightness of the joints between windows and walls were chosen as samples to be tested, namely:

i) Expansive weatherseal foam ;
ii) Sealant (mastic) with backing foam
iii) adhesive and membrane complex.

The sample holder enabled the installation of two different samples for each exposure cycle. All assemblies were made under the technical supervision of the representatives of the products used. The method of implementation was documented elsewhere (Allegre & Louet, 2019).

1) Description of sample n°1 : impregnated foam tape on wooden carpentry

The sample is the assembly of an expansive weatherseal foam tape installed between the frame and the opening of a wooden carpentry. The selected foam tape has an operating range of 5 to 11mm.

This sample holder allows the installation of two samples in parallel. We installed the sample in two configurations:

- Left, in figure 4.1 and 4.3, with an expansion of 10mm (i.e., close to its upper limit)
- Right, in figure 4.1 and 4.3, with an expansion of 6mm (i.e., close to its lower limit)

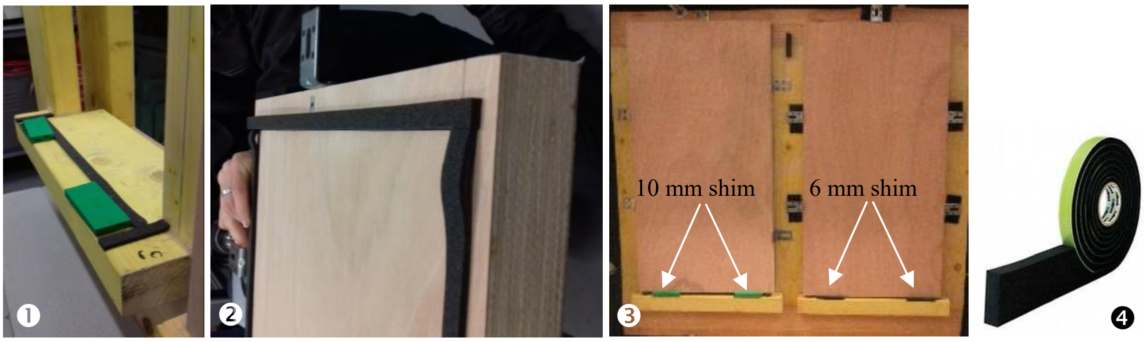


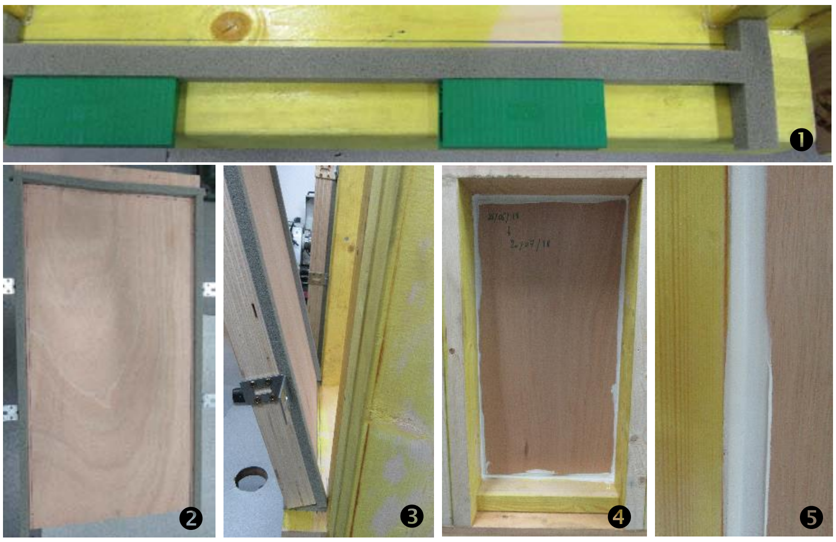
Figure 4 : installation of the sample n°1

2) Description of sample n°2 : backer rod and mastic (sealant) on wooden carpentry

The sample is the assembly of back-up strips and filled up with mastic as a sealant, implemented between the frame and the opening of a wooden carpentry. The selected backer rod has an operating range of 5 to 11mm. A fixing coat was applied to the wooden surface before implementing it.

This sample holder allows the installation of two samples in parallel. We installed the sample in two configurations:

- Left, in figure 5.1 and 5.3, with an expansion of 10mm (i.e., close to its upper limit)
- Right, in figure 5.1 and 5.3, with an expansion of 6mm (i.e., close to its lower limit)



Successive steps for implementation of the assembled products.
The opening of the carpentry was replaced by a plywood board.

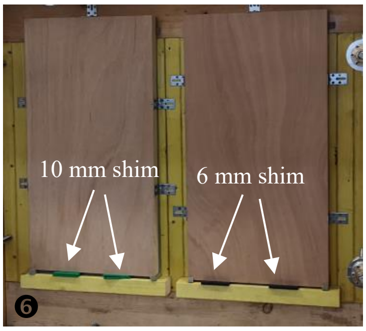


Figure 5 : installation of sample n°2

3) Description of sample n°3 : membrane, adhesive and staples on wooden carpentry

The sample is the assembly of a membrane taped and stapled on the opening of a wooden carpentry. Two identical membranes were implemented in the sample holder (see figure n°6).

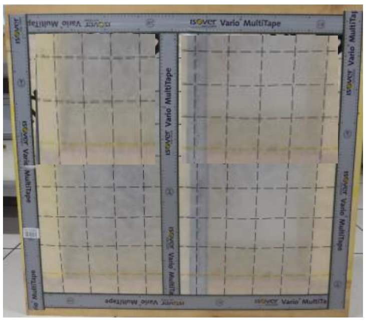


Figure 6 : installation of sample n°3

- the cut-out membrane was positionned flat on the sample support at 3 cm from the edge of the left upright and centered in height
- the membrane was stapled on all edges by positioning a staple every 5 cm around orienting the staples at 45 °
- Adhesive tape was pasted on the central part taking care not to fold

4 RESULTS

4.1 Initial measurements and analysis of sample n°1

Air permeability flowrate measurements for samples 2 and 3 were achieved. However, due to the maximum flowrate delivered of the pressure bench, the pressurization of sample n°1 was impossible to achieve over 15 Pa for positive and negative pressures, see table 3 Complementary tests were performed to ensure the airtightness of the sample holder and are reported elsewhere (Allègre et Louet, 2019).

From figure 7, we can observe that the 3 samples have very different ranges of airflow rate permeability for the initial measurement (i.e., before the ageing test begins). With the sample n°2 as a reference, we assessed at 10 Pa the following ratios between the airflowrate permeability :

- $Q_{10\ sample1}^{+}/Q_{10\ sample2}^{+}$ = 6.78 for positive pressures and $Q_{10\ sample1}^{-}/Q_{10\ sample2}^{-}$ = 5.59 for negative pressures, extrapolated from the equation 1 for sample 2 and from measured values for sample 1
- $Q_{10\ sample3}^{+}/Q_{10\ sample2}^{+}$ = 0.05 for positive pressures and $Q_{10\ sample3}^{-}/Q_{10\ sample2}^{-}$ = 0.08 for negative pressures, extrapolated from the equation 1 for samples 2 and 3

These results show no trend on the impact of the pressurization mode (positive or negative) with the corresponding air permeability flowrate.

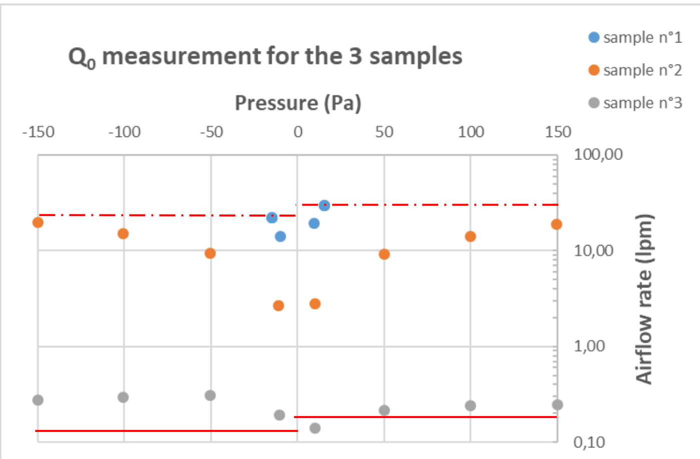


Figure 7 : Results of the samples initial airtightness measurement, permeability as a function of the measured pressure. In red dotted lines, the maximum compensation capacity (air flow rate) of the pressure bench. In red plain lines, the airflow measurement precision.

Table 3 : Sample n°1, measured aiflow rate and differential pressure, as a function of the target pressure (Pa)

+150 Pa	+100 Pa	+50 Pa	+10 Pa	0 Pa	-10 Pa	-50 Pa	-100 Pa	-150Pa
29.6 lpm	29.5 lpm	29.6 lpm	19.4 lpm	0 lpm	14.2 lpm	22.2 lpm	22.2 lpm	22.1 lpm
15.7 Pa	15.7 Pa	15.6 Pa	9.4 Pa	0 Pa	-9.8 Pa	-14.8 Pa	-14.8 Pa	-14.9 Pa

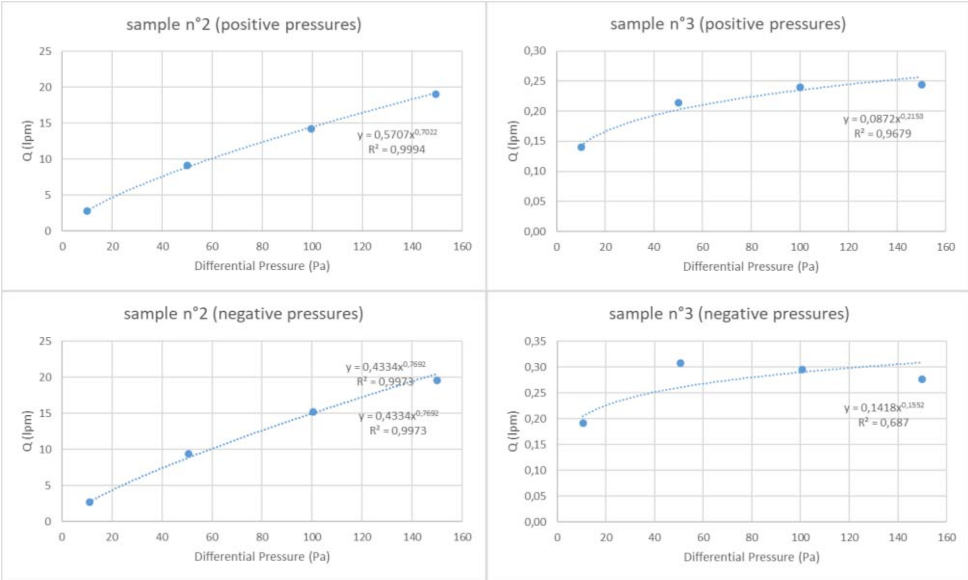


Figure 8 : Results of air permeability flowrates for samples 2 and 3, before ageing test, and the corresponding trendline according to Equation 1.

4.2 Analysis of results of sample n°2

The air permeability flowrate could be measured over the full range (-150Pa to + 150Pa). For each cycle, results were compared with corresponding Q_{test0} results and showed the following trends (see figure 9):

- improved airtightness between Test0 measurement (T0) and Test1 measurement (T1). This improvement was explained by the moisture saturation and therefore the expansion of the wood frame.
- As for T1, we found that T2 showed an improvement in airtightness due to moisture saturation in the wood frame. We could also observe that test T2 did not have any impact on results of T1.
- Although it is of low level, the T3 cycle is the first to deteriorate the airtightness of the sample. The increases of air permeability flow rates were found to be in the range -3% (at -150 Pa) to +7% (at 10 Pa) as compared to test T0
- The rupture occurred after 1h40, corresponding to a temperature of 120 ° C. We observed a sudden drop in pressure and a saturation of the flow. The T4 measurement was performed after sample stabilization and showed a significant impact on the airtightness of the sample for positive pressures, with a difference from -22% to +29% from 10 Pa to 150 Pa for positive pressures ; for negative pressures, the increase was found to be from 0% (at -150 Pa) to +18% (at 10 Pa).

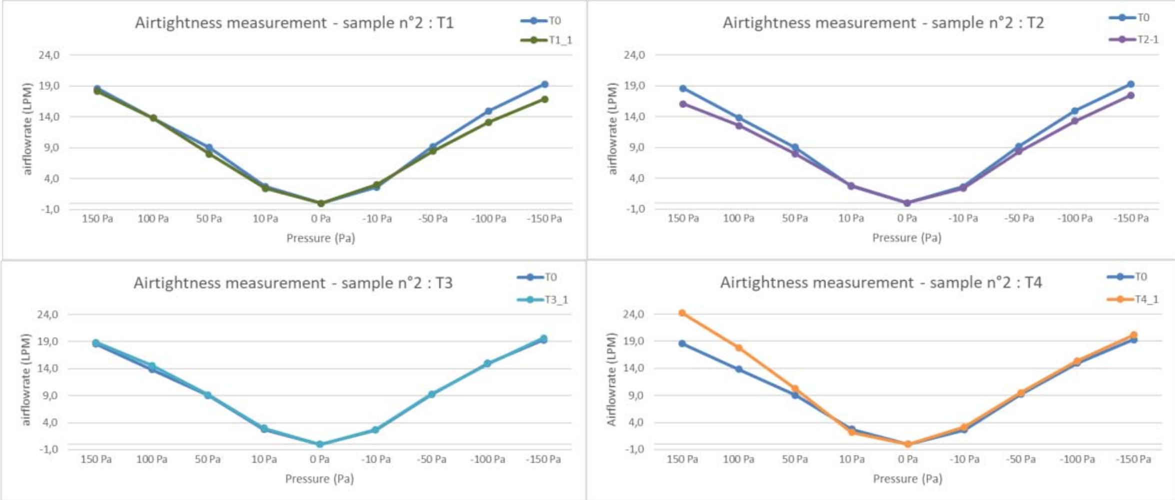


Figure 9: Evolution of air permeability flowrates for sample 2 for the weathering cycle (4 tests)

Table 4 : Sample n°2, results as a function cycles

Cycle	Temperature	RH	Pressure	duration	Results
T1. Thermal Creep	60°C	50%	 -50 Pa / +50 Pa	21 h 2 h	improved airtightness between T0 measurement and T1 measurement.
T2. Weathering	-10 °C + 15 °C +30% +5 °C stabilization	 60 % 45%		24 h 24 h 24 h 24 h 12 h	improved airtightness between T0 measurement and T2 measurement.
T3. Wind			-150 Pa to + 150 Pa	8 h (3 times)	Although it is of low level, the T3 cycle is the first to deteriorate the airtightness of the sample
T4. Break	+1°C/min until 120 °C		250 Pa	100 min	The rupture occurred at 120 ° C and showed a significant decrease of the airtightness of the sample.

4.3 Analysis of results of sample n°3

Sample 3 was very airtight, thus, it was very sensitive to pressure variations (both positive and negative). We did not notice any significant deterioration of the air permeability flowrates for the first 3 tests of the cycle. For the break test (test n°4), the rupture occurred after 40 min, at the temperature of 60°C. After the rupture, the sample's air permeability appeared to increase significantly for negative pressures: Q_{test4}/Q_{test0} ranged from a factor of 1.6 to 3.1 according to the measured pressures. For the positive pressures, we found a dramatic increase for the air permeability flowrate (Q_4/Q_0 ranged from a factor of 56.3 at 10 Pa to 135.7 at 50 Pa ; for pressure larger than 50 Pa, the maximum airflow rate capacity of the bench was reached, at 30 lpm).

5 DISCUSSION

The three types of samples made of assembled products as treatments of carpentry airtightness showed very different results, according to the maximum compensation capacity of the air permeability flow rate of the bench. The sample 1 (expansive weather seal foam) appeared to be too porous for our equipment, whereas the sample 3 (adhesive and membrane complex with staples) appeared to be too airtight.

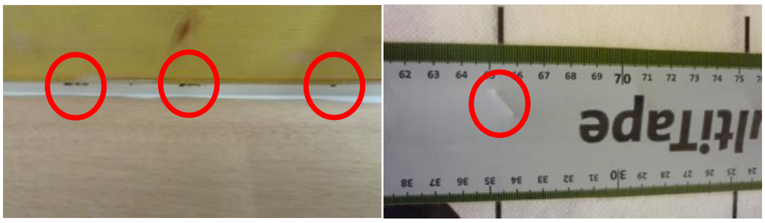


Figure 10: visual observation of cracks on sample n°2 (left, see red; circles) and detached staples (right, see red circles) after the break test

For that reason, no artificial ageing could be achieved with the first sample. On the contrary, for samples 2 (sealant with backing foam) and 3, visual observations on the samples after the ageing test, showed the formation of cracks on sample 2 and the evidence of detached staples on sample 3, creating air leakage occurrences, see figure 10.

Quantitative results confirm these observations, with a slight deterioration of airtightness for sample 2 of up to +7%. Nevertheless, although results show a significant degradation – indeed, quite dramatic, in certain cases – after the break test of sample n°2, we could not draw any conclusion about the artificial ageing of the protocol, due to the elevated temperature of rupture. In fact, the experimental conditions of test n°4 for sample 2 contradicts the previous statement "*Never test products beyond the real life exposure conditions of products*" (see 2.2).

At this stage, preliminary analysis can be addressed regarding the experimental protocol :

- The improvement airtightness during the ageing cycle of sample 2 is probably due to the humidity for the "thermal creep test" and the "weathering test" ; thus we recommend to use inert materials as sample holders for future works.
- As an alternative, we should have investigated the initial state of the sample holder under humidity saturated conditions at T0
- It is interesting to notice that field measurement results from this conference companion paper on Durabilitair research has come to similar conclusions about airtightness durability on wood structure houses, that tend to improve over years [ref Bassam]; probably due to the expansion of the wood with the humidity, that would clog leakages.
- The wind exposure test 3 of the ageing cycle on sample 2 shows a very moderated increase of air permeability. We think that the duration of this cycle was too short, and that exposure durations of at least 1000 h (approximately, 1.5 month) should be necessary; moreover, we suggest that a higher pressure shall be tested to represent more stressing conditions than urban areas
- For the sample 3, it is interesting to notice that during test T1 60°C with a low pressure charge has not induced deterioration in 21 hours but during the break test T4 that occured at 60°C with 250 Pa, it induced a rupture in 40 min therefore the interaction of constraints are critical.

6 CONCLUSION

We developed a $1m^3$ environmental exposure chamber and an experimental artificial ageing protocol, which can test (1mx1m) samples of assembled airtightness products, with a maximum air permeability of approximately 1.8 $m^3/h/m^2$ at 150 Pa. The environmental chamber can expose samples and assess its airtightness up to 29 lpm at +250 Pa (respectively, 22 lpm at -250 Pa), in a temperature range of -30°C to +180°C and humidity of 10% to 95% (saturation). In order to find a compromise between signal stability, usage range and control reactivity on airflow rate, we designed the pressure test bench with technical specifications. We exposed three samples, that presented three orders of magnitude of air permeability. The first sample, prevented us to achieve the pressurisation of the first sample (that was not enough airtight). The ageing tests of the samples 2 and 3 showed a significant degradation of the airtightness performance after the ageing cycle. We could not assess the artificial equivalent aging of the tests of the latter two samples, because the most significant results were obtained during the break tests (cycle n°4). We conclude that modifying the duration and the characteristics of the exposure cycles (humidity, temperature and pressure) would certainly allow more differentiating results in future works. Hence, we recommend for future investigations to carry out characterizations of the humidity impact and the duration of the pressure exposure. The combination of constraints such as temperature and high pressure is perhaps also to look more in the detail, especially for the membranes.

7 ACKNOWLEDGEMENTS

This work was supported by ADEME and French ministry for construction. The views and opinions of the authors do not necessarily reflect those of ADEME and French ministry. The published material is being distributed without warranty of any kind, either expressed or implied. The responsibility for the interpretation and use of the material lies with the reader. In no event shall authors, ADEME or French ministry be liable for damages arising from its use. Any responsibility arising from the use of this report lies with the user. Authors also thank Ulf Antonsson and Eva Sikander for their welcome in RISE (new name for SP) laboratories in Boras (Sweden).

8 REFERENCES

Allègre, F., Louet, D., (2019), *Réalisation d'essai de perméabilité à l'air – Projet DURABILITAIR*. RESCOLL (confidential)

Ackermann, T. (2012). ALTERNATING LOADS – A METHOD FOR TESTING THE DURABILITY OF ADHESIVES IN AIR TIGHTNESS LAYERS.

Antonsson, U. (2015). *Utveckling av metodik för verifiering av bestän- dighet hos system för lufttäthet, etapp 1.* Boras: SPSverigesTekniskaForskningsinstitut.

Langmans, J., Desta, T., Alderweireldt, L., & Roels, S. (2015). Laboratory investigation on the durability of taped joints in exterior air barrier applications. *36th AIVC Conference, Madrid, Spain, 23-24 September 2015* (pp. 615-623). AIVC.

ISO 15927-1:2003 (2003) “Hygrothermal performance of buildings – calculation and presentation of climatic data – part1: Monthly means of single meteorological elements”, International Organization for Standardization

Leprince, V., Moujalled, B., Litvak, A. (2017) *Durability of building airtightness, review and analysis of existing studies* 38th AIVC Conference, Nottingham, United Kingdom, September 2017. AIVC

Michaux, B., Mees, C., Nguyen, E., & Loncour, X. (2014). Assessment of the durability of the airtightness of building elements via laboratory tests. *35th AIVC Conference, Poznań, Poland, 24-25 September 2014* (pp. 738-746). AIVC.

Moujalled, B., Berthault, S., Litvak, A., Leprince, A., and Frances, A. (2019) *Assessment of long-term and mid-term building airtightness durability: field study of 61 French low energy single-family dwellings* 40th AIVC Conference, Ghent, Belgium, October 2019. AIVC

Ylmén, P., Hansén , M., & Romild, J. (2014). Durability of airtightness solutions for. *35th AIVC Conference, Poznań, Poland, 24-25 September 2014* (pp. 268-278). AIVC.