French database of building airtightness, statistical analyses of about 215,000 measurements: impacts of buildings characteristics and seasonal variations

Bassam Moujalled*[1], Valerie Leprince[2], and Adeline Bailly Mélois[1]

1 Cerema, Direction Centre-Est
46 Rue St Theobald
F-38081, L'Isle d'Abeau, France
**Corresponding author:*
bassam.moujalled@cerema.fr

2 PLEIAQ
84C Av de la liberation
F-69330, Mezyeu, France

ABSTRACT

The French database of building airtightness has been fed by measurement performed by qualified testers since 2006. In 2015 and 2016, the database was enriched by 63,409 and 65,958 measurements respectively, which is 74% more than in 2014, making the total number of measurements about 215,000. However, residential buildings (multi-family and single dwellings) account for almost all of measurements, only 4% of tests are performed in non-residential buildings. Indeed, since 2013 the French EP-regulation requires a limit for airtightness level for all new dwellings. The justification of the building airtightness level shall be done either by an airtightness test or by the application of a certified quality management approach.
In the first part, this paper summarizes the recent results of the database regarding buildings' characteristics (building area, main material, ventilation system, insulation...).
The second part proposes first results regarding the evolution of air permeability. In single dwellings, the air permeability at 4 Pa (per unit of envelope area) slightly decreases from year to year with a mean value around 0.41 $m^3.h^{-1}.m^{-2}$ in 2015. In multi-family buildings, the yearly mean air permeability fluctuates between 0.60 and 0.65 $m^3.h^{-1}.m^{-2}$. In non-residential buildings, it fluctuates around 1 $m^3.h^{-1}.m^{-2}$. However non-residential buildings cover a wide variety of buildings. A special focus is made on non-residential buildings depending on the use of the building and its size.
The last part of this paper deals with the impact of the seasonal variations on the measured air permeability in single dwellings depending on climatic zones and buildings construction materials (wood, concrete and brick constructions). An impact of seasonal variations on air permeability is only observed in the case of wood constructions, with slightly higher values during summer in the south of France in particular.

KEYWORDS

Building airtightness, measurements, database, field data

1 INTRODUCTION

Building airtightness is a key issue to achieve low- and very low-energy targets. Therefore, an increasing number of tests are performed in European countries. To improve the reliability of those tests, qualification schemes for airtightness testers are developing all over Europe (Leprince et al., 2017). France, UK and Belgium have taken advantage of those schemes to impose systematic record of airtightness test and to develop databases (Leprince et al., 2017)(Cope, 2017).
The French database of building airtightness was created in 2007 following the implementation of a national qualification scheme for building airtightness measurement.

Thus each qualified tester is required to register all test results in a formatted table and send this register table to the certification body every year. The database is fed annually by these tables. The structure of the table is presented by (Bailly et al., 2015).
The number of measurements in the database has strongly increased since 2013 thanks to the mandatory requirement of the French Energy Performance (EP) regulation which requires a limit airtightness level for new residential buildings. The justification of the building airtightness level shall be done either by an airtightness test performed by a qualified tester, or by the application of a certified quality management approach on building airtightness. Also low-energy labels have helped to strengthen airtightness requirements.
Currently, about 215,000 measurements have been recorded in the database. It includes all the measurements that were performed by certified testers till the end of 2016. In June 2018, they are 871 certified testers.
This paper summarizes the recent results of the database regarding buildings' characteristics, the evolution of air permeability, and the impact of seasonal variations.

2 DATABASE OVERVIEW

Figure 1 shows the evolution of the number of building airtightness measurements and the percentage of measurements depending on the use of the building.
In 2015 and 2016, the database was enriched by 63,409 and 65,958 measurements respectively, which is 74% more than in 2014, making the total number of measurements about 215,000. The number of measurements has been boosted by the mandatory requirement for new residential buildings which has been introduced since January 1st 2013 based on the date of building permit. However, it is only since 2015 that every new residential building is being measured given the delay between the dates of building permits and the achievement. We can expect that the number of tests will be stable around 65,000 tests per year.
Residential buildings account for almost all of measurements (64% for single-family dwellings with 140,542 measurements, and 32% for multi-family buildings with 70,632 measurements), only 4% of tests are performed in non-residential buildings (7,997 buildings). This is due to the fact that the mandatory requirement applies only for residential buildings: for non-residential buildings, it is still possible to use default values in the EP-Calculation. However, since 2013 new "Effinergie" labels require an airtightness measurement for non-residential building with an area below 3,000m². Thus, more data should be collected for these buildings in the next years.

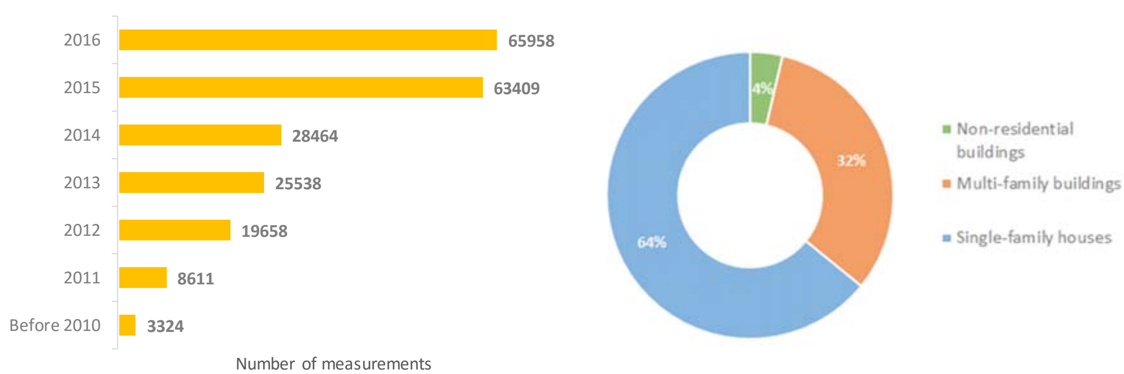

Figure 1:Evolution of the number of building airtightness measurement in France (left) and percentage of measurements depending on the use of the building

Figure 2 presents the distribution of the measurements number depending on the measurement time and the measured extent of building. It shows that only 10% to 15% of residential buildings are tested during construction, against more than 30% in non-residential buildings. Commissioning tests in residential buildings are always reported in the database. However, it is possible that some tests during construction are not filled in the database by the testers.
Regarding the measured extent of the building, almost all measurements in single-family dwellings are performed on the whole building. Conversely, more than 85% of the measurements in multi-family buildings are carried out on a part of the building. In non-residential buildings, almost 70% of measurements are performed on the whole buildings. This results are in accordance with the compulsory measurement protocol which allows measurements based on a sampling method for multi-family buildings over 10m in height (NF EN ISO 9972, 2015) (FD P50-784, 2016).

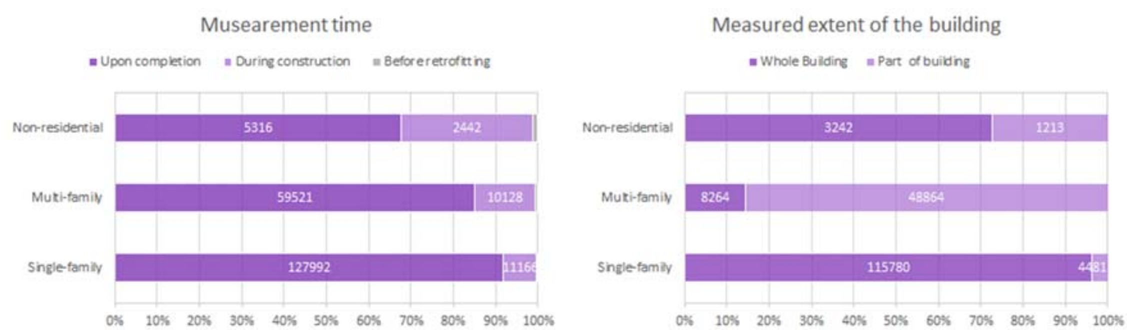

Figure 2: Number of building airtightness measurements depending on the measurement time (left) and the measured extent of building (right)

3 RESULTS

3.1 Main characteristics of buildings

Figure 3 presents the share of buildings with EP-labels depending on the building use and the year of construction. During the first years, measurements in residential buildings were carried out mainly in the buildings with EP-labels. Since 2014, the share of residential buildings with label have dropped due to the mandatory requirement. Thus, measurements from 2015 can be considered as representative of new French residential buildings.
For non-residential buildings, almost 70% of the tested buildings have no label, which means that for non-residential building the main reason for testing is probably to improve the EP-calculation and not to comply with a label. However, to increase the number of test performed either a mandatory requirements or more penalizing default values are needed.

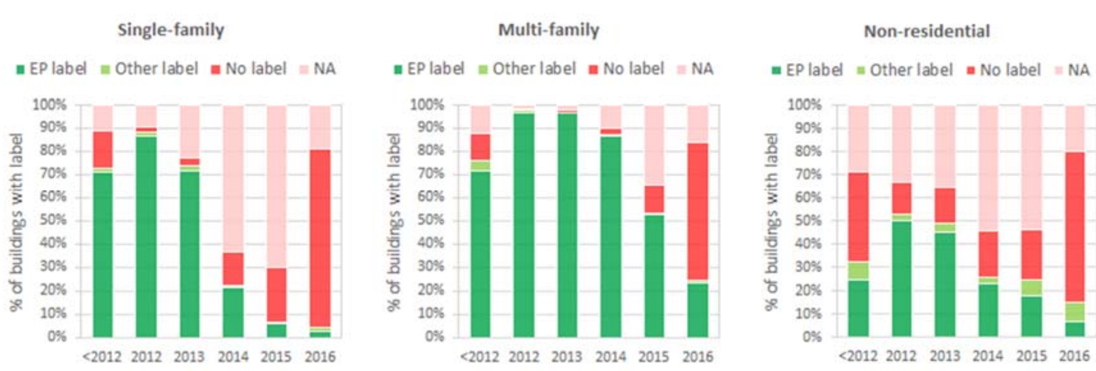

Figure 3: Percentage of buildings with EP-label

Figure 4 presents the characteristics of buildings regarding main construction material and ventilation system for single-family, multi-family and non-residential buildings. The majority of single-family houses are built of masonry, mainly with brick (47%) followed by concrete (28%). Wooden houses account for 8%. For Multi-family buildings, concrete is the main material (44%), followed by brick (28%). Wood accounts only for 2%. For non-residential building, concrete is also the main material (36%), but the wood seems to be more widely used (17%) as it is more than brick (15%).
It is important to note that the airtightness of concrete and brick constructions is treated in the same way in France, in most cases it is made through plasterboards and mastics at the inside facing of the walls. The wooden constructions are mainly wood frame structure, and the airtightness is ensured by the vapour barrier.

Regarding ventilation systems, we first observe that all residential buildings have been equipped with mechanical ventilation, mostly single exhaust systems (94% for single-family houses and 98% for multi-family buildings buildings). In fact, the French regulation requires general and permanent airing of residential buildings. Single exhaust systems include humidity sensitive ventilation system which is the most commonly used system in French residential buildings. Non-residential buildings are also almost all equipped with mechanical ventilation system, with mainly balanced systems (52%).

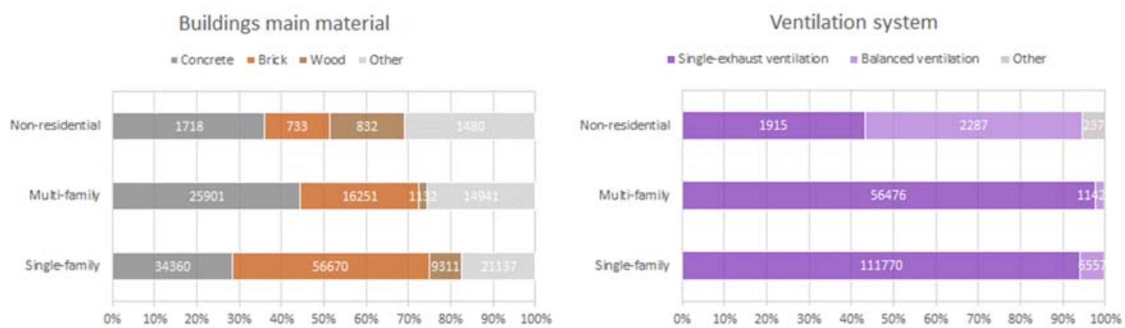

Figure 4: Number of building airtightness measurements depending on the buildings main material (left) and ventilation system (right)

3.2 Evolution of measured building airtightness

The results presented here are expressed according to 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 ($m^3.h^{-1}.m^{-2}$). Only measurements performed upon completion are presented and analysed hereafter in order to perform relevant comparisons.

Figure 5 presents the annual evolution of the number of tests and the average value of the air permeability for residential and non-residential buildings.
For residential buildings, results show a fast increase of the number of airtightness measurements since 2007. This dynamic was first triggered in 2007 by the French EP-label "BBC-Effinergie" and then accentuated with the mandatory requirement in 2013.
The annual increase in the number of measurements comes together with a significant drop in the average value of the air permeability (and thus an improvement in airtightness) during the first years. Since 2013, it has stabilized around 0.4 $m^3.h^{-1}.m^{-2}$ in single-family houses and 0.65 $m^3.h^{-1}.m^{-2}$ in multi-family buildings. The slight increase in multi-family since 2015 can be explained by the fact that every new building is now tested and not only exemplary ones that were applying for a label. The EP-regulation requires that Q_{4Pa_surf} is below 0.6 $m^3/h/m^2$ for single-family houses and 1 $m^3/h/m^2$ for multi-family buildings.

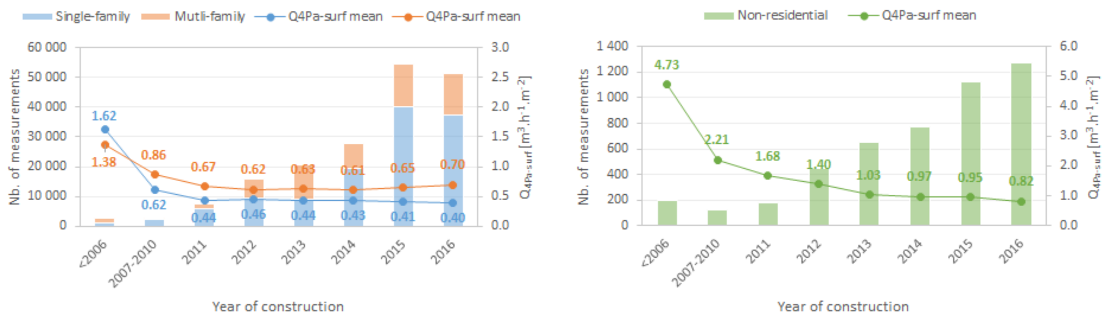

Figure 5: Evolution per year of construction of the number of measurements and the mean air permeability in residential buildings (left) and none-residential buildings (right)

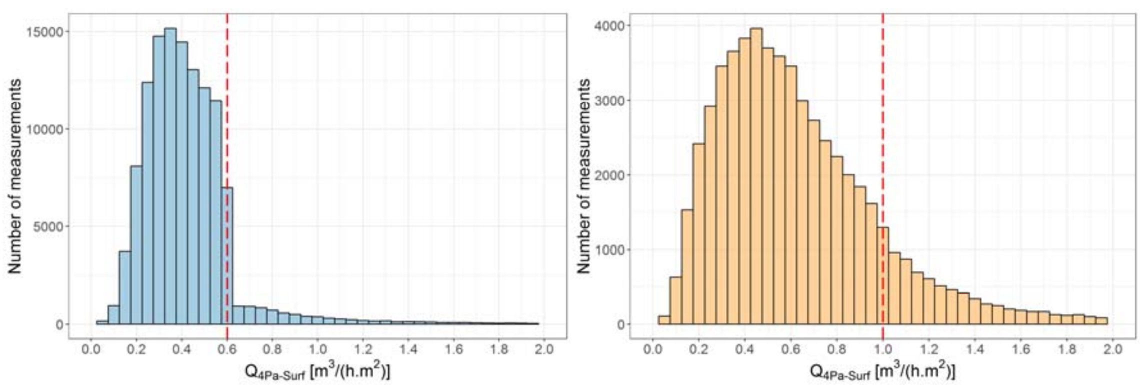

Figure 6: Distribution of building air permeability measured in single-family houses (left) and multi-family buildings (right)

Figure 6 presents the distributions of building air permeability measured in single-family houses and multi-family buildings.

For single-family dwellings, we observe the threshold effect of the mandatory requirement of the EP-regulation at 0.6 m^3.h^{-1}.m^{-2} which creates a discontinuity in the distribution of the measured values of the air permeability. This is due to last-minute corrections during the commissioning test to force the measured air permeability below the regulatory threshold. Thus 93% of the measurements are below 0.6 m^3.h^{-1}.m^{-2}. Also more than half (53%) are below the threshold of EP-label "Effinergie+" 0.4 m^3.h^{-1}.m^{-2}.

For multi-family building, the distribution is more regular and is close to a skew-normal repartition. The threshold of 1 m^3.h^{-1}.m^{-2} seems to be easier to reach in multi-family buildings with 86% of measurements below this threshold, and 73% below the threshold of EP-label "Effinergie+" 0.8 m^3.h^{-1}.m^{-2}. Note that most tests are performed by sampling, so in most cases only dwellings are tested and not common parts.

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. Also the mean value of air permeability has decreased annually to reach 0.82 m^3.h^{-1}.m^{-2} in 2016. In addition, this value is similar for buildings with or without an EP-label.

As for multi-family buildings, Figure 7 shows that the distribution is close to a skew-normal repartition as there is no mandatory requirement; 87% of measurements are below the default value of the EP regulation (1.7 m^3.h^{-1}.m^{-2} for all non-residential buildings except commercial, gym, industrial and transportation buildings for which the default value is 3 m^3.h^{-1}.m^{-2}), and 67% below the threshold of multifamily buildings (1 m^3.h^{-1}.m^{-2}).

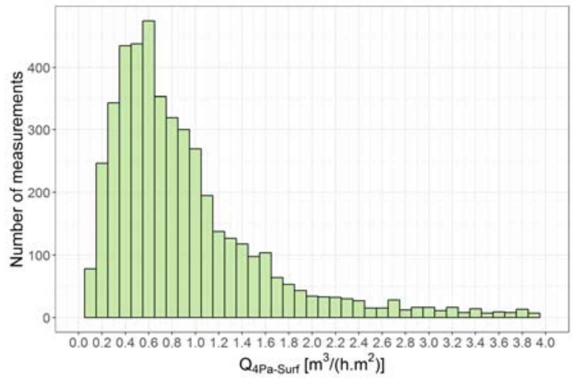

Figure 7: Distribution of building air permeability measured in non-residential buildings

The mean value of air permeability of non-residential in 2016 (with or without EP-label) is approximately half of the default value of the EP-regulation. According to (Leprince et al., 2011), we can expect an energy saving from 10% to 30% when using the average value (0.8 $m^3.h^{-1}.m^{-2}$) rather than the default value.

Despite the absence of a mandatory requirement, airtightness of non-residential buildings continue to improve, but only for those who have decided to care about it.

Non-residential buildings cover a wide variety of buildings. The average value can mask different situations depending on the type of building and the volume. Therefore, a special focus is made on non-residential buildings depending on the use of the building and its size. We present in Figure 8 main summary of the volume of non-residential buildings depending on their use, and in Figure 9 the variations of air permeability depending on the building use and the range of volume for office buildings. In order to perform relevant comparisons, this analysis is based only on non-residential buildings constructed since 2013 as they present comparable values of the annual average air permeability.

The main parts of non-residential buildings are offices (25%), schools (20%) followed by hospitals (10%), gym, restaurants and other non-residential buildings (commercial, hotel, nursery, industrial…). All non-residential buildings present similar volumes with average values below 5,000 m^3, with the exception of Gyms with higher value which is logical for this kind of buildings. The median values are globally less than 1000 m^3 except for schools and gyms with 1,311 m^3 and 1,294 m^3 respectively.

The statistical values of the air permeability of the different uses are globally equivalent, with the exception of restaurants with slightly higher values. This is probably due to the hoods, and to the complexity of the technical equipment which multiplies the number of penetrations through the building envelope.

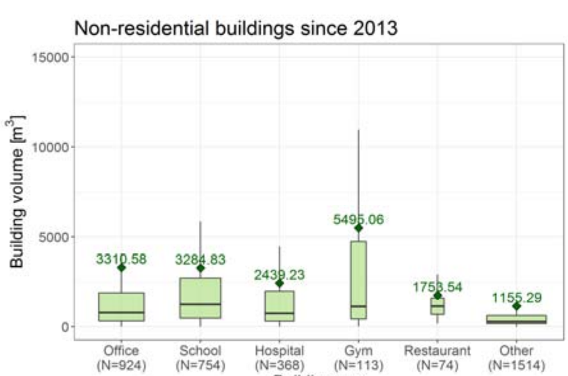

Figure 8: Descriptive statistics of the volume of non-residential buildings since 2013

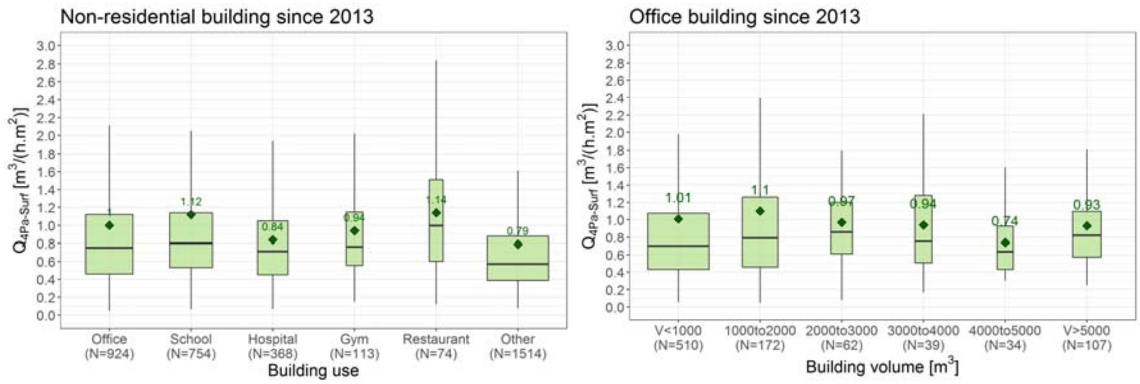

Figure 9: Variation of air permeability depending on the building use (left) and the range of volume for office buildings (right)

The distributions of air permeability by building use are globally heterogeneous with mean values closer to the 3rd quartile than the median. We also observe the same heterogeneity as a function of volume classes for office buildings.

3.3 Impact of the seasonal variations

The impact of seasonal variations on airtightness was already considered by (Kim & Shaw, 1986) (Wahlgren, 2014). A variation of the airtightness depending on the season has been observed in particular for the wood structure houses which can be air tighter in summer than in winter. Another study has also shown that the airtightness of a timber building is affected by the indoor relative humidity (Domhagen & Wahlgren, 2017).

In order to investigate the seasonal impact on airtightness, we have analysed the seasonal variation of air permeability of single-family houses according to the method of construction and local climate. We have classified houses into 3 categories depending on their sensitivity to moisture and the treatment of airtightness:

- wood structure houses where the airtightness is ensured by the vapour barrier;
- heavy structure with interior insulation where the air barrier is ensured by plasterboards and mastics at the inside facing of the walls;
- heavy structure with exterior insulation where the air barrier can be ensured either by plasterboards and mastics (like interior insulation) or by coating on the masonry.

As the relative humidity varies according to the season and the climatic zone, we considered 3 different climates based on the climatic zones of the French EP-regulation: continental climate (H1), oceanic climate (H2), and Mediterranean climate (H3).

Figure 10 to Figure 12 show the seasonal variations of air permeability of single-family dwellings depending on the construction method respectively.
For wooden houses, we do not observe seasonal variations for continental and oceanic climates. On the other hand, for the Mediterranean climate, we observe globally higher values for all seasons. In addition, the summer period shows higher values than in winter for the Mediterranean climate. This result is different from what was observed before for wood houses with higher airtightness during summer period. However, in France, wood constructions are almost always done with a vapour barrier, so the impact of wood distention with humidity is assumed to be low which may explain the difference in conclusion. In addition, the number of measurements in the Mediterranean climate is relatively low compared to other climates, which limits the statistical interpretation of these results.

For heavy structure houses with interior insulation, the results do not show seasonal variations for any climate. As for wooden houses, we observe slightly higher values of air permeability for the Mediterranean climate during all seasons.
Finally, for heavy structure houses with exterior insulation, the number of measurements is not sufficient to make statistical analyses, in particular for the Mediterranean climate. It seems that houses are less air tighter during mid-season. This results needs to be further investigated.

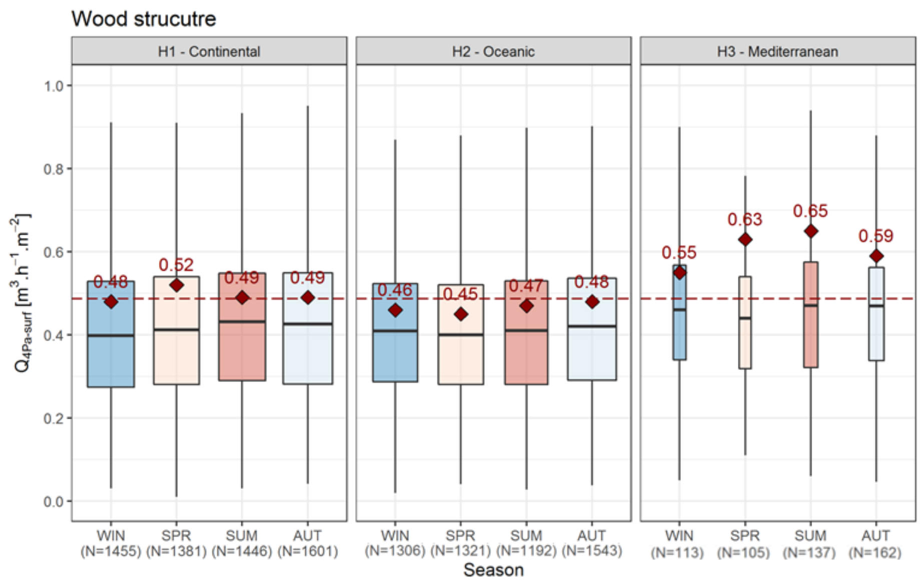

Figure 10: Variation of air permeability for wood structure houses depending on climate and season (mean value is indicated by the red dashed line)

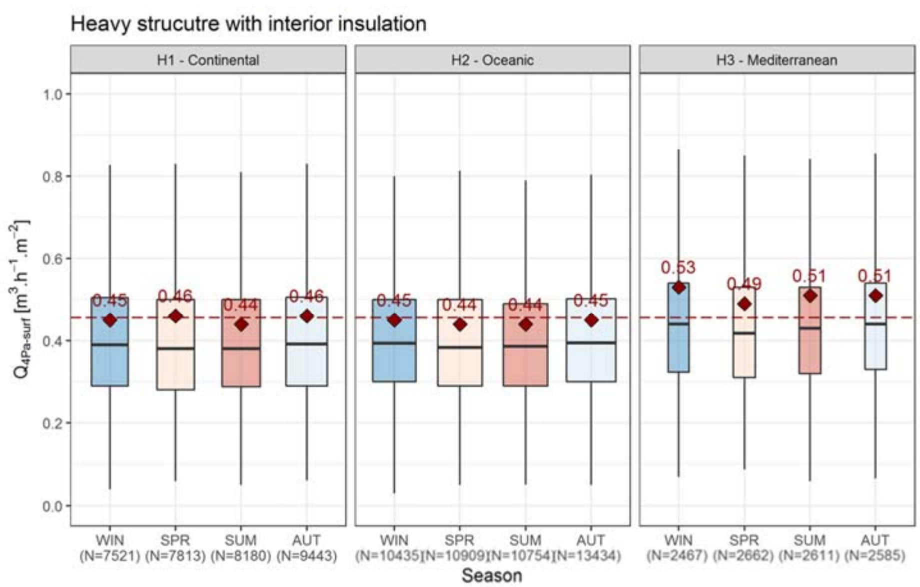

Figure 11: Variation of air permeability for heavy structure houses (with interior insulation) depending on climate and season (mean value is indicated by the red dashed line)

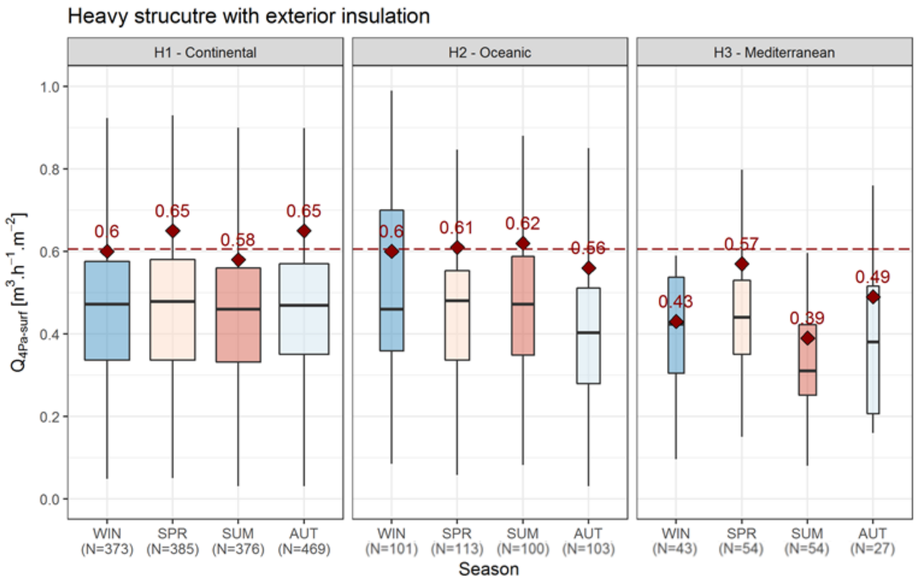

Figure 12: Variation of air permeability for heavy structure houses with exterior insulation depending on climate and season (mean value is indicated by the red dashed line)

4 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 215,000 mostly residential buildings (multi-family and single dwellings). This is due to the fact that the French EP-regulation requires since 2013 a limit for airtightness level for all new dwellings. Therefore, the share of residential buildings with EP-label has dropped since 2014 due to the mandatory requirement. Measurements from 2015 can thus be considered as representative of new French residential buildings.

In single dwellings, the air permeability at 4 Pa (per unit of envelope area) slightly decreases from year to year with a mean value around 0.4 $m^3.h^{-1}.m^{-2}$ in 2016. In multi-family buildings, the yearly mean air permeability fluctuates between 0.60 and 0.65 $m^3.h^{-1}.m^{-2}$. In non-residential buildings, it is around 1 $m^3.h^{-1}.m^{-2}$. However non-residential buildings cover a wide variety of buildings. Offices and schools are the main part of tested non-residential buildings in the database. The air permeability of the different uses is globally equivalent, with the exception of restaurants with slightly higher air permeability. Also air permeability of office buildings is globally equivalent for different volume ranges.

Finally, the impact of the seasonal variations on the measured air permeability in single dwellings was analysed depending on climatic zones and buildings construction materials (wood, concrete and brick constructions). An impact of seasonal variations on air permeability is only observed in the case of wood constructions, with slightly higher values during summer in the south of France in particular. This result needs to be deepened with more measurement results especially in the Mediterranean climate.

5 ACKNOWLEDGEMENTS

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