6 years of envelope airtightness measurements performed by French certified operators: analyses of about 65,000 tests

Adeline Bailly[*1], *Gaëlle Guyot*[1], *and Valérie Leprince*[2]

1 CEREMA – Direction Territoriale Centre-Est
46 rue Saint Théobald – BP128
38081 L'Isle d'Abeau Cedex, FRANCE
**Corresponding author: adeline.bailly@cerema.fr*

2 PLEIAQ
84 c Av. de la République
69330 Meyzieu, FRANCE

ABSTRACT

Since 2000, the French EP-calculations have been considering thermal losses due to building envelope airtightness. The last two regulations (RT2000 and RT2005) had included a default value for airtightness and the possibility to use a better-than-default value with a mandatory justification of this value, especially for voluntary approaches such as the BBC-Effinergie label. In 2013, strengthening the airtightness has become a requirement of the current EP-regulation (RT2012). It has implemented a limit value for airtightness for all new dwellings, and the mandatory justification of the building airtightness level through either an airtightness measurement or the application of a certified quality management approach. Therefore, there are more and more measurements of building envelope airtightness performed in a regulatory context.

In order to assess the quality of those measurements, the French Ministry for Ecology has implemented a process to certify the measurers. The first step of the process involves a qualifying State-approved training, a training exam, and the justification of a sufficient testing experience. Then, every tester is required to fill in a standard form every year. This form describes, for each measured building, various construction characteristics and airtightness measurement results. Since 2009, Cerema has been gathering the forms filled in by all qualified measurers. In 2015, those forms amount to about 65,000 measurements performed on dwellings and non-residential buildings in France.

This paper presents an analysis of this database. First, it proposes an overview of the measured buildings characteristics, including the main structural material and the use of the buildings. The second part of this paper presents first analyses on envelope airtightness. It describes the location of the leaks from criteria established in 2012. It also presents the evolution of the measured airtightness depending on various parameters such as the date of construction and the volume of the buildings. It also provides hints to evaluate the bias induced by thermal conditions through an evaluation of the impact of the season of measurement on the measured airtightness. The last part of this paper gives some feedback about the consequences of requiring a limit value: firstly, on the airtightness of buildings (both those subject to the requirement and those that are not), and secondly, on the practices of measurers.

In conclusion, this paper includes guidelines for using those data for different purposes, such as improving the control of certified measurers and reinforcing airtightness requirements for the next regulation.

KEYWORDS

Envelope airtightness – Measurements – Database

1 GENERAL CHARACTERISTICS OF THE DATABASE: DATA SOURCES

Since 2000, the French EP-regulation takes into account the airtightness of a building envelope. Previous EP-regulations RT2000 and RT2005 used to propose a default value for airtightness, with the possibility to use a better value (if justified). Now, the RT2012 regulation requires a limit airtightness level for residential buildings that has to be justified, but still allows to use default values for non-residential buildings (Charrier, 2015).
Since 2008, an airtightness measurement performed in order to comply with the current EP-regulation, or to justify a better-than default value in the thermal calculation, has to be performed by a third-party tester, certified by Qualibat, the certification body. Moreover, all airtightness tests performed in order to obtain the Effinergie certification also have to be made by a certified tester.
In July, 2015, almost 1,000 testers are certified. The certification includes not only training, examination and testing experience, but also a yearly follow-up. Therefore, all certified testers have to fill in a professional standard form that includes results of all airtightness measurements they have done within the year.
Each year, Cerema gathers those forms and fill in a national database with the airtightness tests results. In July, 2015, the database includes more than 68,000 tests.

The current version of the professional register proposes, for each test, to fill in 39 fields. 29 of them are required to comply with the tester certification. Those fields give information about:

- Building general information: owner, location, use, year of the construction, year of the rehabilitation;
- Special requirements: label, certification;
- Building main characteristics: main material, constructional type, insulation, ventilation system, heating system;
- Measurement protocol: operator, date of measurement, measurement device, time of measurement (building state), method;
- Measurement input data: envelope area (excluding low floor), floor area, volume;
- Measurement results: C_L, n, q_{a4}, n_{50}, uncertainties;
- Leaks: classification of the leaks (46 categories).

The database is composed with this information, after removal of duplications, irrelevant data and incomplete recording.

2 OVERVIEW OF BUILDING MEASURED CHARACTERISTICS

The RT2012 imposes to justify the envelope airtightness only for residential buildings. Nevertheless, some non-residential buildings have been measured, mostly in order to use a better-than-default value in the EP-calculation. Moreover, the Effinergie+ label imposes envelope airtightness measurement for non-residential buildings if the floor area is below 3,000 m². Therefore, the database includes residential and non-residential buildings. The main characteristics of those buildings are presented in the following paragraphs for:

- single-family houses;
- multi-family dwellings;
- non-residential buildings.

The data for about 65,200 buildings have been analysed (about 3,000 entries are incomplete and then have not been taken into account in this study).

2.1 Characteristics of residential buildings

More than half (35,382) of the measured buildings are single-family houses. Most of them are new buildings: 94% have been built since 2010. For others, about 350 (1%), the airtightness measurement has been performed after a rehabilitation.
Concrete block houses and brick houses represent 81 % of the measured houses, and 15% are built in wood. Others material are stone, wood and concrete combined or steel, and a few are built with straw or hemp.

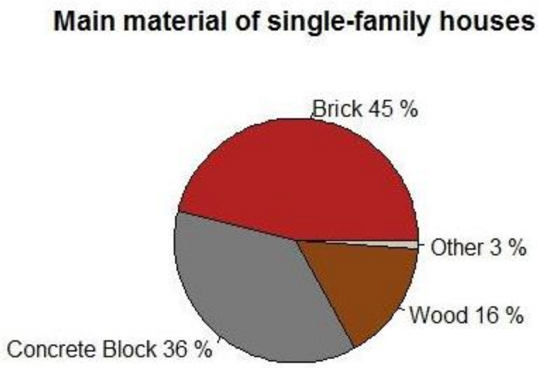

Figure 1: Main material of single-family houses

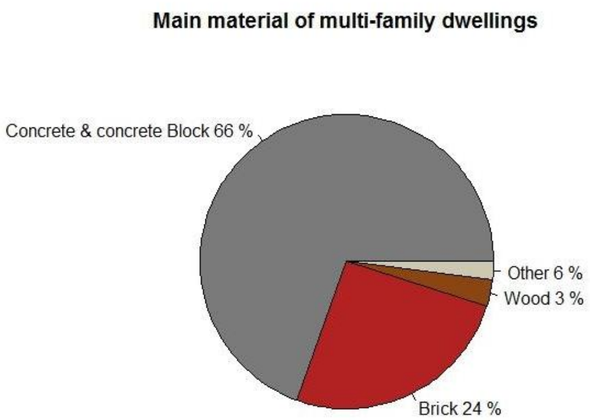

Figure 2: Main material of multi-family dwellings

The second type of buildings are multi-family dwellings: 26,823 buildings have been analysed in this study. They are almost all new buildings: 96% have been built since 2010. For those buildings, concrete and concrete block (66%) and brick (21%) are also the main material used. Wood is only used in few cases (3%).

2.2 Characteristics of non-residential buildings

Even if RT2012 does not impose an airtightness level for non-residential buildings, the database includes measurements results for about 3,000 non-residential buildings. They are mostly new buildings: 92% of them have been built since 2010. They are for the main part office buildings (29%) and schools (28%). Others are mainly health facilities, multi-purpose buildings, shops, gyms and restaurants. The entries of the “others” category (608) presented in figure 3 are lacking the “use” field. Half of the measured non-residential building are built in concrete (47%) and one quarter is built with wood (24%).

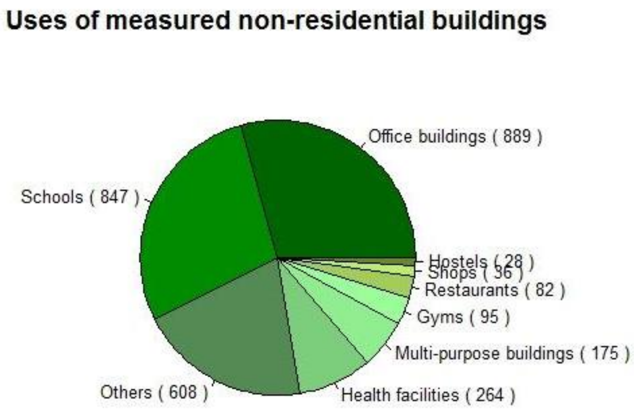

Figure 3: Uses of measured non-residential buildings

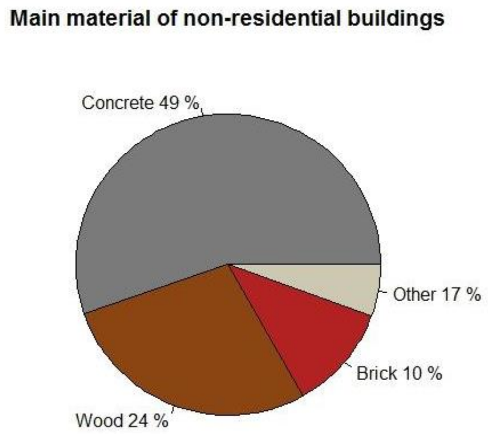

Figure 4: Main material of multi-family dwellings

3 EVOLUTION OF THE AIRTIGHTNESS ENVELOPE OF THE FRENCH BUILDINGS

In France, the reinforcement of buildings envelope airtightness has been pushed at first by the BBC-Effinergie label, which has imposed, since 2008, q_{a4} limit values depending of the type of dwelling. Then, RT2012 has imposed those limits as compulsory limits for all new residential buildings since 2013. The evolution of the airtightness level has been analyzed for each of the three building categories.

3.1 First analysis: leaks location

Eight leaks locations have been established in 2012:

- A: Main envelope area
- B: Wall, roof and floor junctions
- C: Doors and windows
- D: Building component penetrating the envelope
- E: Trapdoor
- F: Electrical components
- G: Door/wall and windows/wall junctions
- H: wood-burner, chimney, elevator, cooker hood…

For each of them, 3 to 8 subclasses are also defined. Those subclasses have been filled in for almost 45,000 buildings.

For single-family houses, an average of 5.4 types of leaks per house are reported by the tester. 30% of the leaks are observed on doors and windows, especially on junctions between windows and jamb and roller shutter box. Electrical components are also an important source of leaks (24%), just as all buildings components penetrating the envelope (18%), in particular ventilation terminal devices (leakage all around them), pipes and ducts (electrical, plumbing).

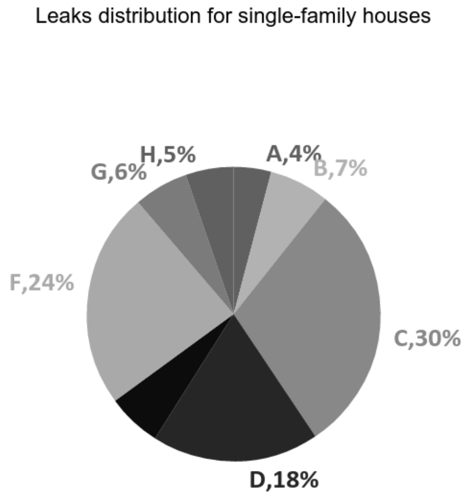

Figure 5: Leaks distribution for single-family houses

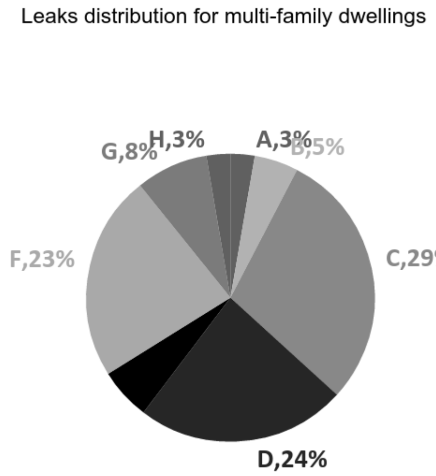

Figure 6: Leaks distribution for multi-family dwellings

The same analysis has been conducted on multi-family dwellings, which leads to an average of 4.8 types of leaks reported per building. The leaks are mainly observed at the same place as for single-family houses: doors and windows (29%), electrical components (23%) and components penetrating the envelope (23%).

Data are also available for 1,772 non-residential buildings. They confirm the previous results: on average, 5.7 types of leaks are reported per buildings, distributed in the same main categories as residential buildings.

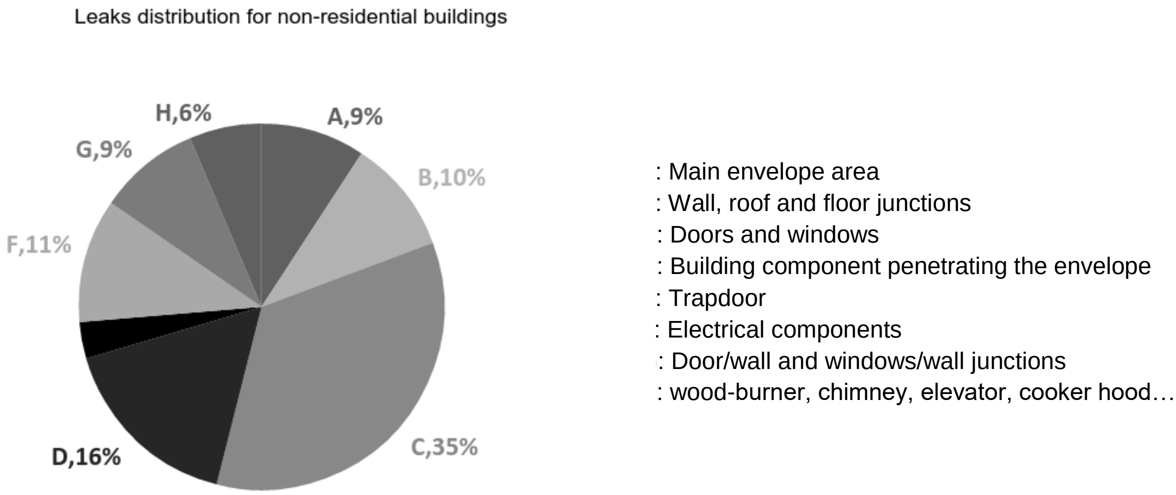

Figure 7: Leaks distribution for non-residential buildings

3.2 Evolution of measurements performed on residential buildings

The RT2012 regulation applies to all new buildings for which the building permit has been accepted since 1 January 2013. Only a few of them are built and have already been measured. Therefore, most of the measured buildings analysed in this study do not have to comply with

RT2012. Nevertheless, most of them have an airtightness objective. Indeed, 72% of the single-family houses were applying for the BBC-Effinergie label, which included an airtightness requirement: q_{a4} has to be below 0.6 $m^3.h^{-1}.m^{-2}$, that is around n_{50}=2.3 h^{-1}. Only about 6,200 of the measured houses did not have a target airtightness value. The same observation is made for multi-family dwellings: 90% of them were applying for the BBC-Effinergie label, which imposed an airtightness level: q_{a4} has to be below 1.0 $m^3.h^{-1}.m^{-2}$.

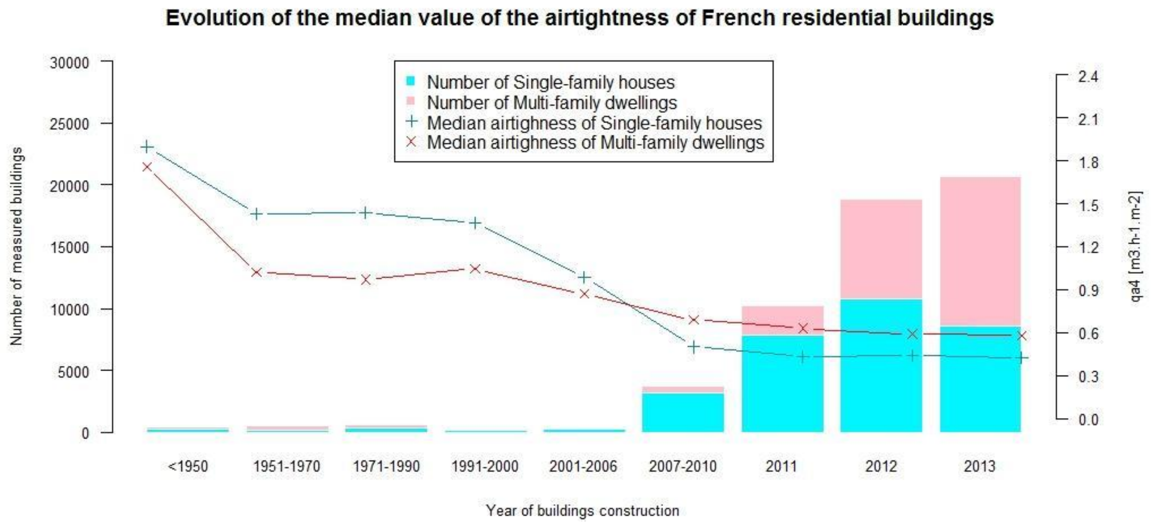

Figure 8: Evolution of the airtightness envelope measurements and their results for residential buildings

Those requirements have an impact on the measurements performed in France. First, the number of airtightness measurements performed on residential buildings is growing fast since 2007 (which corresponds to the beginning of the BBC-Effinergie label): from a few dozens of buildings tested each year before 2007 to about 20,600 in 2013. Secondly, buildings are becoming more and more airtight. Before 2007, measured multi-family dwellings were more airtight than single-family houses. But this does not hold for all buildings: in the sample of those years, more than 75% multi-family dwellings have been tested in order to comply with a certification, whereas less than 25% of the measured single-family houses were candidate to any certification. Since 2007, not only the BBC-Effinergie requirements are met, but the airtightness value is also better than the maximum value: in 2013, half of the measured airtightness envelope of single-family houses is below 0.4 $m^3.h^{-1}.m^{-2}$ and below 0.6 $m^3.h^{-1}.m^{-2}$ for half of the multi-family dwellings. Nevertheless, for most of the multi-family dwellings, the measurements have been performed by sampling, and not directly on the envelope building.

3.3 Evolution of measurements performed on non-residential buildings

Neither the BBC-Effinergie label nor the RT2012 regulation require an airtightness level for non-residential building. Moreover, only 36% of non-residential buildings in the database were applying for the BBC-Effinergie label, and 45% were not applying for any other certification.

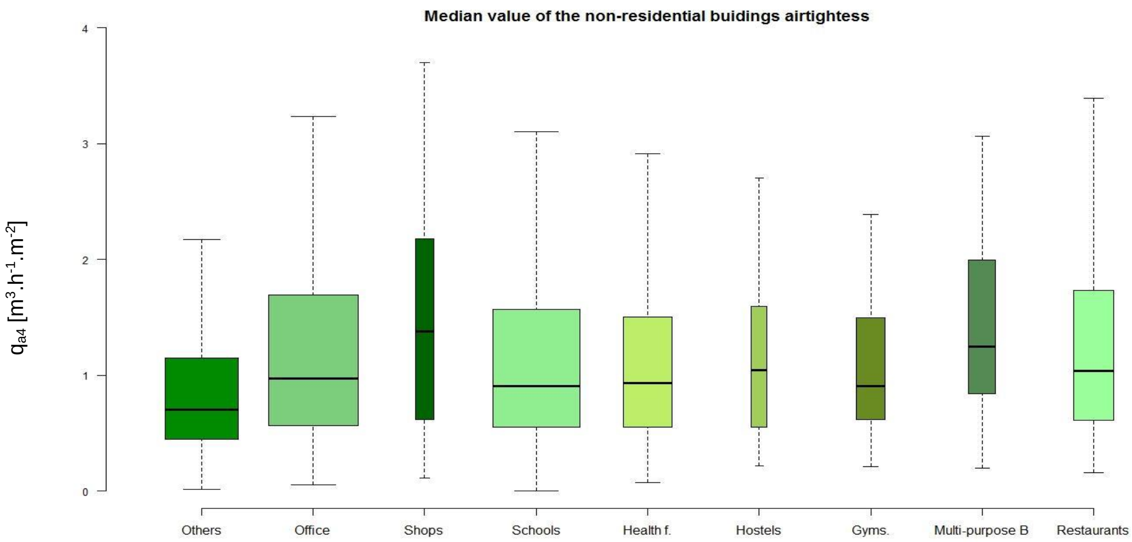

Figure 9: Non-residential buildings envelope airtightness depending on buildings' use

Therefore, depending of the use, the measured buildings envelope are more or less airtight. Nevertheless, for more than half of office buildings and schools, q_{a4} is below 1 $m^3.h^{-1}.m^{-2}$, whereas only 47% of office buildings and 55% schools were applying to a certification.

Among all those non-residential buildings, the measured volume varies quite a lot: from about 20 m^3 to several thousand cubic meters. Figure 10 illustrates that big buildings are not the least airtight.

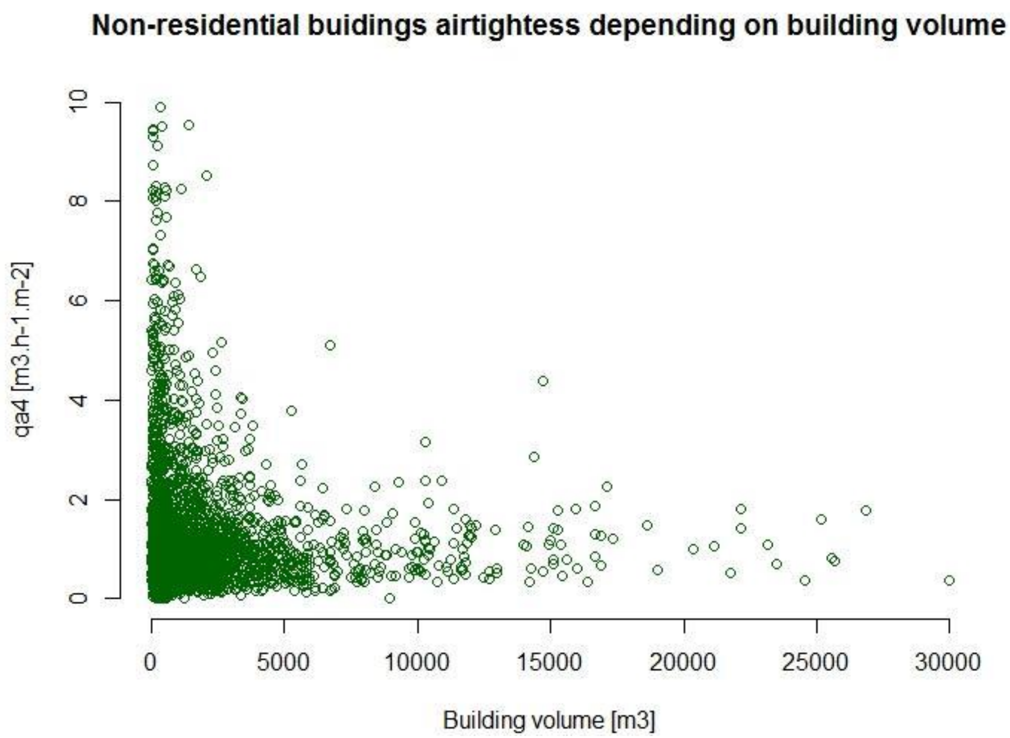

Figure 10: Non-residential buildings envelope airtightness depending on buildings' volume

Indeed, big buildings have the same leaks locations as others: doors and windows, electrical components, pipes and ducts (electrical, plumbing), which have no reason to be bigger when building volume increases.

3.4 Non bias induced by measurement season

The bias induced by thermal conditions could be evaluated through the important size of the database. Therefore, an analysis of the impact of the measurement season on the measured airtightness has been conducted. In France, standard temperatures range from -4°C to 13°C during the winter, and from 12°C to 29°C during the summer (source: meteofrance). Figure 11 presents results of airtightness measurements performed on single-family houses in 2013 (they were no particular climate conditions in 2013 in France).

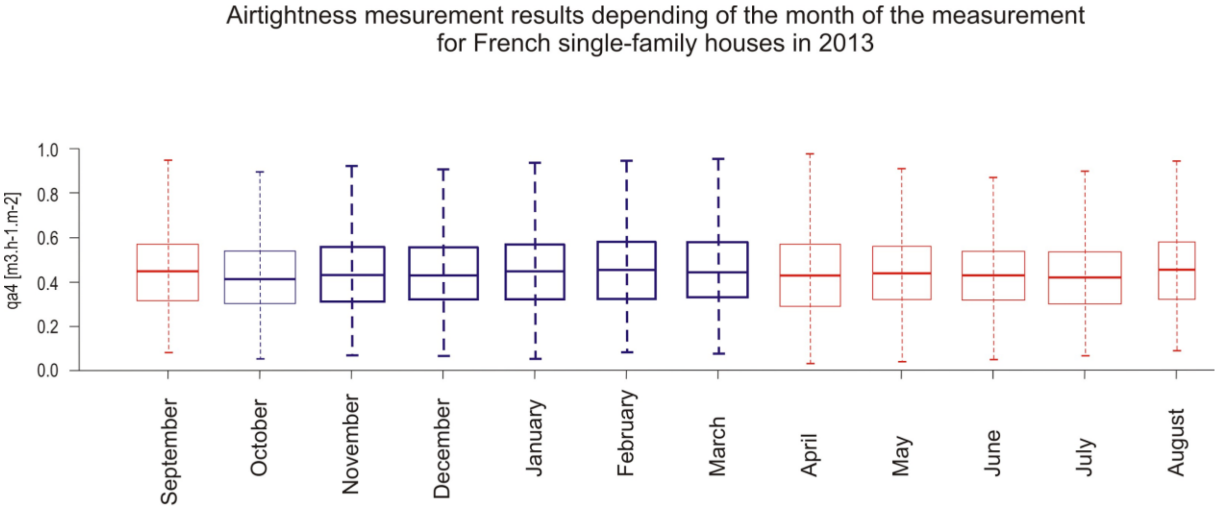

Figure 11: Single-family houses envelope airtightness depending on the measurement season (in 2013)

Those figures have been calculated from about 10,400 tests results. In those thermal conditions, the season of measurement significant impact on the result of the airtightness measurement.

4 CONSEQUENCES OF REQUIRING AIRTIGHTNESS LIMIT VALUES

As explained previously, since 2008, airtightness envelope measurements have been mostly performed on buildings applying for the BBC-Effinergie label and others certifications, especially residential buildings. Therefore, there were a target airtightness value. This calls for some questions:

- Do those buildings comply with the target value?
- What impact of those requirements on the construction sector?
- What impact on testers practices?

The following proposes partial answers to these questions.

4.1 Residential Buildings performance

The results of about 35,000 airtightness measurements performed on single-family houses have been analysed with respect to the BBC-Effinergie maximum value (q_{a4} = 0.6 $m^3.h^{-1}.m^{-2}$). Among those houses,

- 71 % were applying for the BBC-Effinergie label;
- 11% were applying for another certification;
- 18% did not have a target value (no certification).

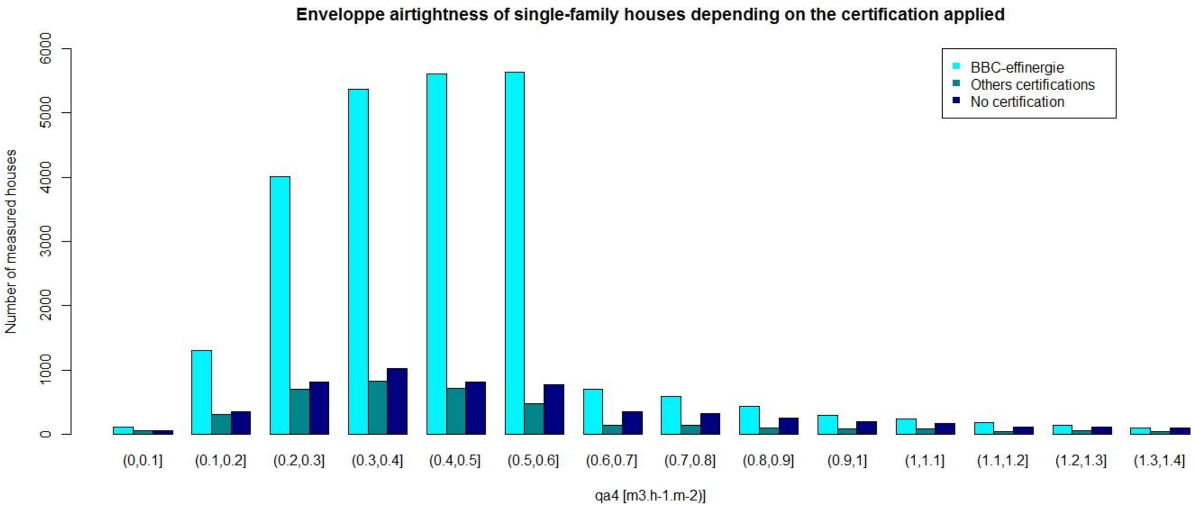

Figure 12: Single-family houses envelope airtightness depending on the certification applied

Figure 12 represents the number of measured houses in each airtightness interval. Almost all houses (87%) applying for the BBC-Effinergie label comply with the limit value, as well as 77% of houses applying for another certification. Moreover, about 70% of houses with no airtightness target meet the BBC-Effinergie label airtightness requirement. The same analysis has been conducted on multi-family dwellings, for which the BBC-Effinergie requirement is 1.0 $m^3.h^{-1}.m^{-2}$. The assessment is the same: 85% of buildings applying for BBC-Effinergie label comply with the limit value, as 69% of "others certifications". Moreover, 67% of buildings with no airtightness target meet the BBC-Effinergie label airtightness requirement.

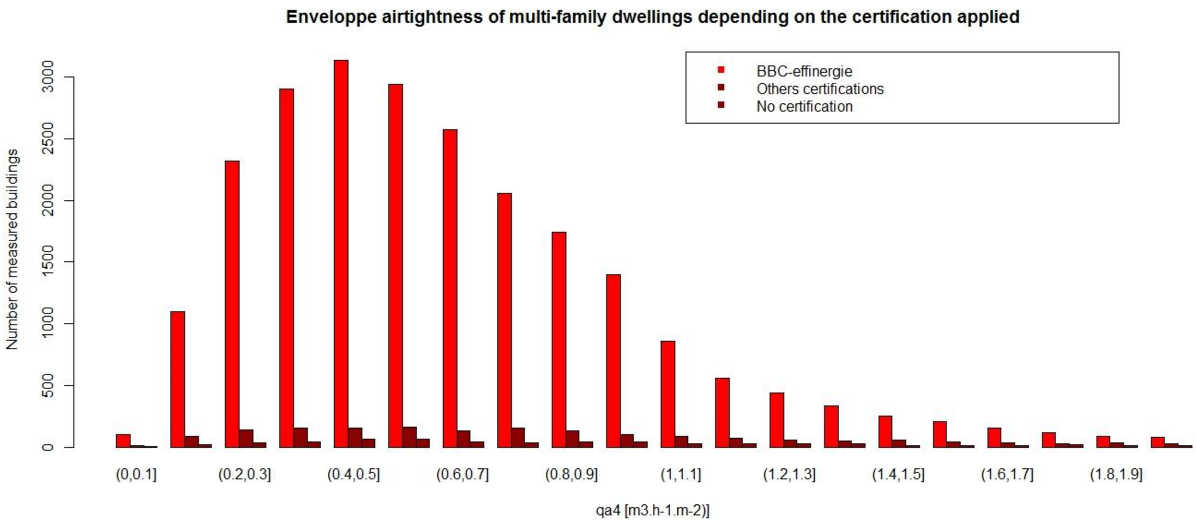

Figure 13: Multi-family dwellings envelope airtightness depending on the applied certification

Those results demonstrate that if the airtightness is taken into account during the design of the building with a reasonable target value, it is not difficult to comply with this objective.

4.2 Testers practices

The last point of this paper nuances the previous conclusion. Indeed, figure 12 shows a distinct "gap" at 0.6 $m^3.h^{-1}.m^{-2}$ for single-family houses applying for BBC-Effinergie label. Figure 14 proposes to zoom in on this "gap".

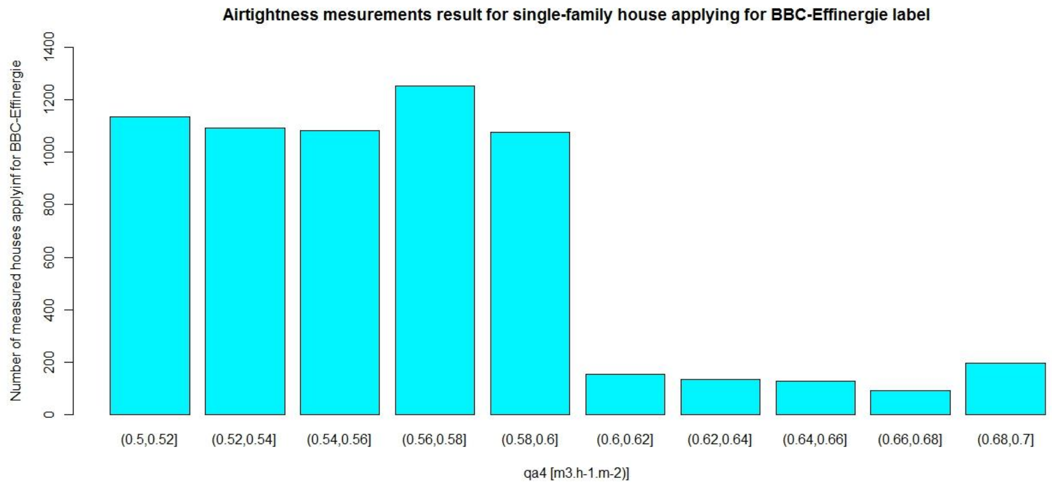

Figure 14: "Gap" of measured envelope airtightness for single-family houses applying for the BBC-Effinergie label

Even if no evidence of the cause of this gap has been provided, it seems reasonable to think that for those houses, the envelope airtightness has been modified just before the measurement. Actually, testers often perform a preliminary test, and the house owner or builder use mastic to seal off some leaks before the tester performs another measurement, in order to comply with the requirement. The pressure on testers could lead to some bad practices which will not ensure the durability of the envelope airtightness.

5 CONCLUSIONS & PERSPECTIVES

The French national airtightness database, with 65,000 measurements results as of today, is expected to be filled in with several thousands of entries each year. Many further analyses of those data should be conducted. First of all, analyses of the leaks location frequencies and of their impacts on the building envelope airtightness may lead to an improvement of the on-site work, through communications with building designers and workers. It may be completed with further analyses of the envelope airtightness, depending on main material, insulation and ventilation systems. Secondly, this database should be used to conduct more studies in order to acquire aeraulic information of building airtightness and leakage studying the *n* value. With this large database, it is now possible to develop a predictive model of building envelope airtightness, for example using principal components analysis.

Finally, several tools will be developed using those data:

- A national observatory website will be online in 2016: it will propose different analyses of the database, through various criteria as material, year of construction, label and certification, location, use of buildings. It will also geographically tag all certified testers.

- A new professional register: a new form will be proposed in order to make data more reliable, easier to process and analyse.
- A control tool with indicators calculated from individual testers statistics, with for instance, measurements results and number of measurements performed each day may be developed to make those checks easier.

6 ACKNOWLEDGEMENTS

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7 REFERENCES

Charrier, S., Bailly, A. and Carrié, F.-R. (2015). *Buildings airtightness in France: regulatory context, control procedures, results*. QUALICHeCK, Factsheet #x.

Bailly, A., Jiang, Y., Guyot, G. and Desfougères, F. (2013). *Preliminary analysis of French buildings airtightness database.* Proceedings of the 34th AIVC - 3rd TightVent - 2nd Cool Roofs' - 1st venticool Conference, 25-26 September, Athens 2013