Durability of building airtightness, review and analysis of existing studies

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ABSTRACT

Mandatory building airtightness testing has come gradually into force in European countries mostly because of the increasing weight of building leakage energy impact on the overall energy performance of low-energy buildings. Therefore, airtightness level of new buildings has significantly improved in the last decade.
However, until now, low expertise is available about the durability of building airtightness at mid- and long-term scales.
The Durabilit'air French research project aims at improving our knowledge on ageing of airtightness products onsite and in laboratory controlled conditions.
This paper is issued from the first task of the Durabilit'air project: the "state of the art". It presents a comprehensive review of studies that deal with building airtightness durability, using mostly as references the AIVC publications but also specific studies from UK, Germany, Sweden and France. It covers field measurements, accelerated ageing in laboratory, seasonal variations and also exposure loads of the air-barrier.
Regarding field measurement studies, it seems that the envelope airtightness decreases during the first years after achievement and then stabilises. The main result of this review is a list of key elements that may govern airtightness variations:

- Measurement uncertainty and how it could be reduced
- Structure movements
- Shrinks of mastics in the first weeks when the house gets heated for the first time
- Drilling of the air-barrier due to the installation of new equipment
- Ageing of assembly due to unsuitable association of products and bad implementation conditions
- And, of course, normal ageing of products.

Such information will be useful for future field measurement campaigns. Besides it is necessary to perform leakage detection together with measurements to be able to explain changes in airtightness level.
The analysis of laboratory ageing studies showed that there is actually no standardised protocol to characterise durability of product assemblies. However, due to the various natures of airtightness products, it seems difficult to define an accelerated ageing universal protocol that would be equivalent to a known amount of years of natural ageing. This paper gives pro and cons of various alternatives to assess the durability of airtightness products in laboratory.

KEYWORDS

Airtightness durability, field measurement, laboratory testing, literature review, building envelope

1 INTRODUCTION

Over the last thirty years, much progress has been made to increase our knowledge about mechanisms governing building’s airtightness and the impact of air infiltrations on energy efficiency, health effects and construction quality related issues. As a matter of fact, since the early 2000's, regulations in many countries explicitly account for airtightness, sometimes with mandatory requirements, as a consequence of Europe's ambition to generalize nearly zero energy buildings by the end of 2020. Nevertheless, less expertise is available today about the durability of airtightness products, at mid- and long- term scales. Indeed, this subject remains very complex, since it covers in the meantime:

- the modelling of the mechanisms of building's and products' loads and deformations
- the accelerated ageing in laboratory controlled conditions and
- the performance characterization from field measurements results.

With the DURABILIT'AIR research project, Cerema, PLEIAQ, CETII and RESCOLL aim at improving knowledge on various questions related to residential buildings envelope airtightness durability. This 36-months project has 4 major objectives:

1) listing the major international research findings dealing with airtightness durability of building products, through a state of the art review;
2) characterizing the evolution over time in mid and long term scales (respectively of 1 to 3 and 5 to 10 years) of the airtightness of existing single family dwellings by on-site measurement campaigns;
3) understanding and modelling the physical mechanisms causing the airtightness performance degradation as a function of time with the purpose of developing a laboratory controlled method in order to test the accelerated ageing of airtightness sensitive products and systems;
4) disseminating the main results of this work, with tools and communications among professional of the building sector in order to promote best practices.

This paper is issued from the first task of the Durabilit'air project: the "state of the art". It presents a comprehensive review of studies that deal with building airtightness durability, using mostly as references the AIVC publications but also specific studies from UK, Germany, Sweden and France. It covers field measurements, accelerated ageing in laboratory, seasonal variations and also exposure loads of the air-barrier.

2 APPROACH

We have made a comprehensive review of studies and existing standards on characterisation of building airtightness durability. The objective was to learn from previous studies to develop protocols for the next steps of the Durabilit'air project:

- characterizing the evolution over time of the airtightness of existing single family dwellings by field measurements;
- testing the accelerated ageing of airtightness products and systems in laboratory controlled conditions.

Therefore this review has focused on studies regarding:

- field measurement of building airtightness years after years;
- variability of airtightness test due to tester, measurement devices, external conditions, seasonal variations, etc;
- physical (and no chemical) stresses on the air barrier inducing its deterioration;
- experimental protocols to estimate ageing of the air barrier.

The long term performance of building airtightness has been a key subject of research in the second part of the 80's (mostly in the USA and Canada). Very few studies were published during the 90's and 2000 but since 2010, this subject has come back into focus in Europe.
The review has been done mostly on studies published from 1995 for two reasons:

- There were a lot of changes in building construction habits and products in the last 20 years.

- Airtightness tests in the 80's were not as reliable as now.

For practical reasons the review mostly includes publications in English or French.

3 RESULTS

3.1 Field measurements

Table 1: Summary of field measurement studies

Country	Number of houses Green: new houses Blue: Refurbished houses	Year of const. or refurbish.	Ageing (year)	Average airtightness (n_{50})	Main material	Airtightness evolustion: Max / Average/ Min	Ref.
US	17	2001	10-13	6 ACH	Wood?	+140% / +15% / -25%	(Chan & Sherman, 2014)
US	17	2007	5-7	10 ACH	Wood?	+150% / 0% / -40%	(Chan & Sherman, 2014)
Belgium	15	2010	1-2	0.6 ACH	Concrete blocks	+120% / +36% / -3%	(Bracke, Laverge, Van Den Bossche, & Janssens, 2016)
Sweden	6	1990	10-20	0.6-4 ACH	Wood?	+580% / +162% / -11%	(Hansen & Ylmén, 2012)
Canada	17	1985	3 then 11	1.5 ACH	Wood	+6% ; +60% / +11% / -16%	(Prowski, December 6-10, 1998)
France	30	2009	5-6	1.8 ACH	Concrete blocks	- / +50% / -	(ADEME, 2016)
Germany	2	1990	25	0.6 ACH	Concrete blocks	1st house: 0% / 2nd : +34%	(Feist, Ebel, Peper, Hasper, Pfluger, & Kirchmair, 2016)
UK	23	2007	1-3	4 ACH	Wood or concrete blocks	+154% / +25% / -33%	(Philips, Rogers, & Smith, 2011)

In every study, results show a significant difference between tested houses: in some houses, the permeability is multiplied by a factor of two while in other it decreases after few years. Most of studies come up with global averaged results and do not explain the variations between houses.

However, interesting results in studies provide clues to explain those variations.

In US, (Chan & Sherman, 2014) noticed that the air leakage increased in average by 15% in the new build homes while no increase in the air leakage was observed in the weatherized homes. It was noted that for the weatherized homes, the joints between building components, that were sealed, do not change their leakage characteristics with time. In new build homes, **the moist wood materials may have shrunk over the first several years, potentially causing leaks in the building envelope.**

In Belgium, (Bracke, Laverge, Van Den Bossche, & Janssens, 2016) have tested the durability on 15 nearly identical houses: build by the same craftsmen with the same products (air barrier done by plaster on the masonry). However, ageing results vary from -3% to +120%, therefore in this case the **main impact** is probably not due to the ageing of products but to other factors such as **occupant behaviour, measurement uncertainty,** etc.

In the Swedish study (Hansen, et al., 2012), conclusions were difficult to draw as the air leakage increased for half of tested houses (up to 6 times) and decreased for the other half. This was not correlated neither with changes made in the construction, nor with the year of construction.

In Canada, (Prowski, December 6-10, 1998) concludes that performance of polyethylene air barriers was unchanged over 8 to 11 years. Although three of houses became leakier, the leakage detection has shown that leakages were not occurring at locations associated with the polyethylene portions of the air barrier. Conversely houses built with the drywall approach degraded slightly over the 11-year monitoring period but there is no evidence that it was due to this approach.

In France, (ADEME, 2016), a case study of 30 tested houses showed that permeability of houses made of concrete blocks (air barrier made by plaster boards) deteriorates more than houses made of wood (air barrier made by membrane). However results are heterogeneous from one house to another. In this study, an important work has been performed to compare leakages locations before and after a few years. It has been noticed that **leakages** are mainly at:

- **Penetrations of the air barrier;**
- **Electrical appliances;**
- **New non-airtight appliances (hood, recessed lighting, etc.).**

However, no correlation has been made between value of airtightness and new leakages in houses.

In Germany, (Feist, Ebel, Peper, Hasper, Pfluger, & Kirchmair, 2016) have performed advanced leakage detection on the air barrier (made with plaster boards). They concluded that only windows and doors gaskets (on the openings) have deteriorated, they have been changed for the new test. **Acrylic mastics, set on backer rod, have not deteriorated at all**.

In UK, (Philips, Rogers, & Smith, 2011) showed on a 23 dwelling sample study that the air permeability of two thirds of the dwellings tested had increased while the air permeability of the remaining third had decreased. They observed that:

- Houses generally became more leaky than the flats.
- Timber frame dwellings showed the largest change in airtightness compared to plastered masonry.
- Six of the eight results that achieved a performance improvement were heated with electric panels rather than a gas and radiator (may be due to the reduced number of service penetrations).

In another project in UK, (Wingfield, Bell, Miles-Shenton, South, & Bob, 2009) have shown that **after few weeks of heating, mastics began to shrink**. On 3 houses, they performed tests before and few weeks after heating and observed up to 30% increase of permeability.

Finally, it is interesting to notice that, in almost every study, the air permeability of part of dwelling tested had decreased. There are few explanations, but apart from measurement uncertainty, it could be the result of settlement, the installation of carpets and floor finishes after the original test, and the presence of plugs in electrical sockets. (Philips, Rogers, & Smith, 2011)

3.2 Uncertainty in airtightness testing

Part of the difference between tests results may be due to airtightness test uncertainty. Deviations in airtightness testing are due to

- Tester behaviour (including building preparation),
- Reproducibility issues,
- Wind and thermal draft impact,
- Measurement device uncertainty,
- Seasonal variation of airtightness.

To limit the impact of tester behaviour, many countries have developed competent tester schemes and specific standards that among other things describe building preparation (Leprince & Carrié, 2014). However (Bracke, Laverge, Van Den Bossche, & Janssens, 2016), noticed that small changes in building preparation, such as locking or not a door, may have an important impact on results when it comes to very airtight buildings. Also for terraced houses, depending on where the air barrier is set, the status of openings in adjoining dwellings may have an impact on the measurement result.

Various studies of repeatability and reproducibility have been performed in the last 5 years (Delmotte, et al., 2011), (Bracke, et al., 2013), (Brennan, et al., 2013).
Main conclusions are:

- The average air leakage rate had a repeatability standard deviation ranging from 3.5% at 4 Pa to 1.4% at 50 Pa (Delmotte, et al., 2011), confirmed by (Bracke, et al., 2013), (Brennan, et al., 2013)). The average air leakage rate had a reproducibility standard deviation ranging from 5.9% at 4 Pa **to 2.4% at 50 Pa** (under favourable conditions: no wind, low temperature difference) (Delmotte, et al., 2011).
- The repeatability and reproducibility improve when tests are performed both in pressurization and depressurization (Delmotte, et al., 2011), (Bailly, et al., 2012) .

The impact of wind on the uncertainty in airtightness testing was studied by (Carrié, et al., 2014). The study concludes that the model error due to the wind on the estimated airflow rate is relatively small for the high pressure point (12% for wind speeds up to 10 m/s at 50 Pa), but it can become very significant with a low pressure point (up to 60% at the low pressure point (10 Pa)). Therefore, when estimating airtightness at 4 Pa, wind could be responsible for significant errors (in some cases more than 35%) (Bailly, et al., 2012).

Seasonal variation of building airtightness is a pending question and has led to various publications with inhomogeneous results. In Sweden, two very tight wood structure houses were tested 10% tighter in summer than in winter during 2 years (Wahlgren, 2014). Study from the early 80's reported seasonal variations in the order of up to 100% (Kim & Shaw, 1986). This is not confirmed in recent studies. However most studies have been performed on very airtight building, therefore variations represent very small airflow rate.
On the other hand, studies of the French (Bailly, et al., 2015) and British (ATTMA website) database on average results for each month show no difference between summer and winter. However those two databases contain mostly houses made of concrete blocks and only few of wood structures. Further statistics shall be done per building type and per local climate to confirm this result.

3.3 Loads on air barrier and equivalent artificial ageing

Very few studies have been performed to quantify loads on the air barrier. (Ackermann, 2012) estimates that 60 to 75% of pressure loads reach the air barrier.
Pressure due to wind can be estimated with the following formula:

$$P_{wind} = \frac{1}{2}\rho C_p v^2 \tag{1}$$

With

v	m/s	Wind speed at building level
Cp	-	Pressure coefficient (up to 0.5 according FprEN 16798-7)
ρ	kg/m^3	Air density

The wind speed at building level can be calculated from meteorological wind speed according to ISO 15927-1.
When the maximum pressure on air barrier is known, BRE digest 346 part 7 proposes pressure cycles that represent 50 years (equivalent to more than 6400 positive/negative pressures).

Estimating thermal and humidity loads is more difficult and depends on the air barrier position. Table 2 summarizes positions and constraints.

Table 2: Air barrier position and constraints

Nature of the air barrier	Membrane, adhesives and accessories			Plasters		Plaster boards, mastic and accessories
Position	Outside insulation (not possible in France)	In the insulation thickness (in France the rule of maximum 1/3 of insulation inside air barrier applies)	Inside	On masonry with insulation inside	Inside insulation	Inside
Constraints	It depends on its actual position may be expose to high temperature when used in roofing		Internal conditions	External conditions	Internal conditions	Internal condition

Internal and external conditions differ from one country to another.
(Lamoulie, et al., 22th-24th June 2015) have studied the hygrothermal conditions in use of bio-based material to assess their resistance to moulds. According to this study, the usual hygrothermal conditions of usual roof and wall configurations in France can be classified according to two use classes:

- a dry use class usually lower than 85% RH with laboratory test conditions of 85%RH and 26°C,
- a wet use class with a usual relative humidity that can be greater than 85% for more than 48 hours with laboratory test conditions of 95%RH and 26°C.

To perform artificial ageing due to temperature variations, "time-temperature superposition principle" can be used. For polymer, the principle is that translation factor can be found between time and temperature. Therefore chemical ageing can be performed rapidly by maintaining a polymer at high temperature (below its glass transition temperature). This translation factor is often computed using WLF model or Arrhenius law. However this

translation factor depends on actual solicitations and on materials. It remains unclear for us how it can be applied to assembly.
Therefore literature, such as ASTM D3611-89 and SATAS give inconsistent information regarding equivalence between artificial and natural ageing.
The time-temperature superposition principle is a chemical ageing, it creates:

- neither physical ageing that can be induced by humidity variation
- nor mechanical ageing that can be induced by pressure variations.

However it is unclear for us whether chemical, mechanical or physical ageing predominates when it comes to airtightness products. Regarding mechanical constraints it is also unclear whether only the maximum pressure has an impact or if the number of cycle is also important.

3.4 Artificial aging

Table 3: Summary of artificial ageing studies

Country	Assembly			Scale		Constraints				Ageing criteria			Test duration	Ageing Equivalent	Ref
	Product alone	2 products	Complete wall	Reduced scale	Scale 1	Extreme loads	Cycles	Heat treatment	Details	Visual	Material properties	Airtightness			
Belgium		X		X		X			Water pressurisation			X	45-70 min	?	(Bracke, Van Den Bossche, & Janssens, 2014)
US (ductwork sealants)		X			X			X	93°C, 84 Pa	X		X	2 yr.	30 yr.	(Sherman & Walker, April 2004)
Sweden			X		X		X	X	80°C, HR cycles	X		X	1 yr.	50 yr.	(Ylmén, Hansén , & Romild, 2014)
Belgium		X		X			X		15/70°C Rain +frost UV+HR			X	8 wk.	?	(Langmans , Desta, Alderweireldt, & Roels, 2015)
Belgium			X		X	X	X		Pressure cycles (up to 1000Pa) 20/90% RH -10/70°C			X	Visual	?	(Michaux, Mees, Nguyen, & Loncour, 2014)
Sweden			X		X		X	X	-150/ 150 Pa 60°C/ 50%HR			X	7 days	?	(Antonsson , 2015)
French standard	X			X				X	50°C 70% HR		X		168 h	?	CSTB, cahier 3710

Michaux et al. in the context of the DREAM project, tested more than 50 buildings walls under pressure, humidity and temperature variations (Michaux, et al., 2014). The impact of

each solicitation was different depending on the kind of air barrier: plasters were sensitive to humidity and temperature (cracks appeared if the plaster was too thin) while membranes were sensitive to pressure variation (due to staples). 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.
SP (Ylmén, et al., 2014) tested both products properties alone and products assemblies implemented in a cell. **They observed no correlation between the durability of the product alone (in term of pealing, etc.) and the durability of the assembly airtightness**. According to the research team involved, this was due to:

- compatibility problems between film and tapes,
- difference in the results for smaller and full scale specimens,
- air channel appearing during the heat treatment.

Therefore they concluded that it was required to develop durability tests of the complete airtightness systems on full-scale set-up.
According to results of this 1st research project, researchers from SP have decided to test products implemented at full-scale wall constructed on a steel frame of 3m*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.
Another ongoing project in Sweden is testing the impact of implementing the air barrier either during cold and humid conditions or with artificial dust projected on the membrane before putting any kind of adhesives or sealants. It seems that the cold conditions (5°C, 90-95% RH) are very detrimental: even before applying the heat treatment the permeability is 5 times higher than the case implemented in ideal conditions and 6 times higher after heat treatment. The dusty environment approximately doubles the air permeability before and after heat treatment.

Figure 1: tested wall in SP (RISE)

4 DISCUSSION

4.1 On-site ageing

Regarding on-site measurements after few years, it seems that the airtightness decreases in the 3 first years after completion and then stabilises.
In literature there are various explanation factors for this phenomenon. In one hand, short term ageing may be due to:

- Heating houses for the first time may induce the shrink of mastics, if the first test was performed before the heating of the house the impact of mastic shrinking is not seen in the first test.
- Mastic shrinking when backer rod are not used
- Structure movements and packing may induce cracking in the junctions between air barrier and penetrations (ex. carpentry or ductwork and plaster board)
- Envelope drilling, lot of them occurs in the first years of life of a building (for kitchen furniture, hood, wood stove, etc.)
- Unsuitable implementation conditions for adhesives and mastic (cold and/or dusty conditions).

On another hand, it seems that some products do not deteriorate in long term (Feist, Ebel, Peper, Hasper, Pfluger, & Kirchmair, 2016) however the durability of assemblies can be deteriorated by the association of incompatible products.

Those explanations for short term ageing are relevant mostly when part of airtightness is made with mastic. When the air barrier is made with a membrane or with plaster on masonry it seems that airtightness durability mostly relies on occupants' behaviour rather than on products (Bracke, Laverge, Van Den Bossche, & Janssens, 2016) (Prowski, December 6-10, 1998).

Therefore it is relevant to couple future field measurements with:

- Questionnaires to occupants to find out drillings made in the air barrier after the first test and check with leakage detection consequences of drilling.
- Leakage detection and visual inspection at visible assemblies of air barrier with specific care on:
    - mastics,
    - penetrations of building structure inside the air barrier (ex. carpentry).
- Information about:
    - Products used for the air barrier including:
        - whether or not backer rod is used under mastics
        - compatibility of products
    - Construction details
    - Period when the air-barrier was layed-out (heating period or not)
    - Whether the air-barrier has been heated prior to the first test

Some of these have been done in field studies. Unfortunately, the correlation between airtightness results and outcome of these analysis were not investigated.

4.2 Reduce measurement uncertainty

The following recommendations would help to reduce the difference between the first and the second test that is due to measurement uncertainty rather than ageing:

- A qualified tester shall perform tests; if possible the same tester shall perform the first and the second test.
- The first test report shall precisely describe building preparation including locked and unlocked external doors.
- Measurement devices shall be calibrated according ISO 9972.
- Measurements shall be performed in low wind conditions.
- Airtightness shall be compared at 50Pa rather than 4 or 10 Pa.
- The average of pressurisation and depressurisation shall be used for comparison.
- Even if the impact is unclear, tests shall be performed at the same season.

4.3 Laboratory ageing

Results of laboratory ageing studies differ from one to another. One of the reasons may be that the protocol is not standardised. Nevertheless, the following general conclusions can be drawn (Langmans, et al., 2015), (Michaux, et al., 2014), (Ylmén, et al., 2014) :

- ageing of assembly' airtightness cannot be correlated with ageing of material properties (peeling, etc.);
- the implementation has a great impact on the durability;
- every product does not have the same reaction under extreme conditions (extreme temperature, humidity or pressure);
- a standardised procedure for artificial ageing of airtightness products is missing to characterise products and assemblies.
- ageing strategy has to be consistent with solicitation on products, the strategy may differ for exterior, indoor or embedded air barrier.

The reproducibility issue

A good reproducibility is, in our opinion, required for a protocol to be used in a certification context.

Most of projects have not tested the reproducibility of their protocols. A major limitation of testing a whole scale 1:1 system is the reproducibility of the protocol as:

- the quality of implementation may have an important impact on product results.
- it is too expensive to test several times the same system and use the average as the result.

Therefore the bigger the assembly (large with many products) is the more difficult it is to guarantee the reproducibility of the test.

The simultaneous load issue

In most studies, the impact of wind load and heat load are tested one after the other. It seems appropriate for estimating the impact of each load separately. However, it seems interesting to characterize the behaviour of products/systems subjected to the following cycle:

- simultaneous heating over melting temperature and wind load;
- cooling under melting temperature with wind load.

This will allow to see if the melting under mechanical constraint has an impact or not on the performance of the system. Note that in this context, melting is a reversible transformation, i.e., if no mechanical constraint is applied to the product when melted, it comes back to its initial stage without deterioration when cooled under melting temperature. The ability of products to melt depends on their nature: for instance, thermoplastics products can melt, whereas thermosetting products cannot.

If the heat treatment is done over the melting temperature without a wind load, the product will soften during the treatment but get back to its initial state when cooled (reversible phenomenon). However, if the sample is pressurised during the heat treatment and then cooled according to the cycle proposed above, the product could remain distorted when cooled which may have an impact on its airtightness.

Practical limitations of an approach to these simultaneous loads include:

- the maximum pressure the air barrier may undergo simultaneously with the maximum temperature is unknown;
- it complicates the test apparatus and procedure.

Ageing issue

Most of studies only include a heat treatment which is not an ageing protocol (they do not pretend to be equivalent to a certain amount of year).

Defining a chemical ageing protocol may be an objective to simulate realistic service lifetimes, for example, by using Arrhenius law based on the fact that chemistry reactions are accelerated at high temperature.
However, we are unsure if Arrhenius laws are applicable and yield the same equivalent ageing for all materials (thermosetting plastics, elastomer and thermoplastics). For thermoplastics, it is important not to pass the glass transition temperature to avoid irreversible changes that would not occur in "real-life".
Moreover, chemical ageing is not suitable to account for physical and mechanical ageing. To consider mechanical ageing equivalent to 50 years, probably wind cycles should also be implemented.
Overall, we are unsure if it is possible to develop a protocol that could guarantee being equivalent to a 50 year ageing for every product.

Steps to develop a protocol

The following table summarizes pro and cons of various options for a protocol

Table 4: Pro and cons of various options to define a protocol

Assembly	**Product alone**		**Simple assembly (2 products)**		**Complete wall**	
	Pro	Cons	Pro	Cons	Pro	Cons
	Simple	No correlation between aging of product and aging of assemblies	Product implemented	1/ Impact of implementation 2/ Interaction between products	Product implemented	1/ Interaction between products 2/ Impact of implementation => Reproducibility? 3/ Cost of experimental set up

Scale	**Scale 1**		**Reduced scale**	
	Pro	Cons	Pro	Cons
	More representative	Cost of experimental set up	Lower cost (use of existing stove, etc.)	1/ Longest samples do not react as shortest (proved for adhesives by (Antonsson, 2015)) 2/ May be difficult to measure very low flowrates

Constraints	**Extreme load**		**Accelerated cycles**		**Heat and humidity treatment (chemical aging)**	
	Pro	Cons	Pro	Cons	Pro	Cons
	Guarantee resistance at normal constraints	Not representative of actual constraints, products not made to resist	Representative	1/Apart from pressure load difficult to defines cycles 2/ Takes long	Stoves already exist	Equivalent aging difficult to determine

Applying constraints	**Simultaneously**		**One after the other**	
	Pro	Cons	Pro	Cons
	More representative	Difficult to estimate the impact of each Complicate the apparatus	Impact of each	Impact of reversible phenomena not seen

Aging evaluation	**Visual**		**Properties of material**		**Airtightness**	
	Pro	Cons	Pro	Cons	Pro	Cons
	Simple, easy to communicate	1/Subjective 2/No correlation with airtightness	Standards exit	No correlation with airtightness	Objective of the study	Measure very small flowrate requires specific devices

Obviously, science is not fully mature to develop a test protocol and facility to characterise the performance of an air barrier system over time, but there are important steps to underline in such investigations:

1) Design the testing facility considering that:
    a. reduced scales may not be representative,
    b. tests have to be repeatable and reproducible.
2) Define implementation conditions (temperature, relative humidity, dusty area, etc.).
3) Specify the loads on clear bases and considering:

c. worst conditions the air barrier undergoes in the field (maximum and minimum temperature, relative humidity and pressure);
d. preliminary tests to evaluate of which impact between steady worst condition or cycling prevails.

4) Consider preconditioning samples focussing on the comparison of products, not on actual ageing. Ageing laws for chemical ageing can be considered bearing in mind that these are applicable to specific product families and reversible effects. The influence of wind cycle loads on mechanical ageing still needs to be investigated.
5) Implement small scale preliminary tests to evaluate the feasibility and results. One should keep in mind that product characteristics (for example tape) can vary a lot depending on the sample size (e.g. tape can be good on a 50-cm but bad on a 3-m facility).

5 CONCLUSIONS

Regarding field measurements studies, it seems that the envelope airtightness decreases during the first years after achievement and then stabilises. The main results of this review are a list of key elements that may govern airtightness variations:

- Measurement uncertainty and how it could be reduced;
- Structure movements;
- Shrinks of mastics in the first weeks when the house get heated for the first time and/or when backer rod are not implemented;
- Drilling of the air-barrier due to the installation of new equipment;
- Aging of assembly due to unsuitable association of product and bad implementation conditions;
- And of course normal ageing of products.

Such information will be useful for future field measurements campaigns. Besides it is necessary to perform leakage detection and some investigations together with measurements to be able to explain changes in airtightness level.

The analysis of laboratory ageing studies showed that there is actually no standardised protocol to characterise durability of product assemblies in term of airtightness. Moreover due to the various natures of airtightness products it seems difficult to define an accelerated ageing protocol that would be equivalent to a certain amount of years of natural ageing. This paper gives pro and cons of various alternatives to assess the durability of airtightness products in laboratory in particular it insists on two conflicting constraints on the tested sample:

- being large enough and realistically implemented to be representative
- being simple enough to ensure the reproducibility of the test.

In the context of the Durabilit'air project, we are moving toward testing simple assembly of maximum 3 products in a 1m*1m frame that fits with existing stoves. Constraints applied would be both pressure cycles and heat treatment (under fix pressure constraint). The durability will be assessed by an airtightness test.

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