Field measurement of the durability of building airtightness - review and analysis of existing studies

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Tightvent Webinar 2020

Durabilit’air project

- 1st task of the Durabilit’air project

Founded by:

V. Leprince - Durabilit’air task 1

Objectives of the project:
- State of the art of major international research findings
- Characterizing the evolution over time in mid and long term scales by on-site measurement campaigns
- Developing a laboratory controlled method in order to test the accelerated ageing of airtightness systems;
- Disseminating the main results of this work to promote best practices.
Objective of the state of the art

- Learn from previous studies
- Improve the protocol for the other tasks of the project
  - Field measurements
  - Laboratory testing

Durability tested on site

- In situ measurement
- Measurement uncertainty, seasonal variation
IN SITU MEASUREMENTS

<table>
<thead>
<tr>
<th>Year</th>
<th>Air Change Rate</th>
<th>Percentage Change</th>
<th>Author(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>10 ACH</td>
<td>+15%</td>
<td>Chan &amp; Sherman, 2014</td>
</tr>
<tr>
<td>2007</td>
<td>6 ACH</td>
<td>0%</td>
<td>Chan &amp; Sherman, 2014</td>
</tr>
<tr>
<td>2010</td>
<td>0.6 ACH to 4 ACH</td>
<td>+36%</td>
<td>Bracke, Laverge, et al., 2016</td>
</tr>
<tr>
<td>1990</td>
<td>0.6 ACH</td>
<td>+162%</td>
<td>Hansen &amp; Ylmén, 2012</td>
</tr>
<tr>
<td>1985</td>
<td>1.5 ACH</td>
<td>+6% (3yr)</td>
<td>Prowski, 1998</td>
</tr>
<tr>
<td>2009</td>
<td>0.8 ACH</td>
<td>+11% (11yr)</td>
<td>ADEME, 2016</td>
</tr>
<tr>
<td>1990</td>
<td>0.6 ACH</td>
<td>+50%</td>
<td>Feist, Ebel, et al., 2016</td>
</tr>
<tr>
<td>2007</td>
<td>4 ACH</td>
<td>0%</td>
<td>Philips, Rogers, et al., 2011</td>
</tr>
</tbody>
</table>

Note: The diagram illustrates the changes in air change rates and their corresponding percentage changes over different years.
Building virtually identical (same craftsmen, same materials) => difference due to occupants behaviour?

Very low flowrate difference, measurement uncertainty?
Extended leakage detection: leaks appear at:
- Penetrations of the air barrier;
- Electrical appliances;
- New non-airtight appliances (hood, recessed lighting, etc.).

Half have increased, half have decreased, correlation neither with construction changes nor with age of the building.

Chan & Sherman, 2014
Chan & Sherman, 2014
Hansen & Yımén, 2012
Acrylic mastics, set on backer rod, have not deteriorated at all. Windows and doors gaskets (on the openings) have deteriorated => changed for the new test.

- Timber frame dwellings showed the largest change in airtightness compared to plastered masonry.
- Shrinking of mastic when heated for the first time? Performance improvement
- Installation of carpets and floor finishes after the original test?
Conclusion on-site ageing

- Seems that the airtightness decreases in the first years after completion and then stabilises.
- Explanation factors:
  - Heating houses for the first time may induce the shrink of mastics
  - Mastic shrinking when backer rod are not used
  - Structure movements and packing may induce cracking in the junctions between air barrier and penetrations
  - Occupants behaviour: Envelope drilling (lot in the first years), etc.
  - Unsuitable implementation conditions for adhesives and mastic (cold and/or dusty conditions).

Impact on the testing protocol

- Questionnaires to occupants to find out drillings made in the air barrier.
- 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 (use of backer road, compatibility of products)
  - Construction details
  - Period when the air-barrier was layed-out (heating period or not)?
  - Air-barrier heated prior to the first test?
Measurement uncertainty:
reference pressure of indicator

<table>
<thead>
<tr>
<th></th>
<th>4 Pa</th>
<th>50 Pa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repeatability</td>
<td>3.5%</td>
<td>1.4%</td>
</tr>
<tr>
<td>Reproducibility</td>
<td>5.9%</td>
<td>2.4%</td>
</tr>
<tr>
<td>Wind impact(10m/s)</td>
<td>Max 60%</td>
<td>Max 12%</td>
</tr>
</tbody>
</table>

Sources: Delmotte_2011, Carrié_2014, Bracke_2014
Measurement uncertainty: seasonal variation

- Impact of indoor humidity?

<table>
<thead>
<tr>
<th>Country</th>
<th>Study Year</th>
<th>Season</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweden</td>
<td>2012</td>
<td>Winter</td>
<td>-10%</td>
</tr>
<tr>
<td>USA</td>
<td>2013</td>
<td>Winter</td>
<td>-10%</td>
</tr>
<tr>
<td>Belgium</td>
<td>2013</td>
<td>Winter</td>
<td>-20%</td>
</tr>
<tr>
<td>USA</td>
<td>1986</td>
<td>Winter</td>
<td>-40%</td>
</tr>
<tr>
<td>Sweden</td>
<td>2012</td>
<td>Summer</td>
<td>+20%</td>
</tr>
<tr>
<td>USA</td>
<td>2013</td>
<td>Summer</td>
<td></td>
</tr>
<tr>
<td>Belgium</td>
<td>2013</td>
<td>Summer</td>
<td></td>
</tr>
<tr>
<td>USA</td>
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<td>Summer</td>
<td></td>
</tr>
<tr>
<td>Sweden</td>
<td>2012</td>
<td>Summer</td>
<td></td>
</tr>
</tbody>
</table>

\[ \frac{Q_{50}}{Q_{50}} = 0.991 \cdot \left( \frac{W_i}{W_f} \right) \]

Impact on the testing protocol

- Reduce measurement uncertainty
  - Same qualified tester perform tests;
  - Reports precisely describe building preparation including locked and unlocked external doors.
  - Measurement devices calibrated according ISO 9972.
  - Measurements in low wind conditions.
  - Airtightness compared at 50Pa rather than 4 or 10 Pa.
    - In flowrate at 50 Pa rather than ratio (n50 or q50) take into account uncertainty
  - Average of pressurisation and depressurisation test
  - Better to perform test at the same season.
Conclusions

Airtightness changes through years

• Seems to decrease in the first years and then stabilise
• On site analysis required to explain measurement results

Low uncertainty required for interpretation

• 50 Pa indicator more reliable
• Test at same season if feasible

Thank you for your attention!

Questions?

Source: AIVC 2017 – Nottingham:
Publication available on Airbase

https://www.aivc.org/resource/durability-building-airtightness-review-and-analysis-existing-studies
DURABILITY AND MEASUREMENT UNCERTAINTY
OF AIRTIGHTNESS IN EXTREMELY AIRTIGHT DWELLINGS

Wolf Bracke, Jelle Laverge, Nathan Van Den Bossche, Arnold Janssens

presenter: Wolf Bracke / 30 January 2020

OUTLINE

• Introduction
• Test repeatability and seasonal variations
• Durability of airtightness
• Conclusions
**INTRODUCTION**

- Airtightness important to meet energy performance requirements
- Increasing number of new houses with airtightness test
- Result of test may have financial consequences (fines, subsidies)
- Reliability of test?
- Long-term performance of airtightness, specifically for airtight houses?

**LITERATURE REVIEW**

- Repeatability (EN13829, method A)
  - St. deviation: 2%
  - Max. variation: 4%
- Reproducability (EN13829, method A)
  - St. deviation: 3%
  - Max. variation: 8%
- Seasonal variation
  - Max. variations: 18%
  - Swelling-shrinkage of wood
- Durability
  - No conclusive results

(Delmotte and Laverge 2011)

(Kim and Shaw 1986)
OUTLINE

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TEST OBJECTS

• Semi-detached passive show house
  • Masonry construction
  • $ACH_{50} = 0.55 \ (°2009)$
• Detached passive show house
  • Woodframe construction
  • $ACH_{50} = 0.21 \ (°2009)$
INFLUENCE OF BUILDING PREPARATION

- EN13829: room for interpretation
  - locking of external doors
  - disconnecting the ventilation system: central or decentral air supply/exhaust
  - position of blower door
  - filling water locks

- Apparently small differences in preparation
- Relatively large impact on measured leakage in passive houses
- $\Delta V_{50}$ of 50 m³/h represents 20 to 35% change in ACH50
REPEATABILITY AND SEASONAL VARIATION
MASONRY HOUSE

- 10 days in 15 months
- 58 tests in total
- Repeatability in line with literature
  - Day 1: 12 measurements
    - Stdev: 1%, max var: 4%
- Variation result of changes in ductwork connections?

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REPEATABILITY AND SEASONAL VARIATION
MASONRY HOUSE

- 9 test days in 15 months
- 53 tests in total
- Repeatability in line with literature
  - Day 2: 12 measurements
    - Stdev: 2%, max var: 5%
- No seasonal variation
OUTLINE

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TEST OBJECTS FOR ANALYSIS OF DURABILITY

• 15 inhabited dwellings from passive house estates
  ○ +2 show houses
• Semi-detached and terraced masonry construction
• Age 3 - 27 months
• New test results compared to original certification tests
DURABILITY OF AIRTIGHTNESS

- Average increase in air leakage by 32%
- Workmanship reproducibility: stdev original measurements = 19%

![Graph showing air leakage rates over test objects]

DURABILITY OF AIRTIGHTNESS: RELATIVE INCREASE

- No significant relation with age
- Part of increase might be explained by differences in building preparation
  - Ventilation systems
  - Locking doors
- Observed leakage
  - Operable doors
  - Service penetration

![Graph showing relative increase in air leakage over age (months)]
CONCLUSIONS

• Study on air leakage in extremely airtight houses
• Relative repeatability intervals in line with literature
  o More specific building preparation guidelines needed for better reproducibility of ambitious leakage requirements
• No clear evidence of seasonal variation of air leakage
• Long-term performance of airtightness
  o 90% of houses showed larger leakage over time
  o Relative degradation of airtightness, but small in absolute values
  o Hard to exclude the impact of building preparation
Assessment of long-term and mid-term building airtightness durability: field study of 61 French low energy single-family dwellings

Bassam Moujalled*, Sylvain Berthault, Andrés Litvak, Valérie Leprince, and Gilles Frances

*bassam.moujalled@cerema.fr

Introduction

- The French research project DURABILITAIR (2016-2019)
  - to improve our knowledge on the variation of buildings airtightness through onsite measurement campaigns (Task 2) and accelerated ageing in laboratory controlled conditions (Task 3)
- Literature review (task 1) showed an important evolution over time of the air permeability in real buildings, especially in the first 3 years
- The second task of the project deals with the quantification and qualification of the durability of building airtightness of single detached houses through field measurement at:
  - mid-term scale (MT)
  - long-term scale (LT)
Methodology

▪ MT and LT measurement campaigns based on two samples of single-detached low-energy dwellings:
  ✓ All dwellings measured upon completion [measurement n0] and treatment of airtightness well known

▪ MT measurement campaign (1-3 years):
  ✓ Sample of 30 new single-detached dwellings
  ✓ The airtightness of each dwelling was measured once per year over the 3-year period [measurements n1, n2 & n3]
  ✓ Five dwellings were measured twice per year (impact of seasonal variations)
  ✓ For six dwellings, the airtightness of an installed window was measured once per year over the 3-year period

▪ LT measurement campaign (5-10 years):
  ✓ Sample of 31 single-detached dwellings constructed during the last 10 years
  ✓ The airtightness of each dwelling was measured once [measurement nx]

▪ Measurement protocol based on ISO 9972 and its French implementation guide, with additional requirements:
  ✓ Measurements to be performed under the same conditions as the measurement upon completion n0 both in pressurization and depressurization
  ✓ Detailed qualitative leakage detection to be performed
  ✓ Questionnaires for occupants to be filled at each measurement regarding the action of the occupants on building envelope
RESULTS

Characteristics of buildings

Year of construction

![Bar chart showing number of dwellings by year of construction and average timespan between measurements.](chart.png)

- **Average timespan between measurements**
  - **MT sample:**
    - n0-n1: 1.7 yr (from 1.1 to 2.7)
    - n1-n2: 0.7 yr (from 0.4 to 1.2)
    - n2-n3: 0.9 yr (from 0.4 to 1.7)
    - n0-n3: 3.4 yr (from 2.8 to 4.2)
  - **LT sample:**
    - n0-nx: 4.6 yr (from 2.6 to 8)
Characteristics of buildings

Type of material & air barrier

- **Mid-Term**
- **Long-Term**

<table>
<thead>
<tr>
<th>Material</th>
<th>Air barrier-A</th>
<th>Air barrier-B</th>
<th>Air barrier-C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brick</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Wood</td>
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<tr>
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</tr>
</tbody>
</table>

**MT sample:**
Masonry walls with interior insulation: Airtightness by plasterboards and mastics at the inside facing of the walls (C)

**LT sample:**
Masonry walls with interior insulation: Airtightness by coating on the masonry (B) or by plasterboards and mastics at the inside facing of the walls (C)

Wood frame houses with insulation between studs: Airtightness by the vapour barrier (A)

Evolution in $q_{50}$

**MT sample**

Evolution of mean $q_{50}$:
- $n_0-n_1$: +58.9 m$^3$.h$^{-1}$ / +18% ($p$-value = 0.037)  
  Timespan = 1.7 years
- $n_0-n_2$: +57.2 m$^3$.h$^{-1}$ / +18% ($p$-value = 0.026)  
  Timespan = 2.7 years
- $n_0-n_3$: +60.4 m$^3$.h$^{-1}$ / +19% ($p$-value = 0.037)  
  Timespan = 3.4 years

Measurement:
- 1-Press
- 2-Depress
- 3-Average
**Evolution in $q_{50}$**

**LT sample**

Evolution of mean $q_{50}$:

n0-nx: +67.7 m³ h⁻¹ / +20%  
(p-value = 0.002)  
Timespan = 4.6 years

**Evolution in $q_{50}$ vs. Timespan**

**MT & LT samples**

No correlation between the evolution in $q_{50}$ and the age of the houses for both MT and LT samples.
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**Analysis of explanatory factors**

**MT sample**

Δq_{50} < -50 m³/h⁻¹
5 houses

-50 < Δq_{50} < +50
13 houses

+50 < Δq_{50} < +150
6 houses

Δq_{50} > +150 m³/h⁻¹
5 houses

1-storey (20)
2-storey (10)

2-storey houses seem to deteriorate more than 1-storey houses → Structural movement?

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**Analysis of explanatory factors**

**Nb. Of levels (MT)**

Δq_{50} < -50 m³/h⁻¹
5 houses

-50 < Δq_{50} < +50
13 houses

+50 < Δq_{50} < +150
6 houses

Δq_{50} > +150 m³/h⁻¹
5 houses
### Analysis of explanatory factors

#### Type of roof (MT)

- **Light frame (20)**
- **Traditional wood frame (8)**
- **Exposed Traditional wood frame (2)**

2 exposed wood frame houses with same type of air barrier: +20\% vs +180\%

→ conditions of implementation?

#### Type of material (LT)

- **Wood frame (6)**
- **Hollow bricks (21)**
- **Concrete blocks (3)**

Wood houses tend to stabilise or even improve over years

→ expansion of wood with humidity?

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**Evolution of leakages**

*MT sample: n3-n0*

**Increase of leakages C, F, D & G**

**NO CORRELATION with the evolution in q50**

<table>
<thead>
<tr>
<th>Δq50</th>
<th>Evolution in nb. of leakages</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 50 m³·h⁻¹</td>
<td></td>
</tr>
<tr>
<td>50 &lt; Δq50 &lt; +50</td>
<td></td>
</tr>
<tr>
<td>+50 &lt; Δq50 &lt; +150</td>
<td></td>
</tr>
<tr>
<td>&gt; +150 m³·h⁻¹</td>
<td></td>
</tr>
</tbody>
</table>

**B: junctions wall/slab**

**C: doors and windows**

**D: penetration through envelope**

**E: trapdoor**

**F: electrical components**

**G: junctions wall/window**

**H: other leakages**

**CONCLUSIONS**
Conclusions

- Same evolution of airtightness at mid and long term
  ✓ Similar increase in $q_{50}$ at mid and long-term (+18% and +20% respectively)
  ✓ No correlation with the age of construction
  ✓ Deterioration mainly during the first 2 years and then stabilisation

- Significant increase in the number of leakages for:
  ✓ Doors and windows, electrical components, penetrations through envelope & junctions between walls and windows
  ✓ But no correlation with the variation in $q_{50}$
Thanks...

Projet DURABILIT’AIR
https://www.durabilitair.com/

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