PLEIAQ

Durability of building airtightness

WORKSHOP "TOWARDS HIGH QUALITY, LOW-CARBON VENTILATION IN AIRTIGHT BUILDINGS"

MAY 19TH 2023

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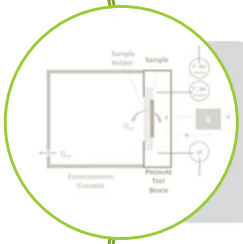
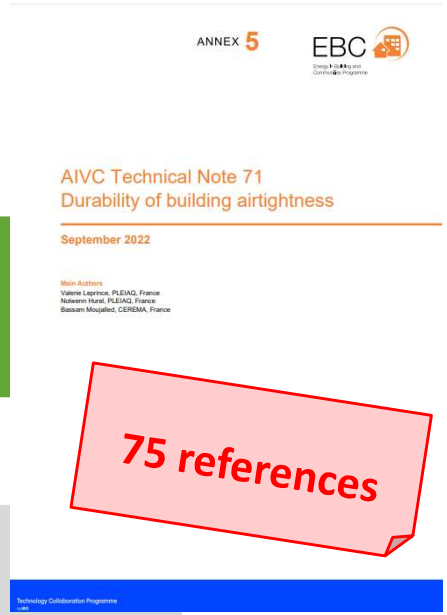
Field studies in real buildings



Experiments in a controlled environment

Implementation conditions impact

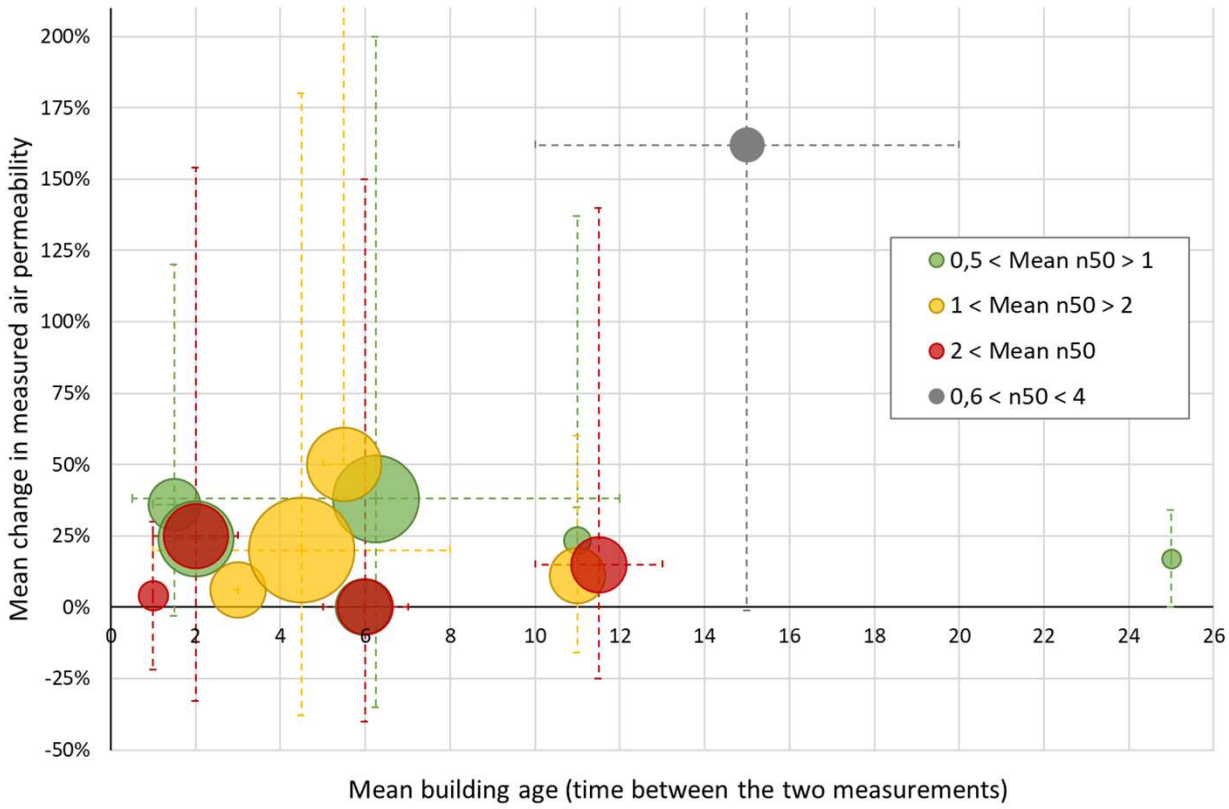


Review of on-site studies testing buildings airtightness durability

Country	Sample size	Year of cons-truction	Age (years)	Mean air permeability n_{50}	Main material	Air permeability evolution	Reference
Belgium	15 new houses	2010	1-2	0.6 ACH	Concrete blocks	Max: +120% Mean: +36% Min: -3%	(Bracke et al., 2016)
	41 new houses	2007 - 2019	0.5-12	0.94 ACH	? (low-energy houses)	Max : +200% Mean : +38% Min : -35%	(Verbeke and Audenaert, 2020)
Canada	17 new houses	1985	3 / then 11	1.5 ACH	Wood	Max: - / +60% Mean: +6% / +11% Min: - / -16%	(Proskiw, 1998)
Czech Republic	4 new houses	2007	11 (or tested regularly between 3 and 11)	0.57 ACH	Wood	Houses A&B : +35% House C: +137% House D: +103%	(Novák, 2018)
France	30 new houses	2009	5-6	1.8 ACH	Concrete blocks	Max: - Mean: +50% Min: -	(ADEME, 2016)
	61 new houses	2009 - 2016	1-8	1.38 ACH	Hollow brick (36) ; Concrete blocs (19); Wood (6)	Max: +180% Mean: +20% Min: -38%	(Moujalled et al., 2021)
Germany	2 new houses	1990	25	0.6 ACH	Concrete blocks	1st house: 0% 2nd house +34%	(Feist et al., 2016)
	17 new houses	?	1.4-10.5	0.42 ACH	Wood (9); Composite (4); Concrete (2) solid (2)	« almost always within the measuring accuracy"	(Peper et al., 2017)
	31 new houses	2000	2	0.37 ACH	? (passive houses)	Mean : +24%	(Erhorn-Kluttig et al., 2009)
Sweden	6 new houses	1990	10-20	0.6-4 ACH	Wood	Max: +580% Mean: +162% Min: -1%%	(Hansén and Ylmén, 2012)
UK	23 new houses	2007	1-3	4 ACH	Wood and concrete blocks	Max: +154% Mean: +25% Min: -33%	(Philips et al., 2011)
	5 new houses	2005	1	5 ACH	Concrete blocks	Max +30% Mean:+4% Min: -22%	(Jez Wingfield et al., 2008)
US	17 new houses	2001-2003	10-13	6 ACH	Wood	Max: +140% Mean: +15% Min: -25%	(Chan et al., 2015)
	17 refurbished houses	2007-2008	5-7	10 ACH	Wood	Max: +150% Mean: 0% Min: -40%	

14 studies from 8 countries

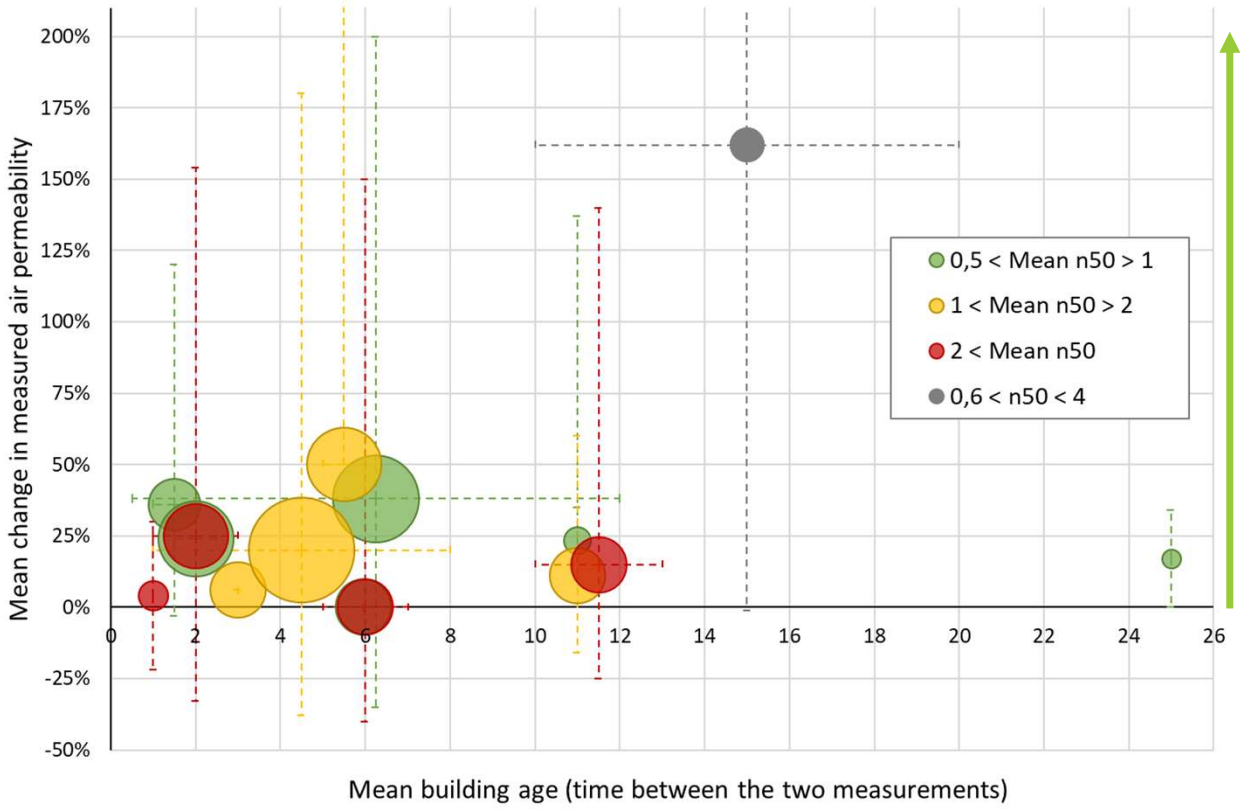
Review of on-site studies testing buildings airtightness durability



Airtightness is **not robust**

→ Significant **changes in air permeability with time** are observed for at least part of the tested houses in all studies except one study (Peper et al., 2017).

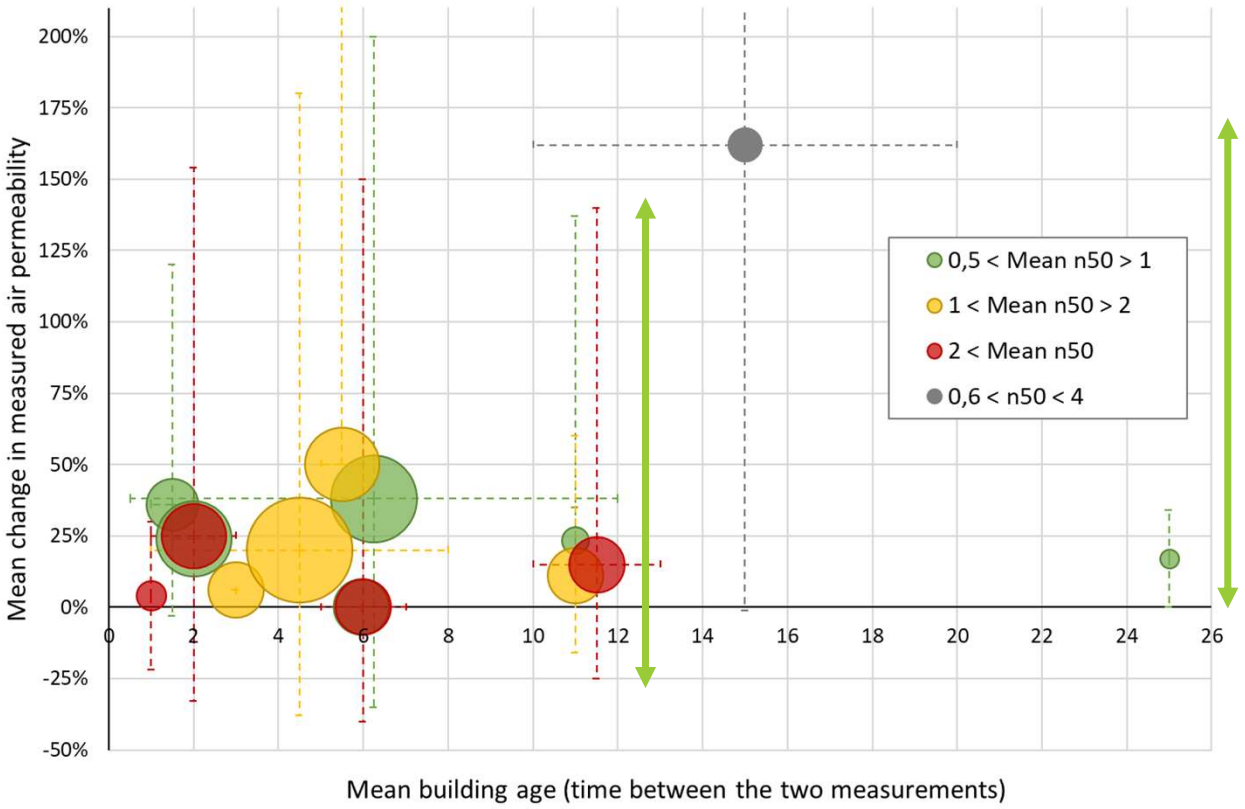
Review of on-site studies testing buildings airtightness durability



Airtightness tends to **deteriorate after completion**

→ The **mean change in air permeability is positive for all studies**. The average of all mean changes weighted by the sample size gives an increase of **24%**.

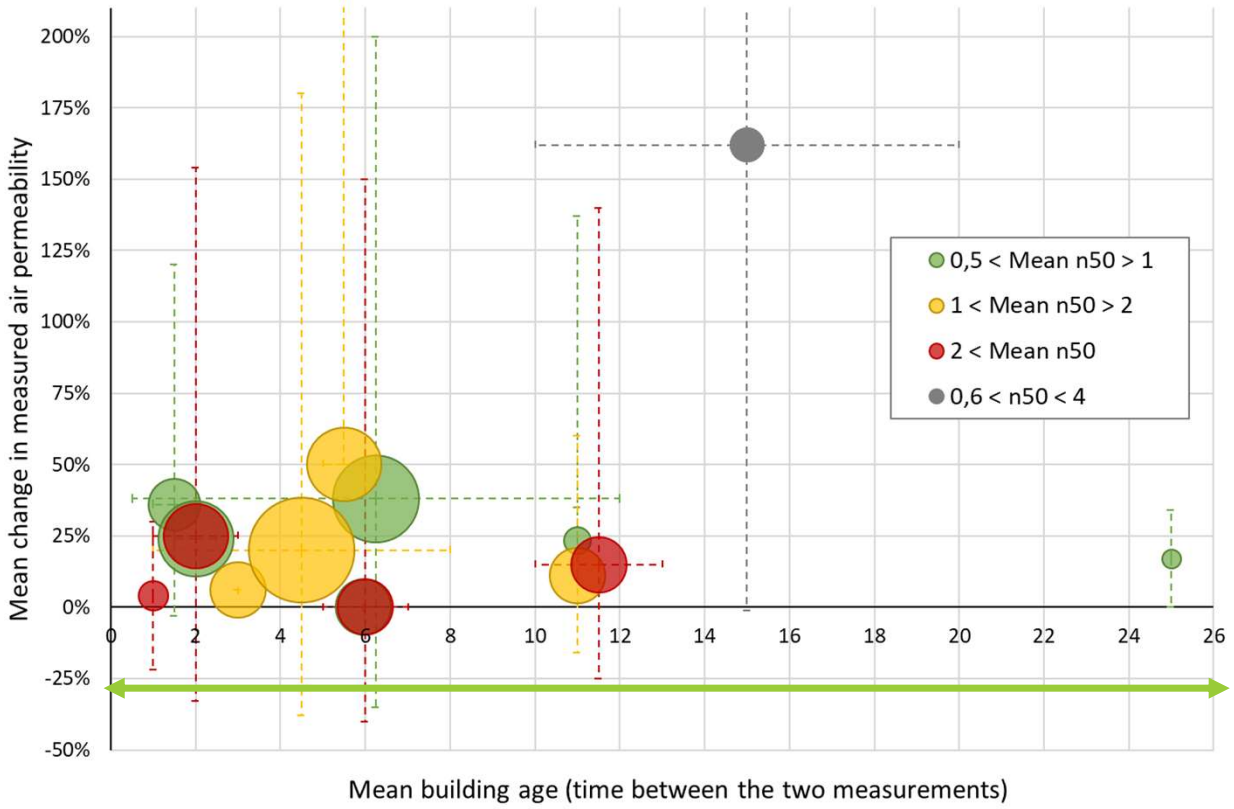
Review of on-site studies testing buildings airtightness durability



Changes in airtightness are **highly variable**

→ For each study **results differ considerably between the tested houses**, with almost always at least one presenting an improved airtightness (by up to 40%) and almost always at least one presenting a very deteriorated airtightness (by up to 580%).

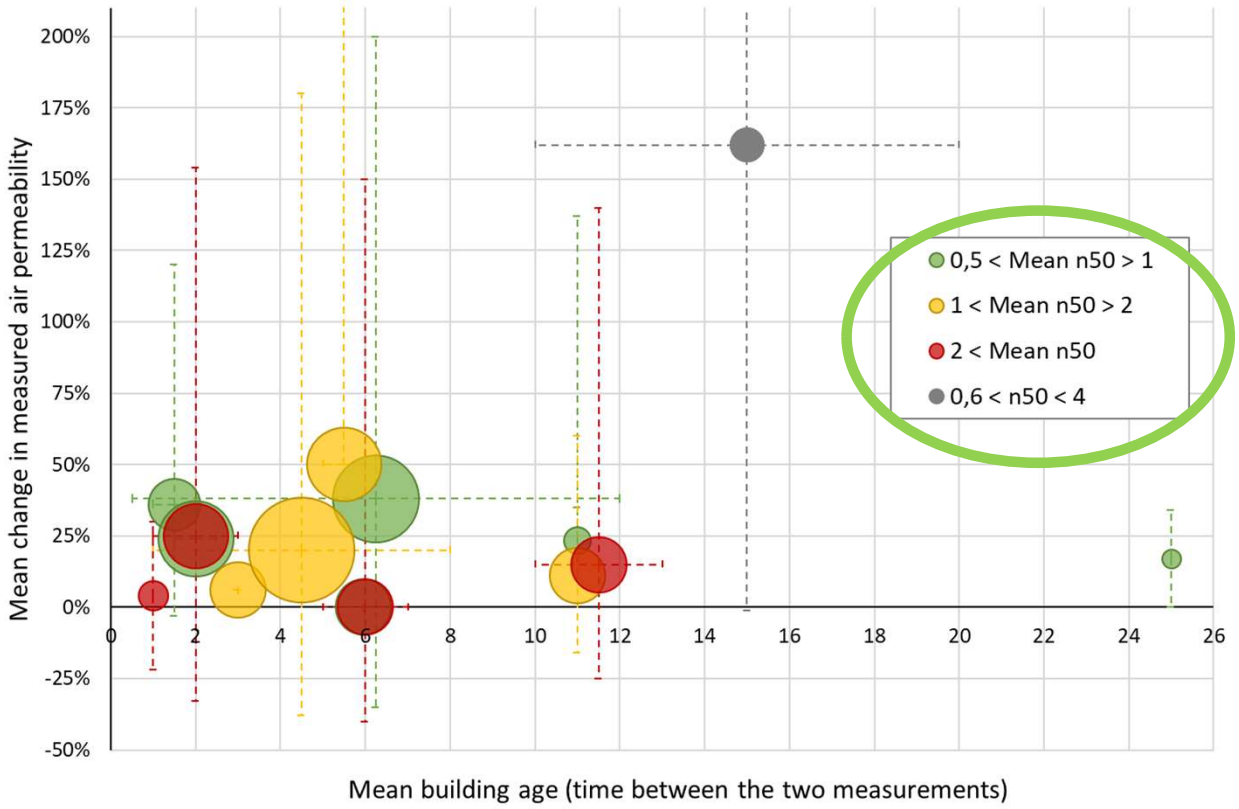
Review of on-site studies testing buildings airtightness durability



Changes in airtightness occur **quickly after construction**

→ The mean change in measured air permeability does not seem to clearly increase with the building age, which would mean that **changes occur mostly within the first (1 or 2) year(s)** of the building use. This is suggested in the study with the largest sample size (Moujalled et al., 2021) and confirmed by a study with buildings tested regularly where air permeability increased mainly in the first years (Novák, 2018).

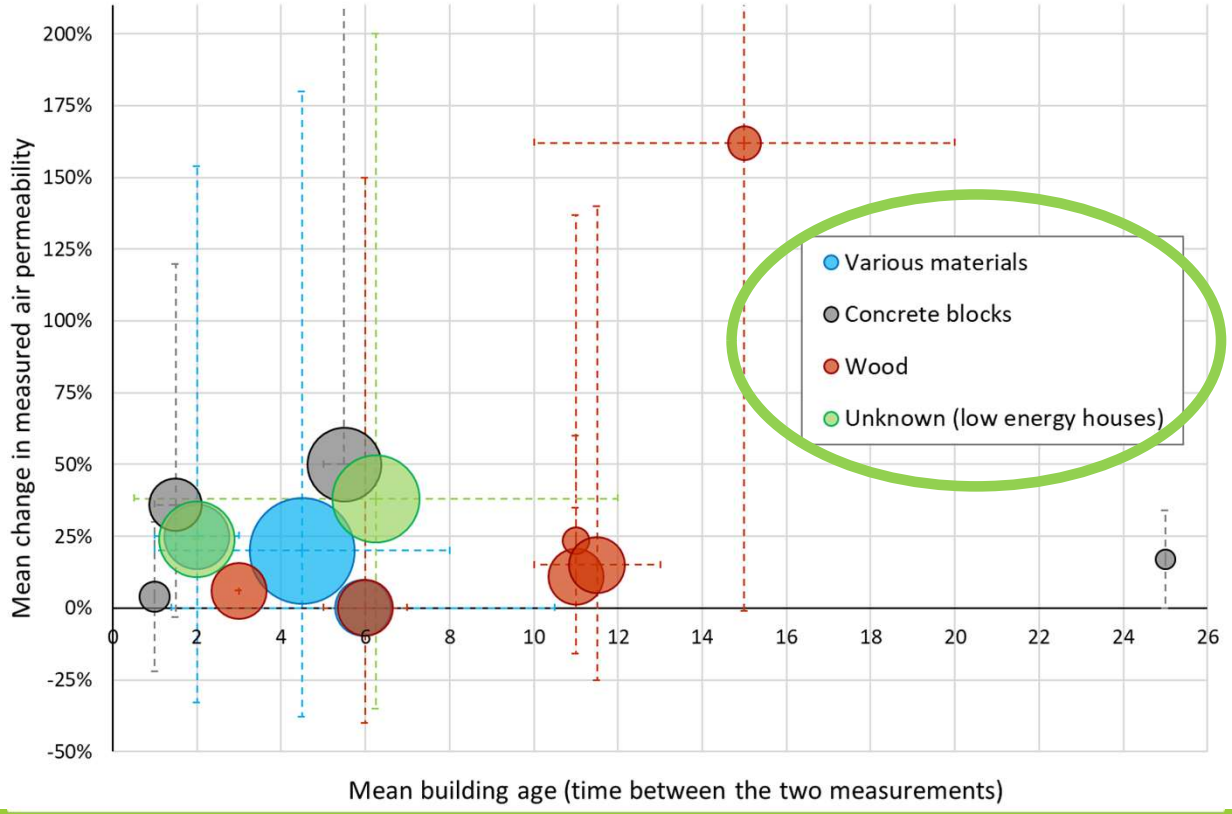
Review of on-site studies testing buildings airtightness durability



Changes in airtightness in absolute terms seem **correlated to the initial air permeability level**

→ The mean change in measured air permeability are given in percentage and there is no clear difference between the three levels of initial air permeability so **changes in absolute terms are bigger for initially more permeable buildings**.

Review of on-site studies testing buildings airtightness durability



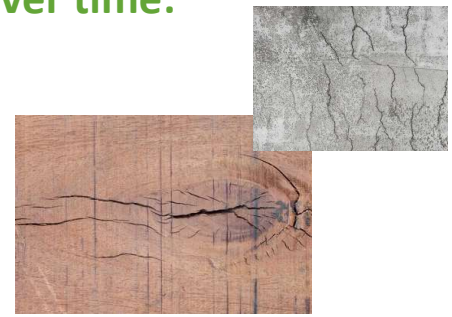
Changes in airtightness **does not seem to strongly depend on the main construction material**

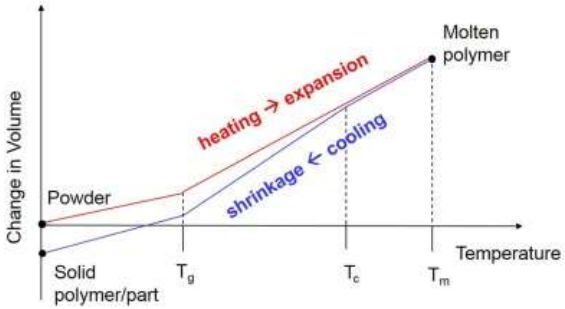
→ Both **wooden and concrete** constructions were sometimes found to have a durable airtightness and other times a strongly deteriorated airtightness.

Key factors for airtightness change over time

Possible factors of airtightness DECREASE over time:

- **Building's natural "movements":**
  - Heating houses for the first time;
  - Shrinkage of mastic
  - Structure movements and packing





- **External interventions:**
  - Drilling hole into the envelope, unless it is done with concern on the air barrier system protection (Novák, 2018).
  - Installation of cables or ductwork after the completion of the building (for example to rooftop solar panels) (Verbeke and Audenaert, 2020).

Key factors for airtightness change over time

Possible factors of airtightness DECREASE over time :

- **Specific building materials and construction types**:
  - **Uncertain impact of the number of storeys**: 2-storey houses seem to deteriorate more than 1-storey ones (Moujalled et al., 2021) but houses generally become leakier than flats (Philips et al., 2011)
  - **Air barriers made of plasterboard seem to deteriorate in average more than air barriers made of polyethylene membrane** (Proskiw, 1998) (Johnston and Lowe, 2006)) (ADEME, 2016)
  - **Air barriers made with membranes can also, however, potentially strongly deteriorate**: timber frame dwellings showed the largest change in airtightness when compared to plastered masonry (Philips et al., 2011), especially in case of exposed wood frame roofs (Moujalled et al., 2021)
- **Poor workmanship**
- **Unsuitable implementation conditions**

Key factors for airtightness change over time

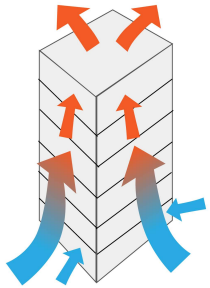
Possible factors of airtightness IMPROVMENT over time :

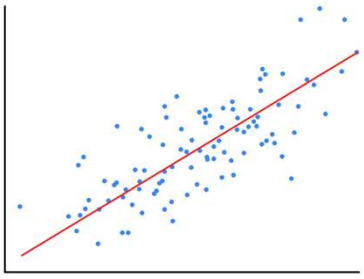
- **The settlement**: the installation of carpets and floor finishes after the original test, the presence of plugs in electrical sockets
- **Wood expansion with humidity** (Durabilit'air 1)
- The **user reducing the air inlets** to decrease the heating load (Ramos et al., 2013)

Uncertainties in airtightness testing

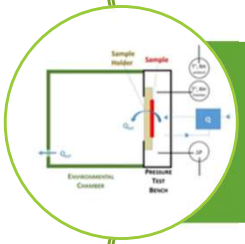
Part of the difference between tests results may not be due to the airtightness change with time but **due to test uncertainty**. Deviations in airtightness testing are due to:

- Variations in the testing protocol (including building preparation and testing equipment installation)
- Wind and thermal draft impact;
- Measurement device uncertainty;
- Seasonal variation of airtightness;
- Regression model.





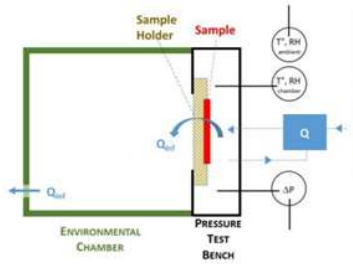
Field studies in real buildings



Experiments in a controlled environment

Implementation conditions impact

Loads on the air barrier and equivalent artificial ageing



- **Various load types:**
  - Pressure load (mechanical ageing): fatigue tests

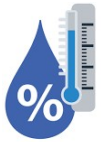
$$P_{wind} = \frac{1}{2}.\ \rho.\ Cp.v^2$$

Table 1 Fatigue test representing typical UK service loads in 50-year exposure period

	Number of cycles	Percentage of design pressure
Apply sequence five times	1	90
	960	40
	60	60
	240	50
	5	80
	14	70
Finish with	1	100

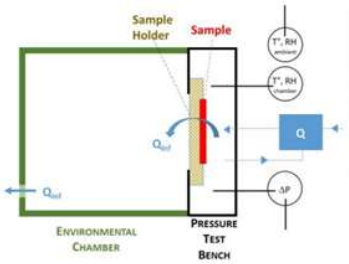
  - Thermal & humidity loads (physical ageing)
    - High temperature & RH are effective in artificial ageing of polymers, of which many adhesives consist
    - The estimation of these thermal and humidity loads is however difficult

Artificial aging at 65 °C / 80 % r.F. in days	Natural aging following ASTM D3611-89 in years	Natural aging following SATAS in years
21	10,5	3
40	20	5,7
80	40	11,4
120	60	17,1



  - Outdoor weathering loads (irradiation and wetting)
    - Some sealing products as building joints can also be used on the **outdoor side** of the wall. Durability tests should include in this case **ultraviolet (and possibly infrared) irradiation as well as wetting tests**.
    - Tapes intended for indoor vapor-barrier application can be affected by solar radiation or wetting **during the transportation, storage or construction period**.

Review of ageing tests for airtightness durability assessment



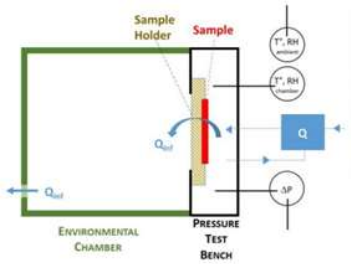
- **Artificial ageing for INDOOR air barrier components/systems**

13 studies from 8 countries

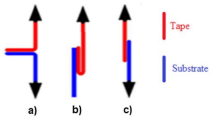
- **Ageing of OUTDOOR sealing products**

→ Less critical but can also impact the building airtightness durability

Key points for laboratory airtightness durability assessment

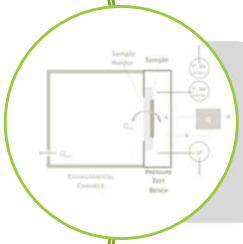


- **The airtightness durability depends on many factors and further research are needed to better define each impact:**
  Product manufacturer; compatibility problems between products; implementation conditions; type of loads



- **Importance of testing the durability of wall assemblies rather than products alone**
  Mechanical resistance tests (peel, shear, …) of products alone seem not relevant for the wall assembly durability assessment
- **All load types should be included in the protocol**
  Different impact of the various constraints (extreme temperature, humidity or pressure) depending on the air barrier type
- **Necessity to test simultaneous loads**
  More representative of reality and necessary
- **General standardised procedure is missing**
- **The ageing strategy has to be consistent with real solicitation of product**

Field studies in real buildings



Experiments in a controlled environment

Implementation conditions impact

Workmanship

4 main issues identified:

- **Workmanship quality and reproducibility**
  - The application of minor technical solutions and educational sessions allowed to reduce the specific air leakage rate by 27% on 14 houses (Colijn et al., 2017)
  - (Böhm et al., 2021) : large differences in airtightness performance for identical types of houses
    → the most important parameter influencing the resulting airtightness values was the **control of the implementation of individual building details during the construction of a building.**
- **Last minute corrections** (J. Wingfield et al., 2008)
  - **secondary sealing** may have benefits in the short-term to pass the airtightness test but is **prone to degradation** over a relatively short time

Workmanship

4 main issues identified:

- **Airtightness tests reproducibility and repeatability** (Bracke et al., 2016):
  - **Reproducibility:** with special attention to airtightness : variance coefficient of 12% on 15 buildings (VS 28% with no special attention to airtightness in (Laverge et al., 2014))
  - **Repeatability:** 2 houses tested up to 10 times a day, on respectively 7 and 6 different days → standard deviation of respectively 1.1% and 2.7% and a maximum variation within the same day of respectively 3.5% and 7.7%
  - **small preparation details** such as locking doors can be determining for passing the test for passive houses (necessity of having the same operator testing all houses when studying airtightness durability)

Workmanship

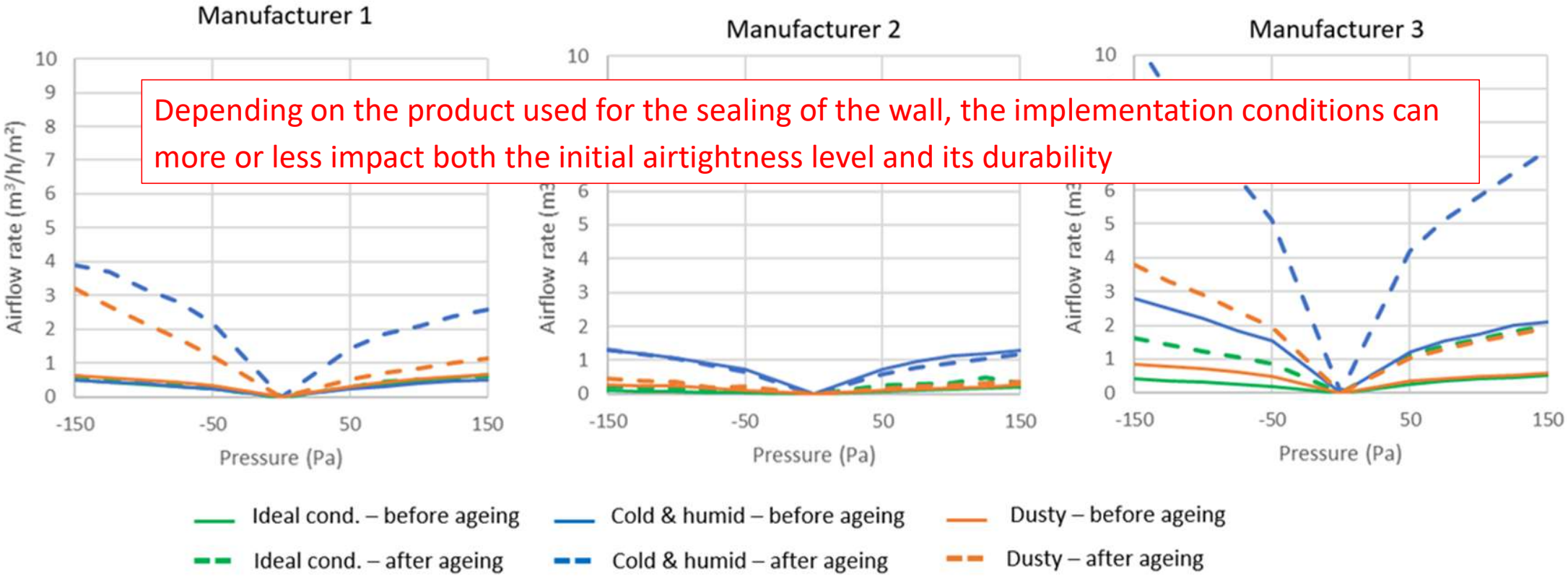
4 main issues identified:

- **Compatibility of products with implementation conditions**
  - (Fufa et al., 2018): importance of the **surface condition** for the adhesion performance with the necessity of **a good adequation between the intended and actual tape use**, and a **special treatment of the substrate** when required
  - (Van Linden and Van Den Bossche, 2020) : tested **18 sealing materials** → faulty workmanship has a significantly greater impact on the material performance than artificial ageing
  - (Nečasová et al., 2017): building joints submitted to **external environment** → *"in most tested cases, diversion from the above-given steps resulted in failure of the sealed joint"*

Temperature, humidity and dust conditions

Main study: (Antonsson and Emanuelsson, 2018)

- **Durability of 3 airtightness systems** (≠ manufacturers) tested with air permeability measurements before and after artificial ageing for 3 implementation conditions:
  - **Ideal conditions**: normal indoor laboratory climate
  - **Cold and humid environment**: about 5°C and 90-95% RH on both sides of the wall
  - **Dusty conditions**: artificial dust (made of crushed concrete sieved to a grain size of max. 0.063 mm, gypsum and wood sawdust) sprayed against the plastic foil
- The **artificial ageing** was done through heat treatment with 7 days under a temperature of 60°C for system 1 and 3 and 70°C for system 2 and a RH of 50%. The authors estimate that it is the equivalent of respectively 25 and 50 years of natural ageing.

Temperature, humidity and dust conditions

Depending on the product used for the sealing of the wall, the implementation conditions can more or less impact both the initial airtightness level and its durability