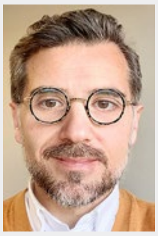
Statistical analysis of the French building airtightness database




BASSAM MOUJALLED[1,2] ADELINE MÉLOIS[1,2] VALÉRIE LEPRINCE[3] GAËLLE GUYOT[1,2]

[1] Cerema, BPE Research Team, 46 rue Saint Théobald, F-38081, L'Isle d'Abeau, France
[2] LOCIE, Université Savoie Mont Blanc, CNRS UMR5271, F-73376, France
[3] Cerema, Direction Territoire et Ville, 2 rue Antoine Charial, F-69426 Lyon, France

The French database of building airtightness was created in 2007 following the implementation of the national qualification scheme for building airtightness measurement. It currently contains about 570,000 measurements. This paper summarizes the results of the analysis of the database regarding the evolution of air permeability, and the impact of detected leakages.

This article is based on a paper presented at the 42nd AIVC - 10th TightVent & 8th venticool Conference "Ventilation Challenges in a Changing World" held on 5-6 October 2022 in Rotterdam, Netherlands.

Keywords: building airtightness, measurements, database, field data, detected leakages

With the constant evolution of the French EP-regulations, good building airtightness has become mandatory to reach required energy performance. The EP-regulation RT2012 introduced for the first time in 2013 minimum requirements for building airtightness in all new residential buildings. The air permeability, expressed by the he French indicator q_{E4} ($Q_{4Pa\text{-}surf}$ in French: air leakage rate at 4 Pa divided by the loss surface area excluding the basement floor) must be lower than 0.6 $m^3.h^1.m^2$ for single-family houses (i.e. around n_{50} = 2.3 h^1) and 1.0 $m^3.h^1.m^2$ for multi-family buildings. The new EP-regulation RE2020 has strengthen the requirements since January 2022 by:

- introducing a new minimum requirement for non-residential (a limit value of 1.7 $m^3.h^1.m^2$ for office buildings and schools of less than 3000 m^2 of surface);
- and adding penalties for measurements by sampling (final result multiplied by 1.2) or tests performed before the completion of all work impacting the envelope air permeability (final result incremented by 0.3 $m^3.h^1.m^2$).

Compliance must be justified either by an airtightness test performed by a qualified tester or by applying a certified quality framework. Thanks to this requirement, more than 60,000 airtightness tests have been carried out each year since 2015. Each test performed by a qualified tester is recorded in the French database on building airtightness, which is therefore growing rapidly (more than half million in 2020). The structure of the database is presented by Mélois (Mélois *et al.*, 2019). It is composed of 39 data fields on the building, the measurement procedure and the test results.

Database Overview

Figure 1 shows the evolution of the number of building airtightness measurements and the distribution of measurements depending on the use of the building.

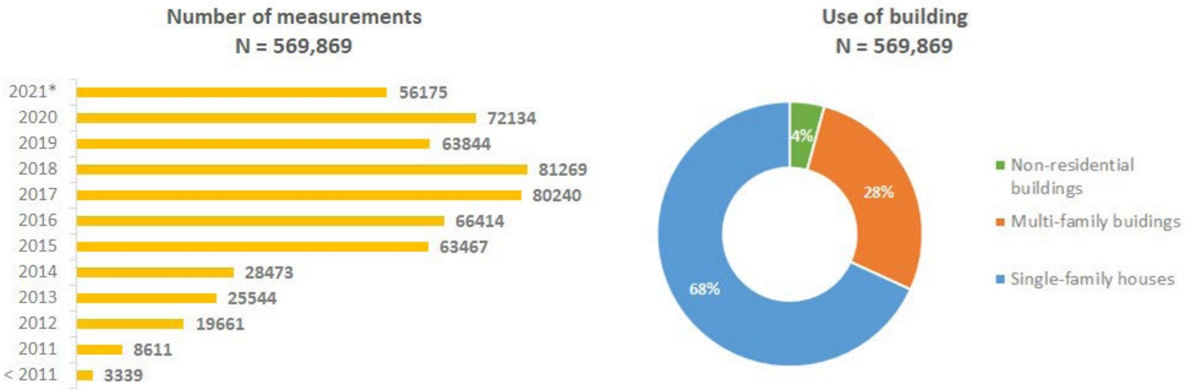
The database currently contains about 570,000 measurements. It takes into account the measurements made in France until 2021. The implementation of the regulatory requirement of the former EP-regulation RT2012 has initiated since 2013 a strong increase in the annual number of tests that fluctuates today between 65,000 and 80,000 approximately.

Residential buildings account for almost all of measurements (68% for single-family dwellings with 388,442 tests, and 28% for multi-family buildings with 157,469 tests). Only 4% of tests are carried out in non-residential buildings (35,958 tests). This is due to the mandatory requirement that applies only to residential buildings.

Changes of air permeability in the last decade

The results presented here are expressed according to the air permeability French indicator $Q_{4Pa\text{-}surf}$, as explained in the introduction. Only measurements performed upon completion are analysed hereafter in order to perform relevant comparisons.

Figure 2 presents the change over the last decade of building air permeability and its distribution.



*The data for 2021 is not complete and corresponds to measurements made by around two-thirds of qualified measurers.

Figure 1. Evolution of the number of building airtightness test in France (left) and distribution of measurements depending on the use of the building.

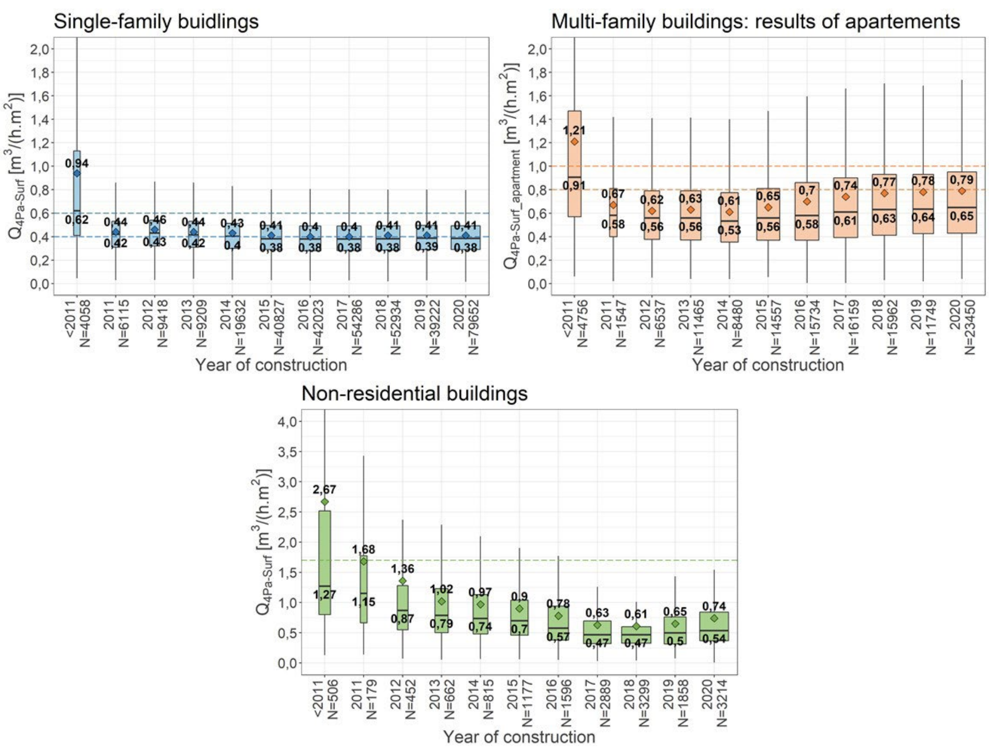


Figure 2. Boxplot of the building air permeability according to the year of construction in single-family, multi-family and non-residential buildings.

For single-family dwellings, the air permeability values decrease quickly in the first years and both median and mean values of $Q_{4Pa\text{-}surf}$ stabilize around 0.4 $m^3.h^{1}.m^2$ (median and mean values of n_{50} are 1.70 and 1.86 h^1 respectively) from 2015, clearly below the limit value of the mandatory requirement (0.6 $m^3.h^1.m^2$).

For multi-family buildings, the air permeability values also decrease quickly in the first years and then increase slightly from 2015. This is probably because every new building is now tested and not only exemplary ones that were applying for an EP-label. Indeed, the application of the mandatory requirement in multi-family buildings has been delayed by two years compared to single-family dwellings. The median and mean values of $Q_{4Pa\text{-}surf}$ tend to stabilize around 0.65 and 0.8 $m^3.h^1.m^2$ respectively (median and mean values of n_{50} are 1.43 and 1.78 h^1 respectively). They are both clearly below the limit value of the mandatory requirement (1.0 $m^3.h^1.m^2$).

For non-residential buildings, as seen above, the number of measurements is much lower. However, results show an annual increase in the number of measurements since 2011, with more than 3,000 non-residential buildings tested in 2020. As for the multi-family buildings, air permeability drops rapidly during the first years, then begins to increase slightly over the last three years as the number of buildings measured increases. The median and mean values of $Q_{4Pa\text{-}surf}$ tend to stabilize around 0.55 and 0.75 m^3. $h^1.m^2$ respectively (median and mean values of n_{50} are 1.82 and 2.38 h^1 respectively).

Analysis of the detected leakages

During each test, a detailed qualitative leakage detection is performed by testers in accordance with the Standard ISO 9972 (AFNOR, 2015) and the French standard FD P50-784 (AFNOR, 2016). Leakages are classified according to the leakage categories of FD P50-784 (see appendix A) with 8 main categories and 46 sub-categories (see appendix A).

Figure 3 shows the frequency of detected leakages by category in single-family, multi-family and non-residential buildings. Leakages through doors and windows (category C), electrical components (category F) and around penetrations through the envelope (category D) are the most frequent leakages detected in all buildings.

In order to analyse the impact of leakages on the air permeability, we have constructed 46 subsamples corresponding to the 46 subcategories of leakages. Each subsample contains the data where a particular leakage

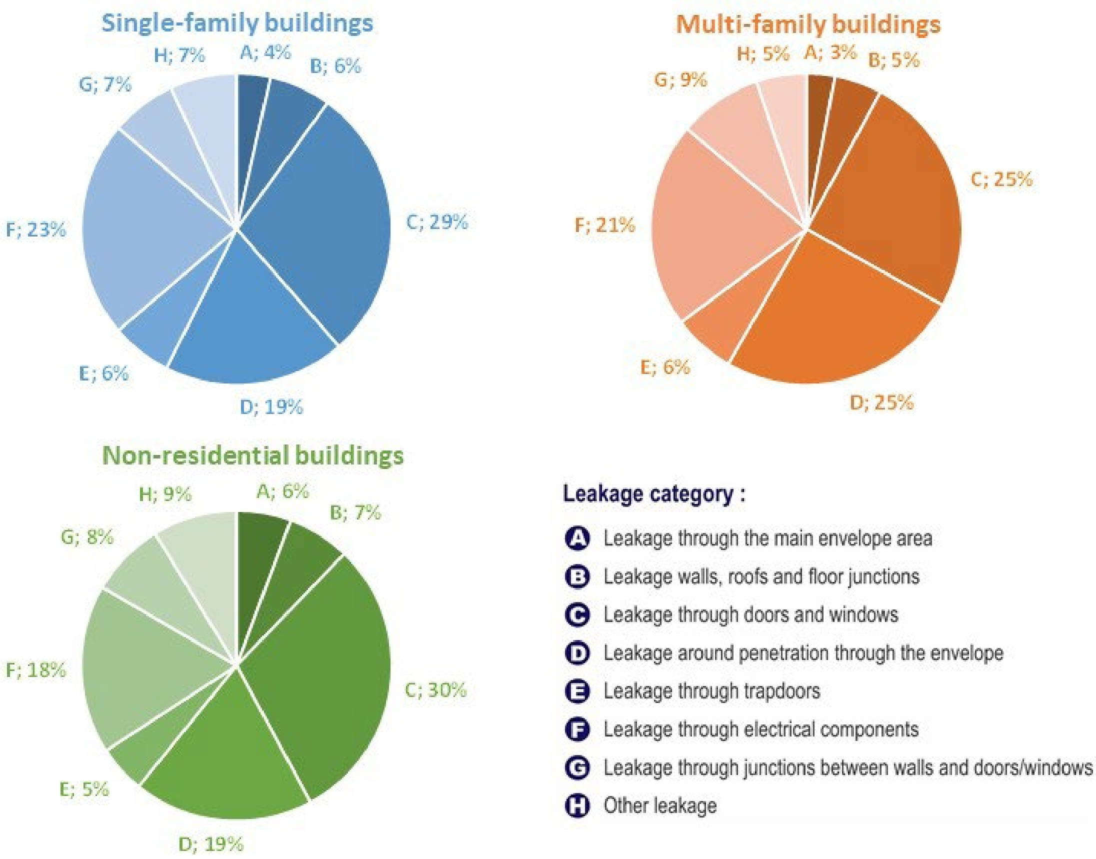


Figure 3. Frequency of detected leakages in single-family, multi-family and non-residential buildings.

is observed. We then compared the mean value of air permeability of each subsample to that of the entire sample using Wilcoxon tests. For this analysis, we used the air change rate at 50 Pa "n_{50}" as indicator to analyse air permeability variations, as it has the lowest error with respect to repeatability, reproducibility, and wind impact (Moujalled *et al.*, 2021).

Figure 4 shows the comparison between the boxplots of n_{50} of all leakage subsamples and the mean value of the entire sample. Leakage subsamples are sorted in decreasing order of the mean value of n_{50}. We can identify the leakage subsamples with highest values $n_{50,}$ the corresponding leakage can thus be considered to have greatest impact on the airtightness (p-value ≪ 0.01).

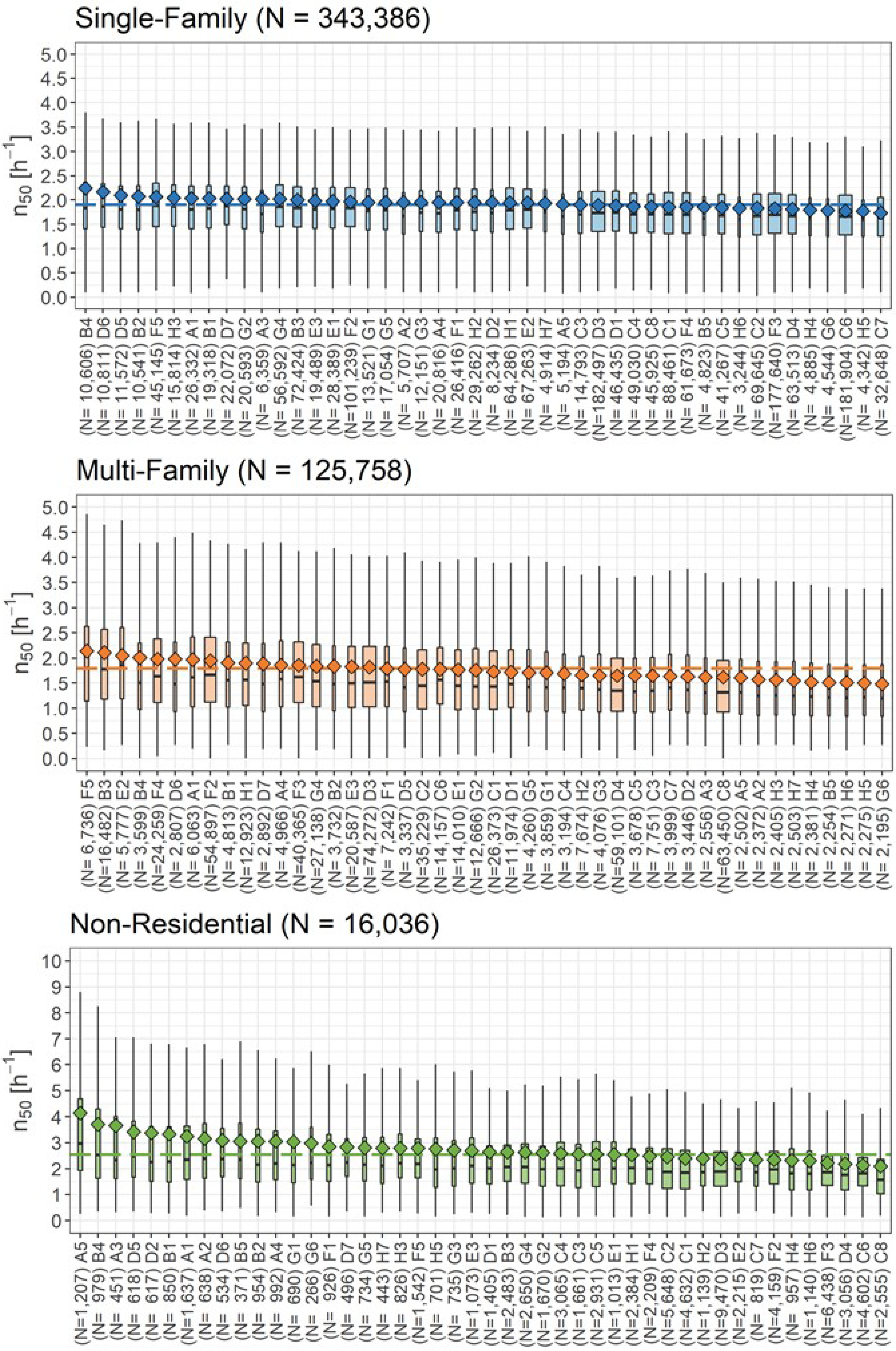


Figure 4. Boxplots of the measured air change rate at 50 Pa n50 in single-family, multi-family and non-residential buildings depending on the type of the detected leakage.

Table 1 shows the top five leakages with the highest values of mean n_{50} in single-family, multi-family and non-residential buildings. It is interesting to note that the B4 leak (junction between wall and ceiling or sloped roof) is among those with a significant impact on air-tightness in all three types of buildings, even though it is not very frequent. Overall, leakages through the main envelope area (A) and the junctions between walls and floors (B) are less frequent but have a significant impact on the air tightness of the building. As the search for leakages is not exhaustive during a test, a bias might exist in the detection of the leakages: leakages can be found only where the testers have looked for.

Conclusions

Since its creation in 2007, the French database of building airtightness has been annually fed by measurements performed by qualified testers. The total number of measurements is now about 570,000 with a majority of residential buildings (68% single dwellings, 28% multi-family buildings against 4% non-residential buildings). This is due to the mandatory requirements of the former EP-regulation RT2012 that was implemented in 2013 only for new residential buildings. It has initiated since 2013 a strong increase in the annual number of tests that fluctuates today between 65,000 and 80,000 approximately. Measurements from 2015 can thus be considered as representative of new French residential buildings. With the new requirement in the current regulation RE2020 for non-residential buildings, we can expect to see a large increase in the number of tests in office buildings and schools in the coming years, similar to residential buildings.

In new single-houses, the mean air permeability is about 0.4 $m^3/(h.m^2)$ at 4 Pa which is significantly below the mandatory threshold value (0.6 $m^3/(h.m^2)$) and 94% of all houses meet the mandatory requirement. In new multi-family buildings, the mean air permeability is about 0.8 $m^3/(h.m^2)$ at 4 Pa which is significantly below the mandatory threshold value (1.0 $m^3/(h.m^2)$) and 94% of all buildings meet the mandatory requirement. In new non-residential buildings, for which there is no mandatory test, the airtightness has improved over the years and is now equivalent to the new multi-family buildings level: 93% of the tested buildings are better than the default value of the RT 2012 (1.7 $m^3.h^1.m^2$). The analyses of detected leakages enable us to identify the most critical leakages that are not always the most frequent ones: leakages through the main envelope area and the junctions between walls and floors are less frequent but have a significant impact on the air tightness of the building. ■

Table 1. *The top five leakages with the greatest impact on air permeability.*

Type of building	Leakages with highest values of mean n_{50} (Occurrence)
Single-family	**B4-Junction between wall and ceiling or pitched roof (3%)** D6-Beam connection with floor or ceiling (3%) D5-Beam or joist connection with walls (3%) B2-Junction between two vertical walls (3%) F5-Lighting components (13%)
Multi-family	F5-Lighting components (5%) B3-Junction between wall and floor (13%) E2-Attic trap door (absent or ineffective seal) (5%) **B4-Junction between wall and ceiling or pitched roof (3%)** F4-Wiring inside internal walls (19%)
Non-residential	A5-False ceiling panels (8%) **B4-Junction between wall and ceiling or pitched roof (6%)** A3-mortar/glue junction between masonry blocks, wall panels (3%) D5-Beam or joist connection with walls (4%) D2-Vapour barrier membrane through which duct, pipe, beams, hatches (4%)

Appendix A – Leakage definition

Classification of leakages according to the French standard FD P50-784 (AFNOR, 2016).

Leakage category	Leakage sub-category
A - Main envelope area	A1 - Other leakage on main envelope area A2 - Vapour barrier membrane (or similar complex): adhesive junction between strips, puncture or tearing A3 - Mortar/glue junction between masonry blocks, wall panels A4 - Puncture (e.g.: wall plug) or unsealed junctions between panels A5 - False ceiling panels
B – Wall, roof and floor junctions	B1 - Other leakage through wall and slab junctions B2 - Junction between two vertical walls B3 - Junction between wall and floor B4 - Junction between wall and ceiling or pitched roof B5 - Junction between vapour barrier membrane and slab
C – Doors and windows	C1 - Other leakage on windows and glazed doors C2 - Window / glazed doors: junction between frame and opening panels C3 - Window & glazed doors: junction between glass and frame defective seal) C4 - Landing door or fire door: poor compression of seals (excluding threshold bar) C5 - Landing door or fire door: absent or ineffective threshold bar C6 - Sliding door: Excessive space between glass panels. and the frame C7 - Sliding door: Evacuation of condensates C8 - Rolling shutter casing
D -Penetration through the envelope	D1 - Other element through a wall D2 - Vapour barrier membrane through which due pipe, beams, hatches D3 - Crossing Floor, walls and/or partitions (any type of pipes and electrical wiring…) D4 - Ventilation air terminals: leaks at periphery of exhaust/supply air vents D5 - Beam or joist connection with walls D6 - Beam connection with floor or ceiling D7 - Stairs: Junction flooring/stairs or vertical walls/stairs
E - Trapdoor	E1 - Another trapdoor E2 - Attic trap door (absent or ineffective seal) E3 - Trapdoor to vertical technical duct (absent or ineffective seal)
F - Electrical component	F1 - Other electrical component F2 - Electrical board F3 - Wiring inside external walls F4 - Wiring inside internal walls F5 - Lighting components
G - Door / window and wall junctions	G1 - Other leakage through wall and door/window junction G1 - Junction between walls and windows or glazed door G3 - Junction between walls and landing door or Fire door G4 - Junction between internal panels and window and glazed door G5 - Junction between internal panels and landing door or Fire door G6 - Junction between vapour barrier membrane and door or window
H - Other	H1 - Other leakage H2 - wood-burner, fireplace insert or boiler. or combustion-air air vent H3 - Extractor hood with external evacuation H4 - Trap door for smokes evacuation H5 - Zenithal lighting roof lights H6 - Elevator door (frame - connecting door…) H7 - Arrival air extraction or not described in the thermal calculation

References

AFNOR (2015) 'NF EN ISO 9972. Thermal performance of buildings - Determination of air permeability of buildings - Fan pressurization method'.

AFNOR (2016) 'FD P50-784. Thermal performance of buildings - Implementation guide for NF EN ISO 9972'.

Mélois, A.B. et al. (2019) 'Improving building envelope knowledge from analysis of 219,000 certified on-site air leakage measurements in France', Building and Environment, 159, p. 106145.

Moujalled, B. et al. (2021) 'Mid-term and long-term changes in building airtightness: A field study on low-energy houses', Energy and Buildings, 250, p. 111257.