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Assessment of mid-term and long-term building airtightness durability

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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 mandatory requirements in their Energy Performance regulation (EP-regulation) regarding the building airtightness. In France, 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 research project "Durabilit'air" (2016–2019) was conducted in order to improve our knowledge on the variation of buildings airtightness through onsite measurement campaigns 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 campaigns at mid-term and long-term scales. This paper presents the results of both MT and LT measurements.

Methodology

The MT campaign aims at characterising the yearly evolution of building airtightness of new dwellings over a 3-year period. A sample of 30 new single-detached low-energy houses (**Figure 1**), measured upon completion (reference measurement n_0), has been selected nationwide. The airtightness of each building was measured once per year over the 3-year period (measurements n_1, n_2 and n_3). Besides, five buildings of this sample were measured twice per year in order to investigate the impact of seasonal variations.

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 (**Figure 1**), measured upon completion (reference measurement n_0), has been selected. The dwellings have been constructed during the last 10 years. The airtightness of each dwelling was measured once (measurement n_x).

The measurement protocol was defined after a detailed literature review (Leprince, 2017). The protocol is mainly based on the standard ISO 9972 (ISO 9972, 2015) and its French implementation guide (FD P50-784, 2016) for the measurement method with additional requirements for the measurement conditions in order to reduce uncertainties due to measurement procedure (measurements under the same conditions as the first measurement upon completion, detailed qualitative leakage detection, questionnaires for regarding the modifications of the building envelope).

Evolution of envelope air permeability

For the MT sample, **Figure 2** shows a significant increase in the mean air leakage rates at 50 Pa (q_{50}) between the measurements n_0 and n_1 by 58.9 $m^3.h^{-1}$, i.e. +18% (p-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-value = 0.002 < 0.05).

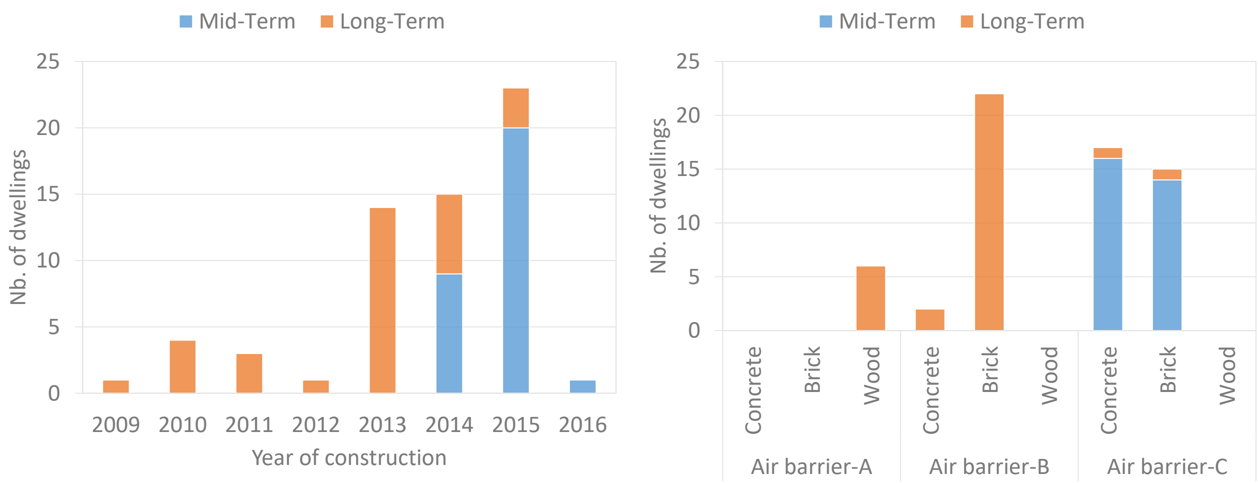

Figure 1. Distribution of buildings depending on the year of construction (left) and buildings main material and type of air barrier (right); Air barrier-A when the air barrier is ensured by vapour barrier, Air barrier-B by coating on the masonry, and Air barrier C by plasterboards and mastics at the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

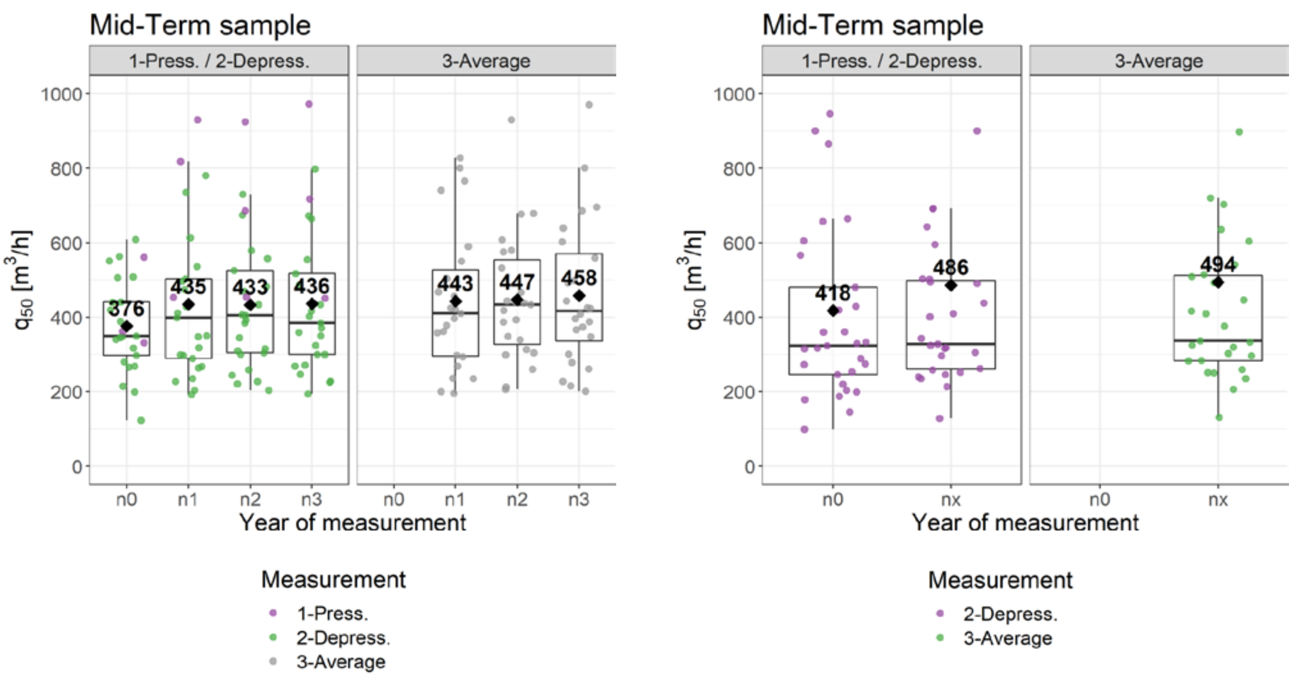

Figure 2. Boxplot of the measured air leakage rates at 50 Pa q_{50} for the measurements n_0, n_1, n_2 and n_3 of the MT sample, and the measurements n_0 and n_x of the LT sample.

In order to analyse the correlation between the evolution of the air permeability and the age of the houses, we have performed a linear regression of the evolution in q_{50} on the timespan between the measurements at completion and the other measurements. It has shown 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 the state of the art done by (Leprince, 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 structural movement due to foundation settlement.

Analysis of explanatory factors

In order to go further in the understanding of the variation of buildings airtightness, we have examined the evolution of air leakage rate q_{50} regarding the houses main characteristics (constructor, number of levels, type of air-barrier, type of material, type of floor, type of roof, type of heating, specific HVAC equipment) and the modifications by the occupants (modification on windows, modification on walls).

Figure 3 and **Figure 4** show the relative gap in q_{50} and the evolution in q_{50} between different measurements for all houses of the MT sample depending on the number of levels and the type of roof respectively.

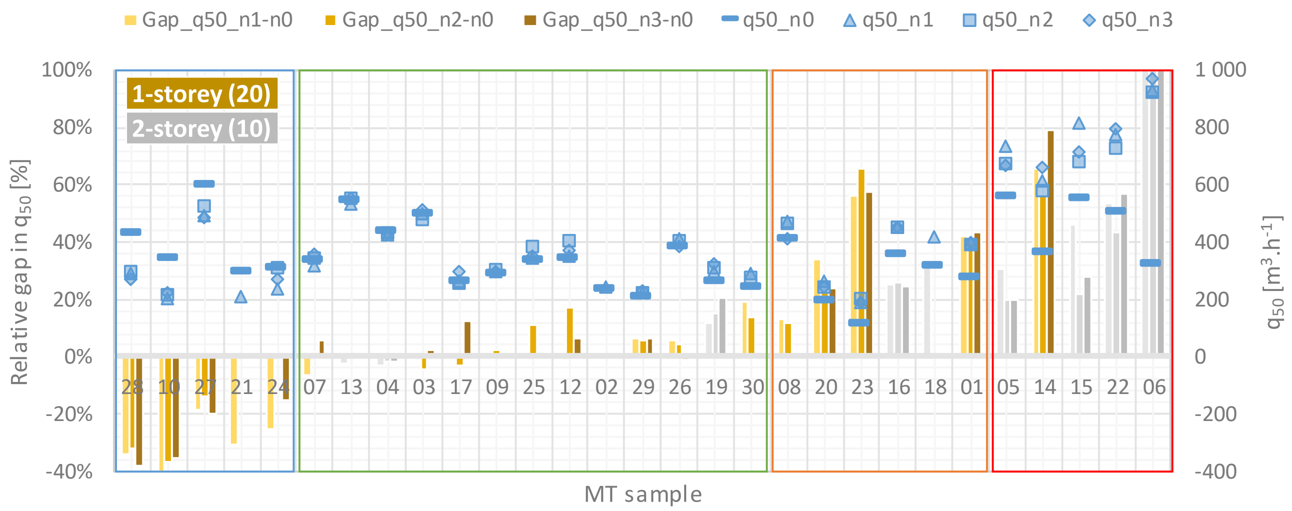

Figure 3. The relative gap in q50 (left y-axis) and the evolution in q50 between different measurements (right y-axis) for all houses of the MT sample depending on the number of levels.

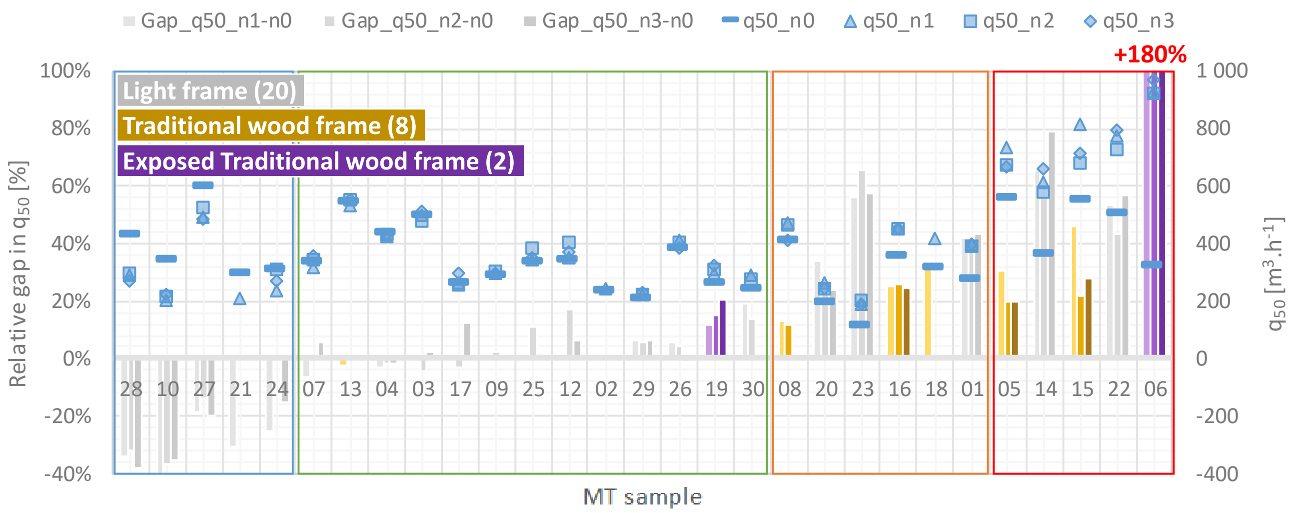

Figure 4. The relative gap in q_{50} (left y-axis) and the evolution in q_{50} between different measurements (right y-axis) for all houses of the MT sample depending on the type of roof.

The houses on the x-axis are sorted in ascending order of the evolution in q_{50}. They are classified into 4 categories:

- significant decrease in q_{50} (< –50 $m^3.h^{-1}$): 5 houses for the MT and LT samples each;
- no or little variations in q_{50} (–50 to +50 $m^3.h^{-1}$): 13 houses for MT sample and 8 houses for LT sample;
- moderate increase in q_{50} (+50 to +150 $m^3.h^{-1}$): 6 houses for MT sample and 10 houses for LT sample;
- strong increase in 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 (**Figure 3**) with traditional wood frame (**Figure 4**). For the two houses with exposed wood frame of this sample (MT06 & MT19), MT06 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 MT19 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.

The same analysis was performed for the LT sample. 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 the same conclusion on wood structure (Litvak, 2019) and it may be due to the expansion of wood with the humidity that may expand the wood and therefore reduce leakages.

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. Therefore, it is difficult to draw general conclusions from these observations about the impact of the modifications by occupants on the evolution of the airtightness.

Evolution of leakages

We have analysed the evolution in the number of leakages for both samples. The results have shown an increase in the number of leakages for doors and windows, electrical components, penetrations through envelope and junctions between walls and doors/windows. 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. 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.

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 have shown 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, 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 identify "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 (Moujalled, 2019).
- 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 heating, specific HVAC equipment.

The following three parameters seem to be correlated with the evolution of the airtightness:

- The material: it seems that the airtightness of wood houses tends 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 deteriorate more than 1-storey ones, which is maybe due to more important foundation settlement.
- The type of roof: houses with traditional wood frame seem to deteriorate more than houses with light frame because of the multiple junctions between the wood and the plasterboard.

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 until one year after building completion, by recording at each measurement the aforementioned parameters. ■

Acknowledgments

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