Onsite evaluation of building airtightness durability: Long- term and mid-term field measurement study of 61 French low energy single family dwellings

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ABSTRACT

The increasing weight of building leakages energy impact on the overall energy performance of low-energy buildings led to a better understanding of the actual airtightness performance of buildings. However, low expertise is available today on the durability of airtightness products in mid- and long-term scales. 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 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 (MT) and long-term (LT) scales.

This paper first presents the field measurement protocol. For the MT campaign, a sample of 30 new single-detached dwellings has been selected nationwide. During the study, the airtightness of each building is to be measured once per year over a 3-year period. A part of this sample is to be also measured twice per year in order to investigate the impact of seasonal variations. The LT campaign is to be carried out with a second sample of 31 existing single-detached dwellings constructed during the last 10 years. The airtightness of each dwelling is to be measured once.

A specific measurement protocol was defined after a detailed literature review. The protocol is mainly based on the standard ISO 9972 for the measurement method with additional requirements for the measurement conditions (same tester, same calibrated measurement device, same building preparation, same pressure difference sequences, same season…). It also includes a detailed qualitative leakage detection and questionnaire for occupants.

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.

Secondly, this paper presents the 61 dwelling samples construction characteristics. All dwellings were tested upon completion. The air flow rates at 4 Pa per envelope area excluding lower floor of both samples show the same mean value around 0.3 $m^3.h^{-1}.m^{-2}$ (n_{50} of 1.4 h^{-1}), with larger variations among the LT sample.

Finally, we discuss first measurement results. Regarding MT sample, results after 1-2 years show a slight increase of airflow rate at 50 PA (q_{50}) with a median value of +6%. However, with exposed timber framing, q_{50} has increased by more than 100%. Regarding LT campaign, measurements results after 3-10 years show a more important increase of q_{50} with a median value of 28%.

The measurement campaigns and data analysis will continue over 2018 to complete the work in order to better understand the in situ variations of the buildings' envelope airtightness.

KEYWORDS

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

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 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 (MT) and long-term (LT) scales. This paper presents the first results of both MT and LT measurements.

2 METHODOLOGY

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 are to be performed:

- The airtightness of each building is to be measured once per year over the 3-year period.
- Five buildings of this sample are to be measured twice per year in order to investigate the impact of seasonal variations.
- For six buildings of this sample, the airtightness of an installed window is to be 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 5 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. In particular, dwellings of the MT sample must be certified according to French quality management approach, thus making available information about construction details.

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 et al., 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 both in 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. 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 is 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, 90 and 31 measurements of building airtightness are to be performed with MT and LT samples respectively, plus an extra of 10 measurements for the seasonal impact, and an another extra of 18 measurements for the airtightness of windows.

This paper explores the measurements results of the first 2 years of MT sample (60 measurements) and the LT sample (31 measurements). The results presented here are expressed according to two indicators:

- the airflow at 50 Pa (q_{50});
- and the air permeability French indicator $Q_{4Pa\text{-}surf}$, which is the airflow rate at 4 Pa per unit of envelope surface area excluding lowest floor ($m^3.h^{-1}.m^{-2}$).

As the measured air leakage rate at 50 Pa is more accurate than at 4 Pa (Delmotte & Laverge, 2011), main analysis of the evolution of the airtightness will be based on "q_{50}". The French indicator "$Q_{4Pa\text{-}surf}$" will be used to check compliance with the mandatory requirement.

3 RESULTS

3.1 Main characteristics of buildings

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

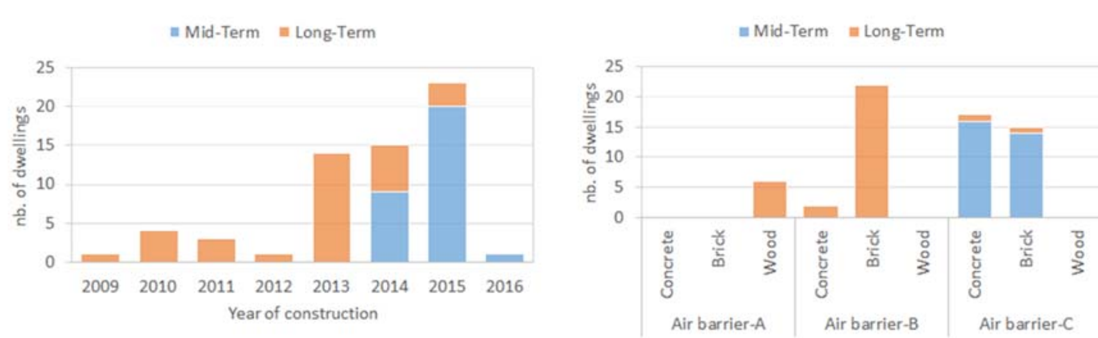

Figure 1: Distribution of buildings depending on the year of construction (left) and buildings main material and type of air barrier (right); Air barrier-A when the air barrier is ensured by vapour barrier, Air barrier-B by coating on the masonry, and Air barrier C by plasterboards and mastics at the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

The MT sample is composed of 30 new single-detached low-energy dwellings 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. All houses are equipped with humidity sensitive single exhaust ventilation system. The airtightness of all houses is treated in the same way, through plasterboards and mastics at the inside facing of the walls (air barrier C).

All dwellings of the MT sample are certified according French quality management approach for building airtightness. Also they are constructed according to the current French Energy Performance (EP) regulation which requires a limit value of 0.6 $m^3.h^{-1}.m^{-2}$ for $Q_{4Pa\text{-}surf}$ in single-family houses. Besides, 9 dwellings had a target value lower than the mandatory requirement of 0.6 $m^3.h^{-1}.m^{-2}$ (6 houses with a target value of 0.5 $m^3.h^{-1}.m^{-2}$ and 3 houses with 0.4 $m^3.h^{-1}.m^{-2}$).

The LT sample is composed of 32 single-detached low-energy dwellings 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. Almost all houses are equipped with humidity sensitive single exhaust ventilation system (only one house with balanced ventilation system). The airtightness of masonry houses of the LT sample is mainly ensured by coating on the masonry (air barrier B), while the airtightness of wooden houses is ensured by the vapour barrier (air barrier A).

Dwellings of the LT samples were all constructed before the current French EP regulation. However, the majority are certified according the French EP label “BBC EFFINERGIE” which has the same requirement of maximum air permeability of 0.6 $m^3.h^{-1}.m^{-2}$.

Figure 2 presents the results of the measured air permeability $Q_{4Pa\text{-}surf}$ upon reception of all buildings. The figure shows also the target values of air permeability. Both samples present the same average and median values of air permeability, around 0.3 $m^3.h^{-1}.m^{-2}$, however the LT sample shows more variations than the MT sample. All buildings of LT and MT samples meet their air permeability target values respectively, except one house of the MT sample with an air permeability of 0.42 $m^3.h^{-1}.m^{-2}$ slightly higher than 0.4 $m^3.h^{-1}.m^{-2}$.

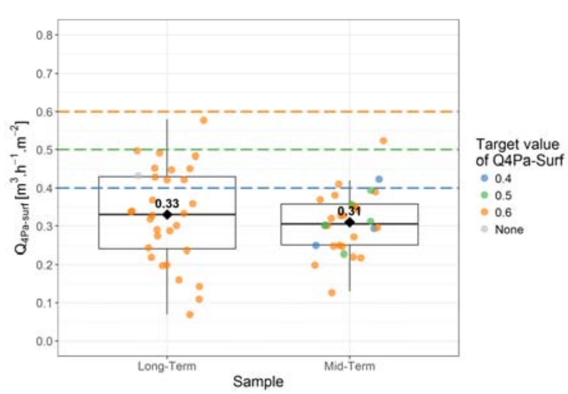

Figure 2: Boxplot and scatterplot of the measured air permeability of buildings at reception (measurement n_0)

For MT sample, 1st-year measurements (measurements n_1) started in November 2016 and finished in May 2017, thus from 1 to 3 years after the measurements upon completion (measurements n_0). The measurements were delayed due to the difficulty in finding occupants who agree to participate in 3 year-long measurement campaigns. The 2nd year measurements (measurements n_2) started in February 2017 and finished in June 2018, less than one year after n_1 to compensate for delays. A house was excluded from the MT sample because of problems during measurement n_1.
For LT sample; all measurements (measurements n_x) were conducted in 2017, from 3 to 8 years after n_0. Only 9 houses aging more than 5 years were measured. This is due to the difficulty of finding houses corresponding to the selection criteria, and also to have the agreement of occupants.

3.2 Results of MT measurements

Figure 3 presents the deviations of the measured q_{50} between n_0, n_1 and n_2 for the pressurization test, the depressurization test and the average between both tests. For the measurements n_0, the dwellings were tested either in pressurization (26 houses) or in depressurization (3 houses), contrary to the measurements n_1 and n_2 performed both in pressurization and depressurization. The measurements are classified into four categories depending on the deviation of q_{50} between n_1 and n_0: the 1st category with a significant decrease of q_{50} (less than -50 $m^3.h^{-1}$), 2nd category with small variations (from -50 to +50 $m^3.h^{-1}$), 3rd category with a moderate increase of q_{50} (from +50 to +150 $m^3.h^{-1}$), and 4th category with strong increase of q_{50} (more than +150 $m^3.h^{-1}$). In "n_2" it is also the same categories determined by the deviation between n_1 and n_0 that are used.

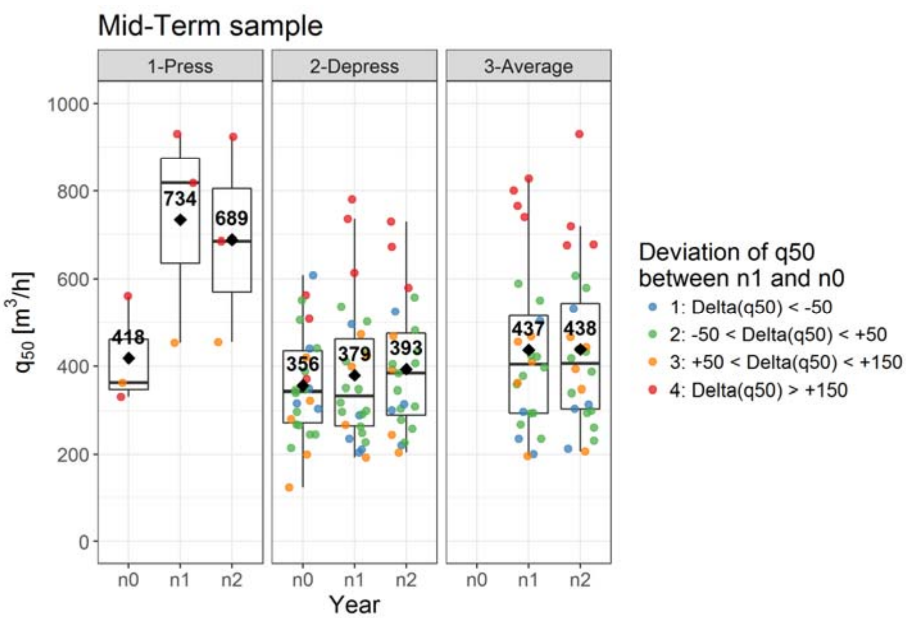

Figure 3: Deviation of q_{50} between n_0, n_1 and n_2 for the MT sample for the pressurization test, the depressurization test and the average between both tests. Measurements n_2 are coloured using the same categories determined by the deviation between n1 and n0.

Results show that the deviations of q_{50} between n_1 and n_0 (for both pressurization and depressurization) vary in a wide range between -150.8 $m^3.h^{-1}$ (-42%) up to a maximum of 599.3 $m^3.h^{-1}$ (181%) with an average value of 52.7 $m^3.h^{-1}$ (16%). However, half of measurements present a deviation lower than 6% (median value of 13.0 $m^3.h^{-1}$). The value of q_{50} has moderately increased for 6 houses. It has strongly increased for 5 houses (in particular for houses tested in pressurization upon reception).

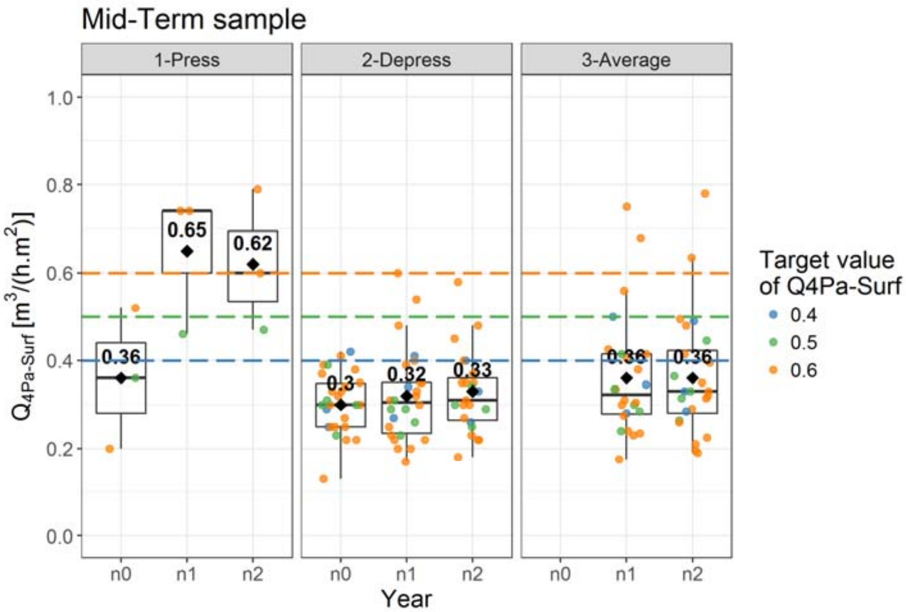

Figure 4: Boxplot of the measured $Q_{4Pa\text{-}surf}$ of the MT sample depending on the measurement year for the pressurization test, the depressurization test and the average between both tests

Figure 4 presents the variations in term of the French indicator $Q_{4Pa\text{-}surf}$. Compared to the target values. Results show very small variations with almost the same mean and median values, except of the three houses tested in pressurization upon reception. Therefore, the majority of houses remain below the target values during n_1 and n_2, except 2 houses exceeding the limit value of 0.6 $m^3.h^{-1}.m^{-2}$.

In order to investigate the variations of q_{50}, Figure 5 presents a comparison of the measured values during n_1 and n_2 against n_0 depending on the type of roof and the number of levels. The impact of the type of roof or the number of levels is not clear, but it seems that the air leakage rates are, in average, more increasing for two-story houses than one-story houses. Also the air leakage rates increase slightly more for houses with traditional wood frame than houses with light-frame wood truss.

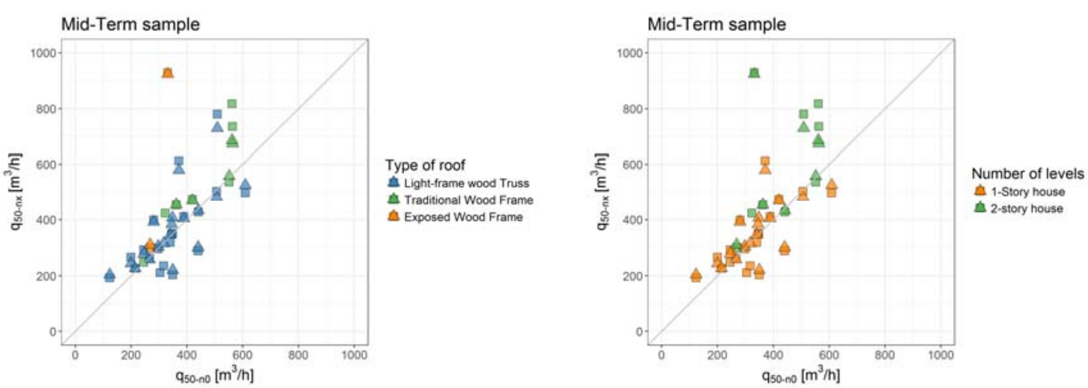

Figure 5: Comparison of q_{50} for MT sample between measurements n_1 (rectangular points) and n_2 (triangular points) against measurement n_0 depending on the type of roof (left) and the number of levels (right)

We observe the particular case of a measurement that is largely above the others. It's a two-story house with an exposed wood frame roof where q_{50} has increased by +180%. For this house, it was observed a significant increase of the number of leakages at the junctions between the wood frame and the ceiling or the walls (Figure 6).

Figure 6: leakages at the junctions between the wood frame and the ceiling or the walls

As mentioned in paragraph 2, a detailed qualitative leakage detection is performed at each measurement. Figure 7 presents the comparison of the numbers of observed leakages between measurements n_0, n_1 and n_2 for each category of leakages as defined in (FD P50-784, 2016). Results show an increase in the number of leakages for doors and windows, electrical components, penetrations through envelope and finally junctions between walls and doors/windows. In particular, the numbers of leakages of doors and windows are largely higher than other categories. However, it's difficult to conclude about the impact of the number of leakages on the evolution of q_{50}. Further analysis is needed in order to investigate the correlation between the leakages and q_{50}.

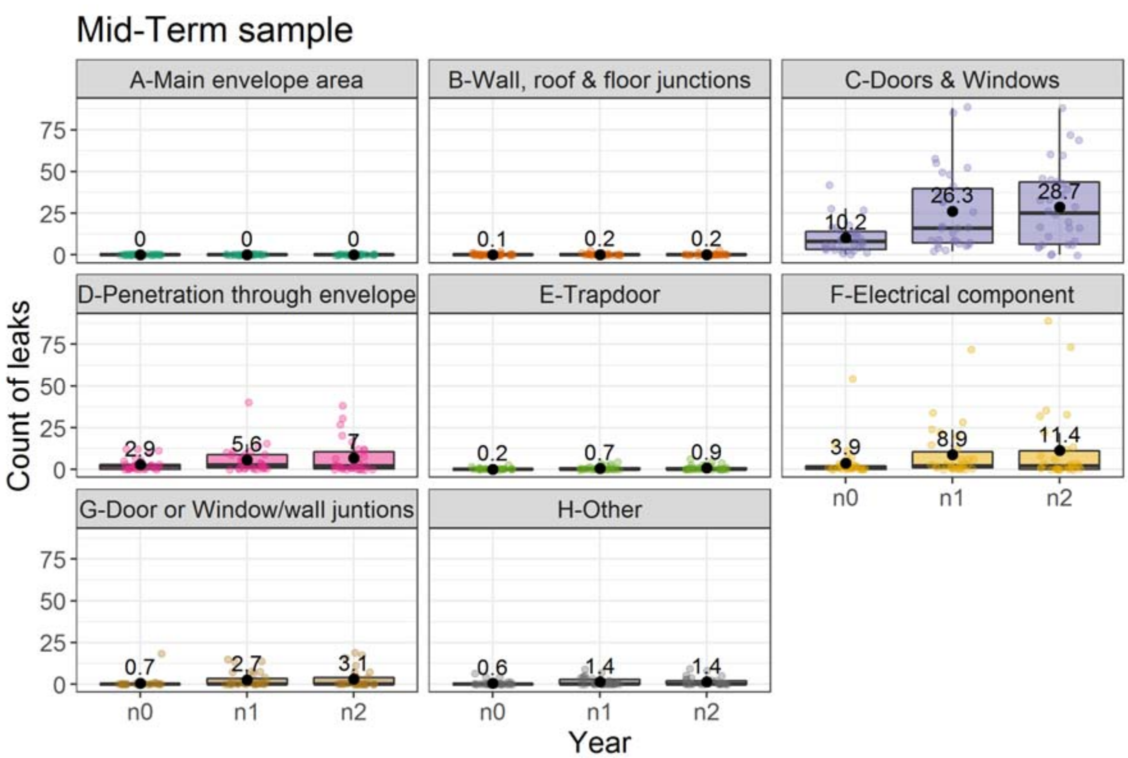

Figure 7: Comparison of the numbers of observed leakages of MT sample between measurements n_0, n_1 and n_2 for each category of leakages

3.3 Results of LT measurements

Figure 8 the deviations of the measured q_{50} between n_0 and n_x for the pressurization test, the depressurization test and the average between both tests. For n_0, the dwellings were only tested in depressurization, contrary to the measurements n_x performed both in pressurization and depressurization. The measurements are classified into four categories in the same way as for MT sample.

As for MT sample, results show that the deviations of q_{50} between n_x and n_0 vary in a wide range between -208.9 $m^3.h^{-1}$ (-30%) and 521.7 $m^3.h^{-1}$ (+292%) with an average value of 79.4 $m^3.h^{-1}$ (+28%). LT sample presents globally higher increase of q_{50} than MT sample, with half of measurements increasing by more than 29% (median value of 67.8 $m^3.h^{-1}$). Only 8 houses show small variations of q_{50}, whereas 10 houses with moderate increase and 8 houses with strong increase.

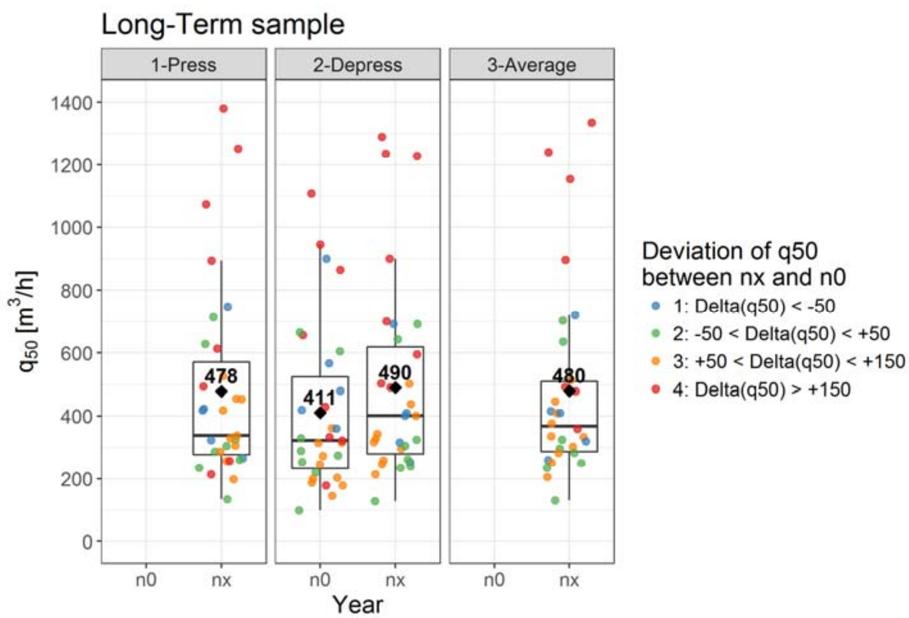

Figure 8: Deviation of q_{50} between n_0 and n_x for the LT sample for the pressurization test, the depressurization test and the average between both tests

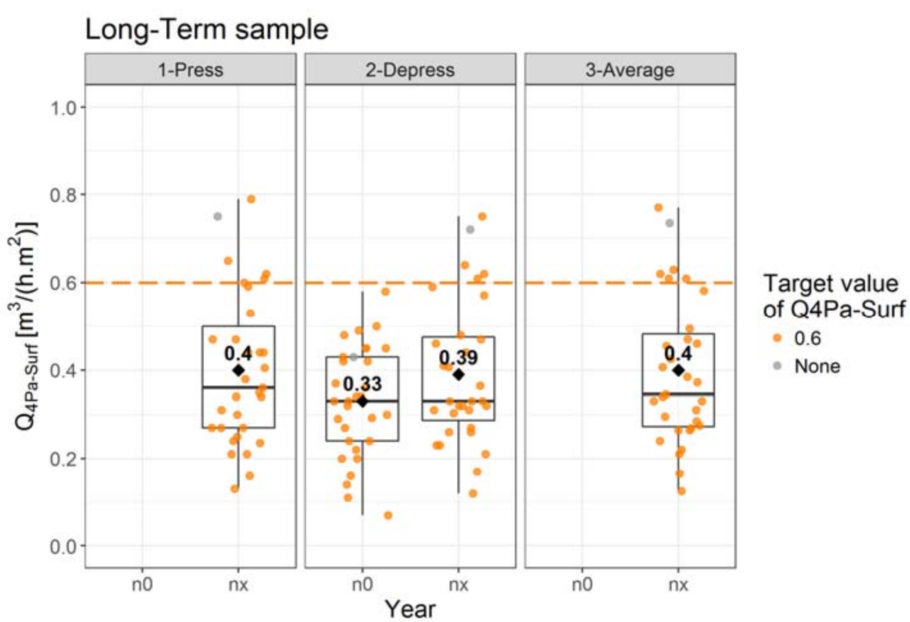

Figure 9: Boxplot and scatterplot of the measured $Q_{4Pa\text{-}surf}$ of the LT sample depending on the measurement year for the pressurization test, the depressurization test and the average

Figure 9Figure 4 presents the variations in term of the French indicator$Q_{4Pa\text{-}surf}$. Compared to the target values. Results show slightly higher variations than MT sample, with an average value at n_x of 0.39 $m^3.h^{-1}.m^{-2}$ against 0.33 $m^3.h^{-1}.m^{-2}$ at n_0. The majority of houses remain below the target values during n_x, except 5 houses exceeding the limit value of 0.6 $m^3.h^{-1}.m^{-2}$. In order to investigate the variations of q_{50}, Figure 10 presents a comparison of the measured values during n_1 and n_2 against n0 depending on the type of air barrier and the number of levels. As for MT sample, the distribution of the points does not allow to identify an impact of the type of air barrier or the number of levels.

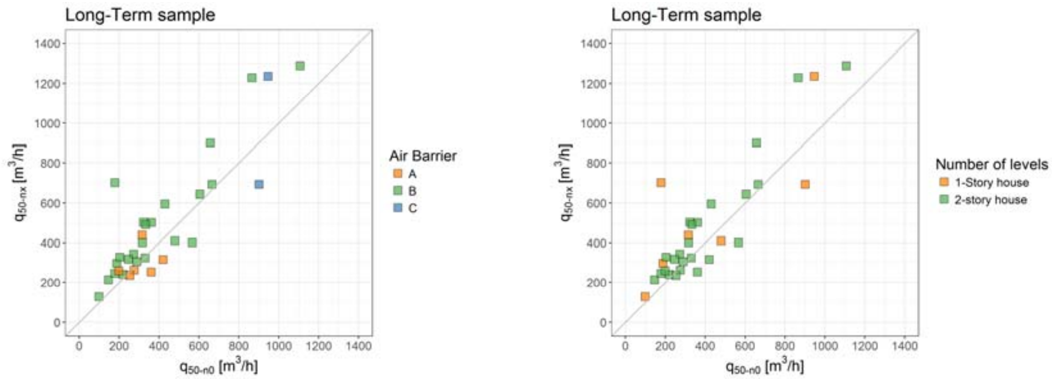

Figure 10: Comparison of q_{50} for LT sample between measurements n_x (rectangular points) against measurement n_0 depending on the type of air barrier (left) and the number of levels (right)

Figure 11 presents the comparison of the numbers of observed leakages between measurements n_0, n_1 and n_2 for each category in the same way as for MT sample. Results show also an increase in the number of leakages for doors and windows, electrical components, penetrations through envelope and junctions between walls and doors/windows. However, the numbers of leakages are much lower than MT sample. Indeed, the leakage detection of LT sample was performed in a less detailed manner than the MT sample as there is no annual follow-up of leakages to be performed.

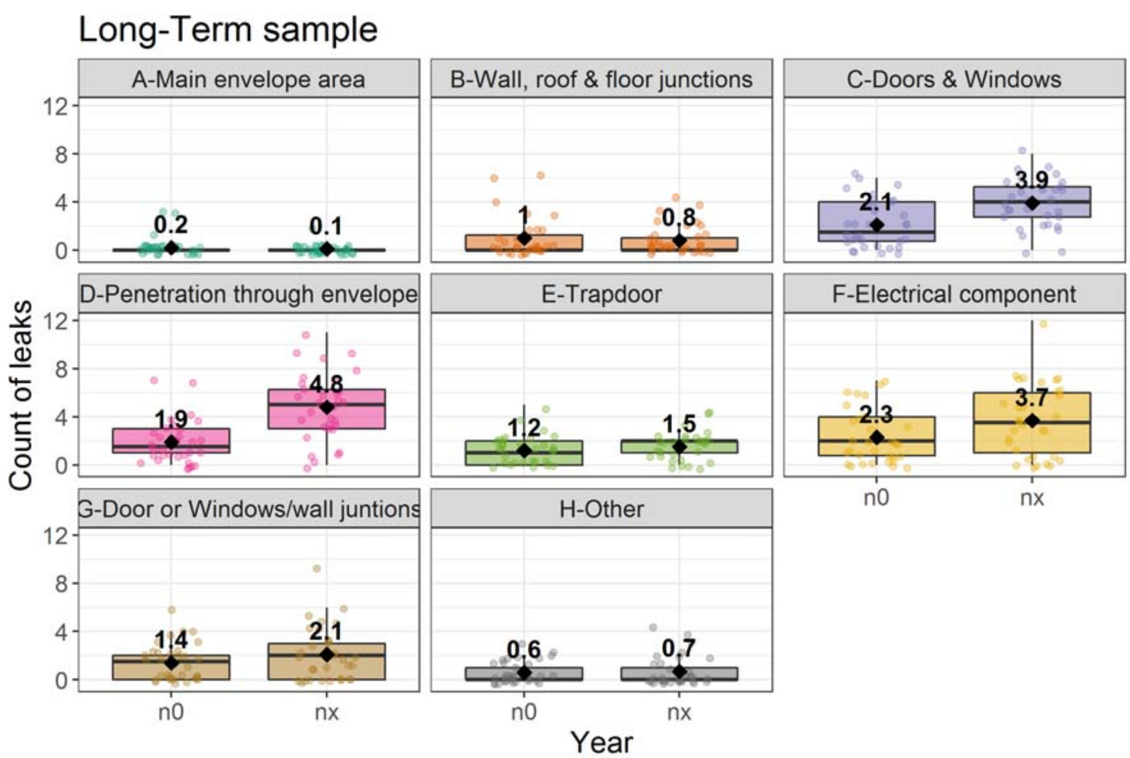

Figure 11: Comparison of the numbers of observed leakages of LT sample between measurements n_0 and n_x for each category of leakages

4 CONCLUSIONS

The building airtightness durability of French low energy single family dwellings was assessed in real conditions at mid- and long-term scales, through two field measurement campaigns: a MT campaign with a sample of 30 new houses, and a LT campaign with a sample of 31 existing houses.

Regarding mid-term sample, results after 1-3 years show a slight increase of the air leakage rate at 50 Pa (q_{50}) with an average increase of +16% and a median value of +6%. However, q_{50} has increased by more than +100% in the case of a 2 -story house with an exposed wood frame roof, due to many leaks at the junctions between the wood frame and the ceiling or the walls. For the LT sample, results after 3-8 years show a more important increase of q_{50} with an average and a median value around 28%. The increase in building air permeability is less important than in the previous studies (Bracke et al., 2016)(ADEME, 2016). A significant increase of the number of leakages was observed for doors and windows, electrical components, penetrations through envelope and junctions between walls and doors/windows. However, it's difficult to conclude about the impact of the number of leakages on the evolution of q_{50}.

The measurement campaigns and data analysis will continue over 2018 to complete the work in order to better understand the in situ variations of the buildings' envelope airtightness depending on the envelope characteristics. Further analyses will also be performed in order to investigate the impact of seasonal variation, the durability of airtightness of installed windows, and the correlation between the leakages and the air leakage rate.

5 ACKNOWLEDGEMENTS

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