Assessment of long-term and mid-term building airtightness durability: field study of 61 French low energy single-family dwellings

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ABSTRACT

The French ongoing research project "Durabilit'air" (2016-2019) aims at improving our knowledge on the variation of buildings airtightness through onsite measurement and accelerated ageing in laboratory controlled conditions. This paper presents the final results of the second task of the project. This task deals with the quantification and qualification of the durability of building airtightness of single detached houses. It is done through field measurement at mid-term (MT) and long-term (LT) scales.

We first present the field measurement protocol. For the MT campaign, a sample of 30 new single-detached houses has been selected nationwide. During the study, the airtightness of each building was measured once per year over a 3-year period. A part of this sample (5 houses) was also measured twice per year during two different seasons in order to investigate the impact of seasonal variation. In addition, the air permeability of a window was measured once per year over the 3-year period in 5 houses. The LT campaign was carried out with a second sample of 31 existing single-detached houses constructed during the last 10 years. The airtightness of each house was measured once.

A specific measurement protocol was defined after a detailed literature review. The main challenge is to understand the variations of the airtightness and to identify whether it is related to the products/assembly ageing, the maintenance conditions or other factors such as the occupants' behaviour. The protocol is based on the standard ISO 9972 for the measurement method of building air permeability with additional requirements for the measurement conditions. It also includes a detailed qualitative leakage detection and questionnaire for occupants.

Secondly, this paper presents the construction characteristics of both samples. All houses were tested upon completion. The air changes per hour at 50 Pa pressure difference (n_{50}) of both samples show the same mean value of 1.4 h^{-1}, with larger variations among the LT sample.

Finally, we discuss measurement results. Regarding MT sample, the air permeability slightly increases during the first year (mean increase by 18%), and then stabilizes during the second and third year. However, for some houses with exposed timber framing, n_{50} has increased by more than 100%. Regarding LT campaign, the air permeability (n_{50}) show a similar increase after 3-10 years with a mean value of 20%. Measurements performed during two different seasons did not show a significant impact of seasonal variation. The results show globally an increase in the number of detected leakages for all houses, but this increase is not always correlated with the change in air permeability. For 10 houses of both samples, the building airtightness has improved. For 6 houses, this improvement is maybe due to the building material (wood), the maintenance of windows, or the sealing of leaks by occupants but for 4 houses, we have not been able to explain this improvement.

KEYWORDS

Airtightness durability, field measurements, building envelope, low-energy house

1 INTRODUCTION

The increasing weight of building leakages energy impact on the overall performance of low-energy buildings led to a better understanding and characterization of the actual airtightness performance of buildings. Several European countries have already included in their Energy Performance regulation (EP-regulation) mandatory requirements regarding the building airtightness. This is the case in France, where the EP-regulation requires a limit airtightness level for residential buildings that must be justified by measurement. However, low expertise is available today on the durability of building airtightness and its evolution in mid- and long-term scales.

The French ongoing research project “Durabilit'air” is conducted since 2016 for a 42-month period, in order to improve our knowledge on the variation of buildings airtightness through onsite measurement campaigns and accelerated ageing in laboratory controlled conditions.

As part of this project, a comprehensive literature review about building airtightness durability was realized by (Leprince et al., 2017). This review showed an important evolution over time of the air permeability in real buildings, with an increase of more than twice in some cases. The air permeability seems to increase in the 3 first years and then stabilise.

This paper is issued from the second task of the “Durabilit'air” project. This task deals with the quantification and qualification of the durability of building airtightness of single detached houses. It is done through field measurement at mid-term and long-term scales. This paper presents the results of both MT and LT measurements.

2 METHODOLOGY

2.1 Onsite measurements

In order to evaluate the durability of the building airtightness in real conditions at mid- and long-term scales, two field measurement campaigns were conducted: a mid-term (MT) campaign and a long-term (LT) campaign.

The MT campaign aims at characterising the yearly evolution of building airtightness of new dwellings over a 3-year period. Therefore, a sample of 30 new single-detached low-energy houses, measured upon completion, has been selected nationwide. The following measurements were performed:

- The airtightness of each building was measured once per year over the 3-year period.
- Five buildings of this sample were measured twice per year in order to investigate the impact of seasonal variations.
- For five buildings (four buildings from this sample plus one additional building), the airtightness of an installed window were measured once per year over a 3-year period.

The LT campaign aims at characterising the evolution of building airtightness of existing dwellings over a longer period from 3 to 10 years. A second sample of 31 existing single-detached dwellings, measured upon completion, has been therefore selected. The dwellings have been constructed during the last 10 years. The airtightness of each dwelling was measured once.

All dwellings were selected according to well-defined criteria to reduce uncertainties about main factors impacting building airtightness. In particular, all dwellings should be tested upon completion, and the test reports should be available and in accordance with the standard ISO 9972 (NF EN ISO 9972, 2015) and its French implementation guide (FD P50-784, 2016). Information about the treatment of the building airtightness must also be available.

The main challenge of this project is to understand the variation of the airtightness and to identify whether it is related to the products/assembly ageing, the maintenance conditions or other factors such as the occupants' behaviour. Therefore, a specific measurement protocol was defined after a detailed literature review (Leprince, Moujalled, & Litvak, 2017). The protocol is mainly based on the standard ISO 9972 and its French implementation guide for the measurement method with additional requirements for the measurement conditions in order to reduce uncertainty due to measurement procedure:

- Each dwelling is to be measured under the same conditions as the first measurement upon completion as far as possible (same tester, same calibrated measurement device, same building preparation, same pressure difference sequences, and same season). Measurements are to be performed in both pressurization and depressurization. Deviations from the conditions of the first test are to be reported.
- Detailed qualitative leakage detection is to be performed at each measurement according to the leaks categories of the French implementation guide of ISO 9972 (FD P50-784, 2016). In particular, an annual follow-up of leaks is to be performed for the dwellings of MT sample during the 3 years.
- Questionnaires for occupants are to be filled at each measurement in order to identify the modifications of the building envelope due to the action of the occupants (i.e. drillings made in the air barrier after the first test, replacement of products…).

At the total, 84 and 31 measurements of building airtightness were performed for MT and LT samples respectively, plus an extra of 10 measurements for the seasonal impact, and an another extra of 15 measurements for the airtightness of windows.

2.2 Results analysis

The results presented here are expressed according to the airflow at 50 Pa (q_{50}) for which the measurement is more reproducible than at 4 Pa (Delmotte & Laverge, 2011).

For the MT sample, four measurements are carried out on each building: just after completion of the building (reference measurement n_0), then at 1 year (measurement n_1), 2 years (measurement n_2) and 3 years (measurement n_3) after completion. For the LT sample, two measurements are carried out on each building: just after completion of the building (reference measurement n_0), then at 3 to 10 years after completion (measurement n_x).

Boxplots are used to graphically summarise the main descriptive statistics of measured air leakage rates q_{50} for each measurement of both samples. It shows means alongside medians and quartiles. One-sided paired t-test (95% confidence level) is performed to analyse the statistical significance of the increase in the mean q_{50} between the reference measurement n_0 and the other measurements of each sample. Shapiro test is also performed to check the normality of the samples of measurements.

Multiple linear regression is performed to analyse the correlation between the evolution in the measured air leakage rates q_{50} and the evolution in the numbers of detected leakages.

Regarding the measurements of seasonal variations and windows, no statistical analysis is performed as the sample size is small for both (5 buildings in each case). We will only look at the evolution of the measured air leakage rates per each building.

3 RESULTS

3.1 Main characteristics of buildings

Figure 1 shows the distribution of buildings of MT and LT samples according to the year of construction and buildings main material and type of air barrier.

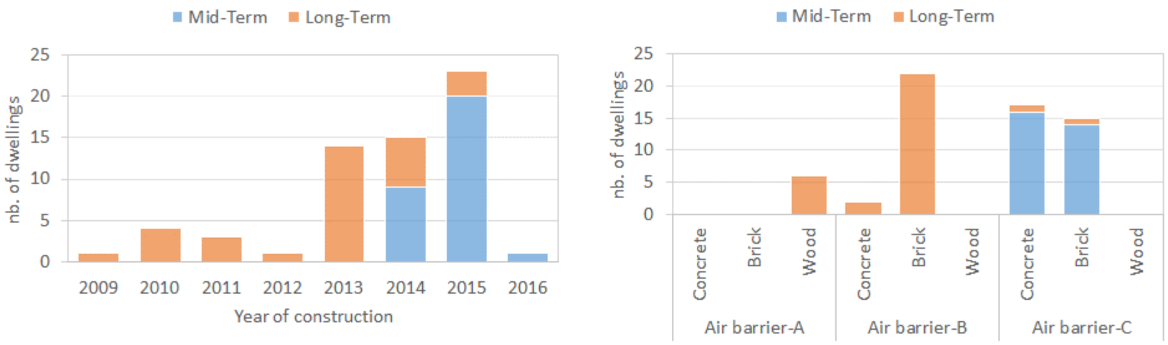

Figure 1: Distribution of buildings depending on the year of construction (left) and buildings main material and type of air barrier (right); Air barrier-A when the air barrier is ensured by vapour barrier, Air barrier-B by coating on the masonry, and Air barrier C by plasterboards and mastics at the inside facing of the walls

The MT sample is composed of 30 new single-detached low-energy houses constructed mainly in 2014 and 2015, with 20 one-story houses and 10 two-story houses. The average floor area is 124.1 m² with a minimum of 87 m² and a maximum of 172.2 m², and the average volume is 217.1 m^3 with a minimum of 156.1 m^3 and a maximum of 363.9 m^3. All houses are built of masonry with interior insulation (16 houses with concrete blocks and 14 with hollow bricks). The majority of roofs are made of light-frame wood truss (20 houses), against 8 houses with traditional wood frame and 2 houses with an exposed traditional wood frame. Single exhaust ventilation system with humidity control is installed in all houses. The airtightness is done through plasterboards and mastics at the inside facing of the walls in all houses (air barrier C).

The LT sample is composed of 31 single-detached low-energy houses constructed between 2009 and 2015, with 7 one-story houses and 25 two-story houses. The average floor area is 147.9 m² with a minimum of 83.1 m² and a maximum of 269 m², and the average volume is 256.6 m^3 with a minimum of 138.9 m^3 and a maximum of 478.2 m^3. The majority of houses are built of masonry with interior insulation (25 houses with hollow bricks and 3 with concrete blocks), against 6 wooden houses. The majority of roofs are made of light-frame wood truss (27 houses), against 5 houses with flat roof. A balance ventilation system is installed in 1 house while all other have a single exhaust ventilation system with humidity control. The airtightness of masonry houses of the LT sample is mainly done by coating on the masonry (air barrier B), while the airtightness of wooden houses is done by the vapour barrier (air barrier A).

The measurements upon completion (measurement n_0) of both samples showed the same mean value of the air changes per hour at 50 Pa n_{50} of 1.4 h^{-1}, with larger variations among the LT sample (standard-deviation of 0.65 h^{-1} for LT sample against 0.33 h^{-1} for MT sample).

For MT sample, 1st-year measurements (measurements n_1) started in November 2016 and finished in October 2018, thus from 1 to 3 years after the measurements n_0 upon completion. The measurements were delayed due to the difficulty in finding occupants willing to be involved in a 3 year-long measurement campaigns. Thus, the average timespan between measurements n_0 and n_1 is 1.7 years, and the average timespans between the following measurements are less than one year to compensate for the delay (0.7 year between n_1 and n_2, and 0.9 year between n_2 and n_3). For three houses, measurements n_2 and n_3 were not carried out because of the withdrawal of occupants during the project. Besides, a house was excluded from the MT sample because of problems during measurement n_1.

For the LT sample, all measurements (measurements n_x) were conducted in 2017, from 3 to 8 years after n_0 (average timespan of 4.6 years between n_0 and n_x). Only 9 houses older than 5 years were measured. As for MT, it has been difficult to find houses, fulfilling selection criteria with volunteer occupants. A house was excluded from the LT sample because of problems during measurement n_x.

3.2 Evolution of envelope air permeability

Figure 2 and Figure 3 show the boxplots of the measured air leakage rates at 50 Pa q_{50} for the different measurements of MT and LT sample respectively.

For the measurements n_0, tests were performed by either pressurisation or depressurisation unlike the other measurements where tests were performed by both pressurisation and depressurisation. Boxplots show the results of the measurements n_1, n_2 and n_3 for MT sample, and n_x for LT sample, for the same houses tested by pressurisation or depressurisation at n_0, in order to be comparable to the reference measurements n_0.

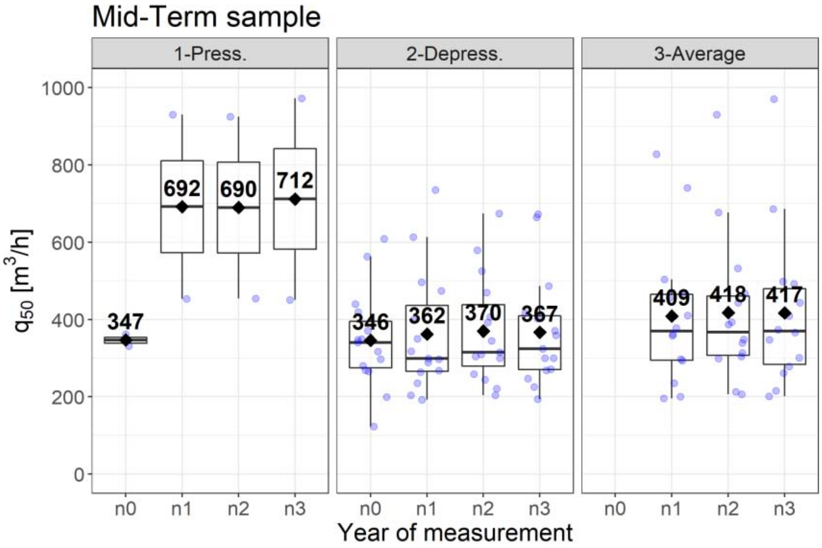

Figure 2: Boxplot of the measured air leakage rates at 50 Pa q_{50} for the measurements n_0, n_1, n_2 and n_3 of the MT sample for the pressurization test, the depressurization test and the average between both tests.

For the MT sample, when considering both pressurisation and depressurisation measurements at n_0, we can observe a significant increase in the mean q_{50} between the measurements n_0 and n_1 by 58.9 $m^3.h^{-1}$, i.e. +18% ($p\text{-value} = 0.037 < 0.05$), than a stabilization of q_{50} at n_2 and n_3. For the LT sample, we observe similar results as MT sample with a significant increase in the mean q_{50} between n_0 and n_x by 67.7 m^3/h, i.e. +20% ($p\text{-value} = 0.002 < 0.05$).

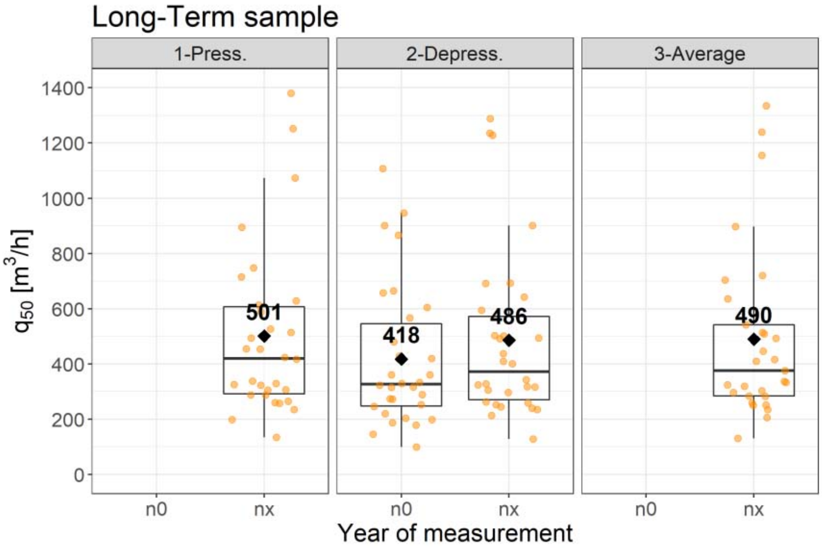

Figure 3: Boxplot of the measured air leakage rates at 50 Pa q_{50} for the measurements n_0 and n_x of the LT sample for the pressurization test, the depressurization test and the average between both tests

Figure 4 shows a lack of correlation between the evolution in q_{50} and the age of the houses for both MT and LT samples. Therefore, the air permeability does not seem to change with the age of the building; it varies mainly during the first two years of the building, and then stabilizes, as observed in previous studies (Leprince, Moujalled, & Litvak, 2017). Variations during the first two years may have several origins, including actions by the occupants when they move in the building (e.g. installing furniture, picture frames, downlight…), the first heating of the building or the first seasonal cycles.

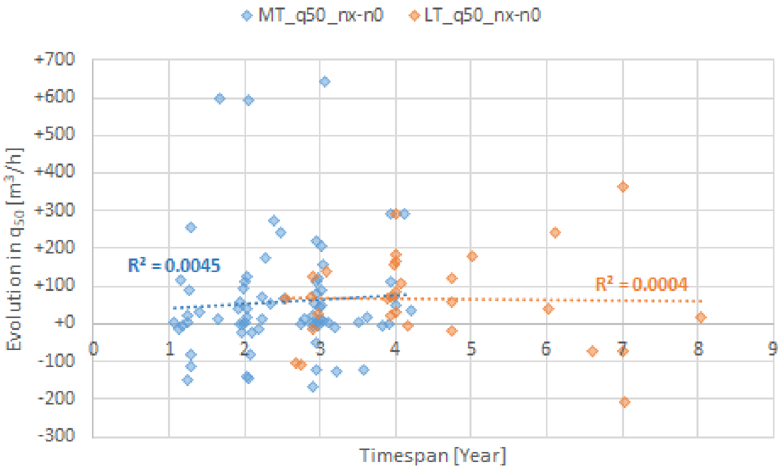

Figure 4: Measured evolution in q_{50} for MT and LT samples according to the age of the houses (timespan between the measurement at completion n_0 and the other measurements n_x)

3.3 Analysis of explanatory factors

As there is almost no evolution between the results of n_1, n_2 and n_3 for the MT sample, we will focus in the analysis on the evolution between n_0 and n_1.

Tables 1 and 2 show the evolution in q_{50} in relation to the main characteristics of the houses (constructor, number of levels, type of air-barrier, type of material, type of floor, type of roof, type of heating, specific HVAC equipment) and modifications by the occupants (modification on windows, modification on walls). The houses in the table are sorted in ascending order of the evolution in q_{50}. They are classified into 4 categories depending on the evolution in q_{50}:

- significant decrease of q_{50} (< -50 $m^3.h^{-1}$): 5 houses for the MT and LT samples each;
- no or little variations of q_{50} (-50 to $+50$ $m^3.h^{-1}$): 13 houses for MT sample and 8 houses for LT sample;
- moderate increase of q_{50} ($+50$ to $+150$ $m^3.h^{-1}$): 6 houses for MT sample and 10 houses for LT sample;
- strong increase of q_{50} ($> +150$ $m^3.h^{-1}$): 5 houses for MT sample and 7 houses for LT sample.

It is difficult to make statistical analysis to identify the impact of different factors on the evolution in q_{50} due to the small size of the samples regarding the factors.

For the MT sample, we are generally observing an upward trend of q_{50} for 2-storey detached houses with exposed wood frame. For the two houses with exposed wood frame of this sample (MICT06 & MICT19), MICT06 has become much leakier (q_{50} at n_1 almost 4 times higher than n_0), mainly because of leakages appearing at the junction between the wood and the plasterboard (shrinkage of mastic). While the airtightness level of MICT19 has remained almost stable between n_0 and n_1. Knowing that both houses are tighten with the same method, the conditions of implementation of the air-barrier seem to have an impact on the durability of the airtightness. Unfortunately, it was not possible for us in this study to collect information on the

conditions of implementation; our knowledge was limited to the type of treatment of the airtightness from the technical plans, without having information about the products and their implementations. Therefore, it would be interesting to investigate this factor in future studies.
For the LT sample, we observe that the airtightness of wooden houses (6 houses) has generally remained stable and even improved for 2 houses. It is interesting to notice that laboratory testing has come to same conclusion on wood structure (Litvak, Allègre, Moujalled, & Leprince, 2019) and it may be due to the expansion of wood with the humidity that would expand the wood and therefore reduce leakages.

Table 1: Evolution in q50 for MT according to buildings mains characteristics and modifications by occupants (M1: concrete block – M2: bricks – M3: wood construction – F1: floor on crawl space – F2: Slab on grade – F3: Cellar – R1: light-frame wood truss – R2: Traditional wood frame – R3: Exposed wood frame – R4: Flat roof – H1: Heat pump - H2: Gas boiler – H3: Wood stove – H4: Electric heating – E1: Thermodynamic water heater – E2: Heat pump water heater – E3: Electric heat water – E4: Solar thermal – E5: Solar PV – E6: DHW by gas boiler – M: Maintenance – R: Replacement – D: Drilling)

	Δq50_n1-n0 < -50 m3/h					-50 m3/h < Δq50_n1-n0 < 50 m3/h												
	MICT28	MICT10	MICT27	MICT21	MICT24	MICT07	MICT13	MICT04	MICT03	MICT17	MICT09	MICT25	MICT12	MICT02	MICT29	MICT26	MICT19	MICT30
Δq50_nx-n0 $[m^3 \cdot h^{-1}]$	-151	-146	-112	-93	-81	-22	-15	-13	-4	-2	0	3	3	3	13	23	31	46
Constructor	C11	C2	C11	C9	C9	C2	C5	C8	C2	C6	C2	C11	C5	C3	C9	C11	C5	C9
Nb. of levels	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0
Type of air-barrier	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Type of material	M2	M2	M2	M2	M1	M2	M1	M1	M2	M1	M2	M2	M1	M1	M1	M2	M1	M1
Type of floor	F1	F2	F1	F2	F2	F2	F1	F2	F2	F1	F2	F1	F1	F2	F2	F1	F1	F2
Type of roof	R1	R1	R1	R1	R1	R1	R2	R1	R1	R1	R1	R1	R1	R2	R1	R1	R3	R1
Type of heating	H1	H4	H1	H1	H1	H1	H1	H2	H3	H2	H1	H1	H2	H1	H1	H1	H2	H3
HVAC Equipement	E2	E3	E2	E2	E2	E2	E1	E1	E1	E4	E1	E1	E1	E2	E1	E1	E1	E1
Modif_Window	M			M					R						R			
Modif_Walls	D		D	D	D		D	D	D	D	D	D	D	D	D			D

	50 m3/h < Δq50_n1-n0 < 150 m3/h						Δq50_n1-n0 > 150 m3/h				
	MICT08	MICT20	MICT23	MICT16	MICT18	MICT01	MICT05	MICT14	MICT15	MICT22	MICT06
Δq50_nx-n0 $[m^3 \cdot h^{-1}]$	54	68	69	92	101	118	173	243	257	272	599
Constructor	C2	C7	C1	C12	C5	C10	C8	C6	C4	C1	C2
Nb. of levels	0	0	0	1	1	0	1	0	1	1	1
Type of air-barrier	C	C	C	C	C	C	C	C	C	C	C
Type of material	M2	M2	M1	M2	M1	M1	M1	M1	M2	M1	M2
Type of floor	F3	F1	F1	F1	F1	F2	F1	F1	F1	F1	F2
Type of roof	R2	R1	R1	R2	R2	R1	R2	R1	R2	R1	R3
Type of heating	H1	H3	H2	H1	H2	H3	H1	H2	H3	H2	H3
HVAC Equipement	E2	E1	E5	0	E1	E3	E1	E1	E1	E1	E1
Modif_Window			R							R	
Modif_Walls	D	D	R	D	D	D		D	D	D	D

Table 2: Evolution in q50 for LT according to buildings mains characteristics and modifications by occupants

	Δq50_nx-n0 < -50 m3/h					-50 m3/h < Δq50_nx-n0 < 50 m3/h							
	MILT21	MILT20	MILT13	MILT17	MILT08	MILT31	MILT29	MILT04	MILT22	MILT26	MILT06	MILT10	MILT15
Δq50_nx-n0 $[m^3 \cdot h^{-1}]$	-209	-108	-103	-72	-71	-18	-12	-6	17	20	27	29	38
Constructor		C1	C1	C2	C3	C1	C1	C3		C3	C3	C3	C3
Nb. of levels	0	1	1	1	0	1	1	1	1	1	1	0	1
Type of air-barrier	C	A	A	B	B	A	A	B	B	B	B	B	B
Type of material	M2	M3	M3	M2	M2	M3	M3	M2	M2	M2	M2	M2	M2
Type of floor	F1	F2	F2	F1	F1	F2	F2	F1	F1	F1	F1	F1	F1
Type of roof	R1	R1	R1	R1	R1	R1	R1	R1	R1	R4	R1	R1	R1
Type of heating	H1	H4	H4	H4		H4	H4	H4	H4	H4	H1	H4	H1
HVAC Equipement	E1	E1	E1	E5	E3	E1	E1	E1	E1	E1	E1	E1	E1
Modif_Window										D			
Modif_Walls	D	D	D	D	D	D	D	D	D	D	D	D	D

	50 m3/h < Δq50_nx-n0 < 150 m3/h										Δq50_nx-n0 > 150 m3/h						
	MILT30	MILT23	MILT03	MILT11	MILT28	MILT16	MILT02	MILT32	MILT12	MILT07	MILT25	MILT09	MILT19	MILT14	MILT01	MILT05	MILT27
Δq50_nx-n0 $[m^3 \cdot h^{-1}]$	60	67	68	71	72	84	109	123	125	140	158	166	180	182	244	290	363
Constructor	C1	C3	C3	C3	C3	C3	C3	C1	C3	C3	C3	C3	C3	C3	C3	C4	C3
Nb. of levels	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	0	1
Type of air-barrier	A	B/C	B	B	B	B	B	A	B	B	B	B	B	B	B	C	B
Type of material	M3	M2	M2	M2	M2	M2	M2	M3	M2	M2	M2	M2	M1	M1	M2	M1	M2
Type of floor	F2	F1	F1	F1	F1	F1	F1	F2	F1	F2	F1	F1	F1	F1	F1	F1	F1
Type of roof	R1	R4	R1	R1	R4	R1	R1	R1	R1	R1	R4	R1	R1	R1	R1	R1	R1
Type of heating	H4	H4	H2	H2	H4	H3	H4	H4	H4	H4	H4	H4	H4	H1	H1	H1	H2
HVAC Equipement	E1	E1	E4	E4	E1	E6	E1	E1	E1	E1	E1	E1	E1	E1	E1	E1	E6
Modif_Window						R											
Modif_Walls	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D

Regarding the modifications on the envelope made by occupants, the information was collected through questionnaires. We have identified mainly two categories of modifications:

- modification on windows (Modif_window): maintenance (M) or replacement (R) of some elements;
- modification on the walls: replacement (R) of some elements or drilling the walls (D).

As showed in Table 1, one window was modified in MICT28 (adjustment of the hinge) and another one in MICT21 (adjustment of the service door overlooking the garage), which probably explain the improvement of the airtightness. While the replacement of windows in MICT22 and MICT23 seem probably to deteriorate the airtightness. This is also the case of MILT16 of the LT sample in Table 2.
Regarding the modifications of walls, all houses were generally modified by the occupants (drilling the walls for installing furniture, decoration, hood, downlight led...) whatever the evolution of the airtightness. In some cases (MILT 25 & MILT27), the degradation of the airtightness is may be due to the installation of a heat pump which required the piercing of the walls in order to be able to install the cables and the ducts. In other cases (MILT8 & MILT21), the improvement of the airtightness is may be due to the fact that the occupants have sealed the leaks detected during the test at completion at the junction between the ducts and the ceiling. However, it is difficult to draw general conclusions from these observations about the impact of the modifications by occupants on the evolution of the airtightness.

3.4 Evolution of leakages

Figure 5 and Figure 6 show the evolution in the number of leakages for MT sample and LT sample respectively for each category of leakages as defined in (FD P50-784, 2016). The houses are sorted in ascending order of the evolution of q_{50}. The categories of leakages are the following:

- A: leakages through main envelope area;
- B: leakages through wall, roof and floor junctions;
- C: leakages through doors and windows;
- D: leakages around penetration through envelope;
- E: leakages through trapdoor;
- F: leakages through electrical components;
- G: leakages through junctions between wall and door/window;
- H: other leakages.

The figures show an increase in the number of leakages for doors and windows (C), electrical components (F), penetrations through envelope (D) and junctions between walls and doors/windows (G).

However, multiple linear regression has been performed and has shown that the evolution in q_{50} is not correlated with the evolution in the number of leakages. As we can see on both figures, for some houses with a decrease in q_{50}, there is an increase in leakages equivalent to houses with a strong increase in q_{50}. Therefore, a thorough leakage location detection is not useful as long as it does not quantify leakages for the analysis of the onsite durability. Thus, new methods are needed to detect and to quantify leakages.

Gathered information on the modification of the envelope has explained a part of the evolution in q_{50}. However, neither leakages detection nor building characteristics are correlated with the observed evolution of q_{50}. Therefore, there are probably other parameters not considered in this study, which have an impact on the durability of the airtightness. One guess is that the environmental conditions (temperature, dustiness) when the air barrier is implemented may have an impact on the durability of the airtightness. It was not possible for us to collect information on these parameters, but it would be interesting to investigate this parameter in future studies.

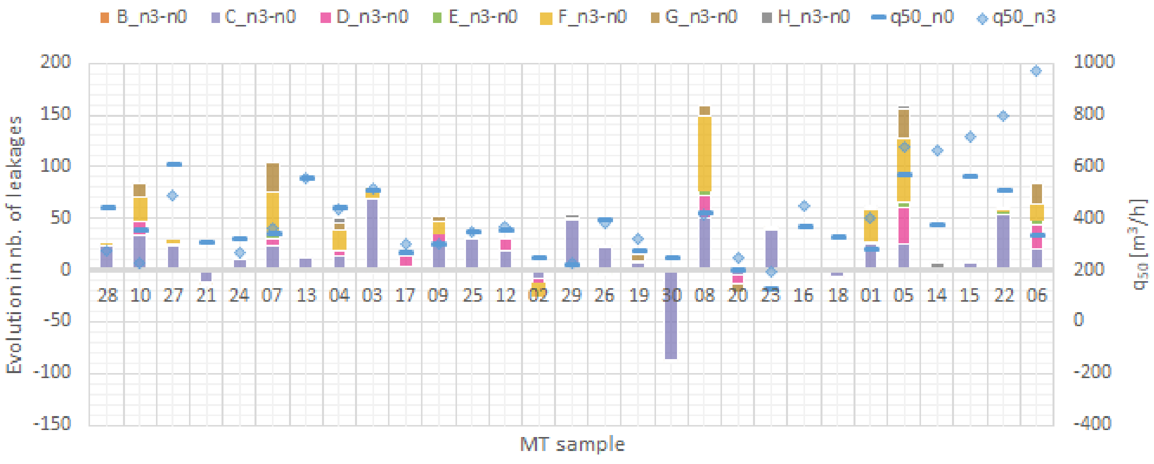

Figure 5: Evolution in detected leaks numbers for MT sample

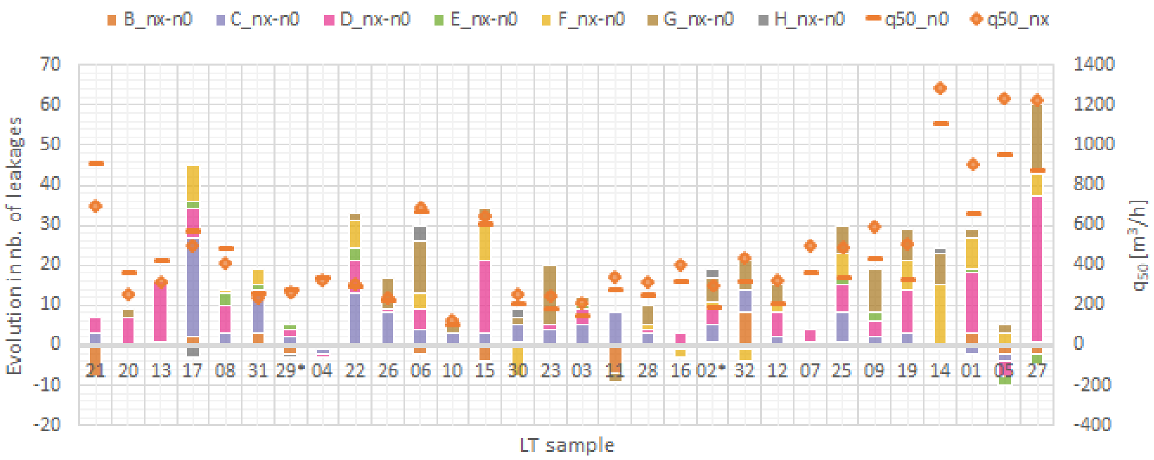

Figure 6: Evolution in detected leaks numbers for LT sample

3.5 Impact of seasonal variations

Figure 7 shows the evolution of the measured air leakage rates at 50 Pa q_{50} depending on the moment of measurement for the five houses of the MT sample.

Globally, we do not observe a seasonal variation in q_{50} except for MICT 22. In case of MICT22, q_{50} has strongly increased after the measurement at completion (SUM-14). But since the second measurement in winter 2017 (WIN-17), the house seems to be slightly more airtight in summer than in winter. Unfortunately, measurement n_2 is missing between SUM-17 and SUM-18 to confirm this observation. It is interesting to notice that this is the only 2-storey house while the four others are 1-storey houses.

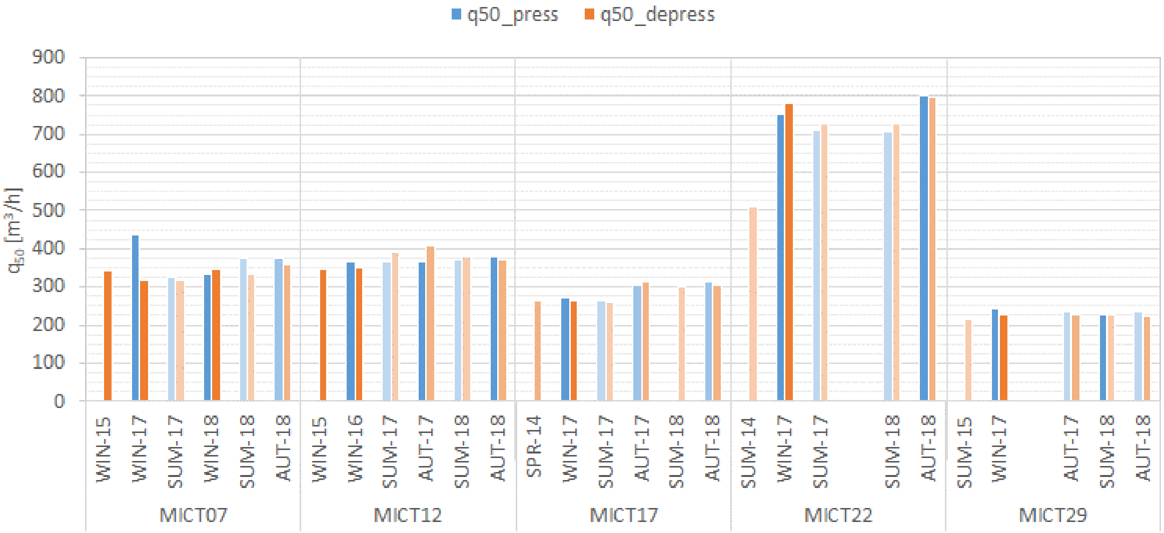

Figure 7: Evolution in q50 for the measurements with seasonal variations of the MT sample (WIN: Winter; SUM: Summer; AUT: Autumn; SPR: Spring)

3.6 Evolution of windows air permeability

The window air permeability was measured with the PAM device as described in (Fournier, Berthault, & Carrié, 2007). Figure 8 shows the results of the measured air leakage rates at 100 Pa and the results of the leakages detection for the five windows. We note that the air permeability of the windows was not measured at completion. Thus, the reference measurements n_0 are missing. We can only analyse the evolution of the airtightness between n_1 and n_3.

Globally, we observe small variations between measurements n_1, n_2 and n_3. As for the envelope, we do not observe any correlation between the evolution in detected leakages and the evolution in air leakage rates of the windows. In addition, the evolution in the air leakage rates of windows is not correlated with the evolution in the air permeability of the envelope.

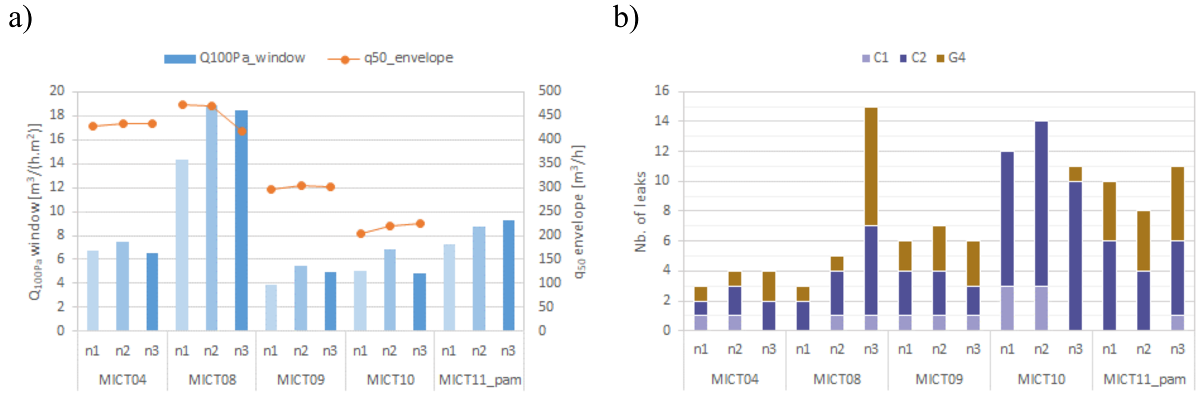

Figure 8: Evolution in the measured air leakage rates at 100 Pa (a) and the number of leakages (b) for the measured windows of the MT sample (C1: other leakage through window – C2: leakage through the junction between the window leaf and frame – G4: leakage through the junction between the window and the wall)

4 CONCLUSIONS

The durability of building airtightness of low energy single-detached houses was assessed through two field measurement campaigns at mid-term (MT) and long-term (LT) scales.

The results showed that the airtightness of houses can deteriorate mainly during the first two years and then it seems to stabilise as:

- For MT sample, the mean and median values of the air leakage rates q_{50} in years n_1, n_2 and n_3 are equivalent;
- MT and LT samples show the same mean evolution of the air leakage rate q_{50} (respectively +18% and +20%).

However, as for other studies (Leprince, Moujalled, & Litvak, 2017), we have observed that the building airtightness deteriorated significantly in some houses while in others it stabilised or even improved. With this study, it has not been possible to determine “where and why” new leakages are appearing however; it has led us to the following useful conclusions:

- One of the two houses with exposed wood-frame has become much leakier, mainly because of leakages appearing at the junction between the wood and the plasterboard (shrinkage of mastic). While the airtightness of the other house has remained almost stable. Therefore, the conditions of implementation of the air-barrier seem to have an impact on the durability of the airtightness.
- It has not been possible to determine the location of the new leakages causing the deterioration of the airtightness. New methods are needed not only to locate but also to quantify more precisely leakages. A thorough leakage detection is not useful as long as it does not quantify leakages for the analysis of the onsite durability.
- Observed variations of the air permeability are not due to seasonal variations and given the strict protocol applied in this study, they are probably not due to measurement uncertainty.

- The evolution of the airtightness does not appear to be correlated in this study with the following parameters: constructor, type of air-barrier, type of floor, type of roof, type of heating, specific HVAC equipment.

The two parameters that seem to be correlated with the evolution of the airtightness are:

- The material: it seems that the airtightness of wood houses tend to stabilise or even improve over years, maybe due to the expansion of wood with humidity.
- The number of levels: 2-storey houses seems to more deteriorate than 1-storey ones, which is maybe due to more important foundation settlement.

Regarding the houses where the airtightness has improved (10 houses for both samples), this improvement is maybe due to the building material (2 wooden houses), the maintenance of windows (2 houses), or the sealing of leaks by occupants (2 houses). However, for the other four houses, we have not been able to explain it.

Therefore, the results of this study do not stress the need to perform long-term study on the durability of airtightness, but on the contrary to better understand where and why leakages appear during the first year, which causes the deterioration of the building airtightness (very short-term ageing). Other parameters need to be considered, such as the environmental conditions (hygrothermal, dustiness) during the implementation of the air barrier or the evolution of the temperature and humidity inside the building during the first year. In addition, modifications made by occupants need to be known more closely. More frequent airtightness measurements (e.g. monthly measurements) could be performed on a small sample of houses over the period from the implementation of the air barrier till one year upon building completion, by recording at each measurement the aforementioned parameters.

5 ACKNOWLEDGEMENTS

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