PRELIMINARY ANALYSIS OF A FRENCH BUILDINGS AIRTIGHTNESS DATABASE

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ABSTRACT

Pushed at first by the labels backed onto the 2005 French energy performance (EP) regulation, and later on by the 2012 energy performance regulation, which imposes envelope airtightness requirements for any new dwellings, and pulled by a growing interest for low-energy labels, an important market transformation is observed in France on envelope airtightness measurement.

A framework has been set to supervise the authorized measurers' activities. Within this framework, the measurers must fill a standard register for each measurement they perform. Every year, since 2006, this file has to be sent to CETE de Lyon to set a database. It represented around 31.000 envelope airtightness data in August 2013 and around 100.000 new data are expected each year with the new EP regulation.

In 2013, a database and specific tools have been developed in order to make the most of this numerous data. Five airtightness indicators (Q_{4Pa_Surf}, n_{50}, NL, w_4, ELA_n) can be analysed through 20 parameters concerning: region and climate zone, building use, certification/label, building age, construction mode and main material, insulation type, ventilation system, heating system, measurement devices, method of the measurement, local measured (envelope or part of building), floor area and volume.

This paper describes the database, and presents some preliminary analysis about residential and non-residential buildings envelope airtightness based on the impact of several parameters: label and connected applicable airtightness requirement, building volume, ventilation system and main material.

KEYWORDS

Airtightness, database, measurement

INTRODUCTION

In France, air-leakage measurements of buildings envelopes have been increasing in recent years, pushed by some low-energy labels such as BBC-Effinergie, Passiv'Haus and Minergie. Furthermore, since January 1st 2013, the new French energy performance regulation (RT2012) is in effect. Therefore, airtightness measurements are now expected to represent about 100 000 data each year. Indeed, according to the RT2012, each residential building envelope has to respect some performance targets, and to justify its airtightness. The EP regulation imposes different requirements for the French indicator Q_{4Pa_Surf} (the air permeability at 4 Pa divided by the loss surfaces area excluding basement floor):

- 0.6 $m^3.h^{-1}.m^{-2}$ for single family houses (corresponds to an n_{50} = 2.4 h^{-1} for a ratio V/A*=1.3)

- 1 $m^3.h^{-1}.m^{-2}$ for multi-family dwellings (corresponds to an n_{50} = 2.3 h^{-1} for a ratio V/A* =2.3).

**The ratio V/A=Volume/ loss surfaces area excluding basement floor. The previous values correspond to the average of database ratio for these kinds of building*

Moreover, a new label has been introduced: Effinergie Plus, with more restrictive requirements:

- 0.6 $m^3.h^{-1}.m^{-2}$ for single family houses;
- 0.8 $m^3.h^{-1}.m^{-2}$ (sampling measurement) or 1 $m^3.h^{-1}.m^{-2}$ (entire building envelope measurement) for multi-family dwellings;
- compulsory measurement for non-residential building with a volume of less than 3 000 m^3, without requirement.

In this context, any air leakage measurement has to be done by a certified operator. According to the authorization process [1], each operator has to complete a professional register that includes results of all air leakage measurements he has done. This register is one of the main sources of data to study airtightness in French constructions.

This paper first explains the framework of the airtightness database developed by the CETE de Lyon from certified operators registers. Secondly, it describes the main properties of measured buildings, including distributions by use, year of construction and main material, for residential and non-residential buildings. Then, this article presents a state of the art of French buildings airtightness developed from this database, according to indicators such as buildings use, label candidacy and ventilation system.

1 DATABASE: DATA AND OPERATING SYSTEM

For each measurement, French certified operators have to include all information concerning label and connected applicable airtightness requirement, building volume and cold wall area, ventilation system, structure and insulation type, and measurement season into a standardized Excel spreadsheet. The database includes all information of operators register and more. It extracts geographical data (region, climate zone) and, when data are complete, calculates the value of five airtightness indicators:

$$Q_{4Pa\_Surf} = \frac{C_L * 4^n}{A_{Tbat}} \quad (1) \qquad n_{50} = \frac{C_L * 50^n}{Volume} \quad (2) \qquad w4_{Pa} = \frac{Q_{4Pa\_Surf} * A_{Tbat}}{Area} \quad (3)$$

$$ELA_{4Pa} = \sqrt{\frac{\rho}{2*4Pa}} * Q_{4Pa\_Surf} \quad (4) \qquad NL = 1000 * (\frac{ELA_{4Pa}}{Area}) * (numbers of . floors)^{0,3} \quad (5)$$

with A_{Tbat} = loss surfaces area excluding basement floor *(m^2)*, *Area* = Floor area *(m^2)*, C_L=air leakage coefficient *($m^3.h^{-1}.Pa^{-n}$)*, n = air flow exponent and ρ = air density *($kg.m^{-3}$)*.

According to each case, (1) and (2) could be included in recorded data or calculated: if the building is measured to obtain the Passiv'Haus label, the airtightness indicator is n_{50}; else, it is Q_{4Pa_Surf}. Indicators (3), (4) and (5) are calculated by the database tool.

2 FIRST RESULTS

2.1 Location and properties of measured buildings

On August, 2013, the database includes about 31 000 measurements. For some of them (about 4 200), the building region has not been identified. Figure 1 presents the distribution of the others measurements by region. Even if regions have different area and density, this map reveals that measurements are not equally distributed on the French territory. Indeed, some examples can be given:

- two regions are responsible for respectively 6% and 8% of the national residential constructions, and count about respectively 10% and 13% of measurements;
- one region is responsible for 8% of the national residential constructions and counts only 3% of measurements.

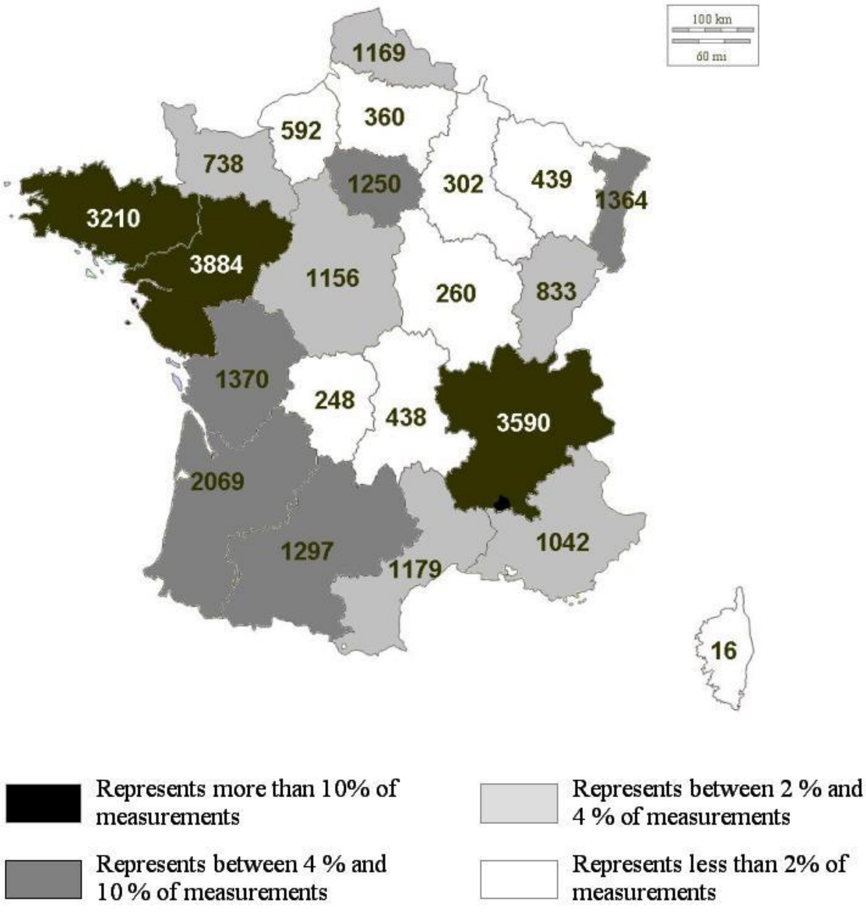
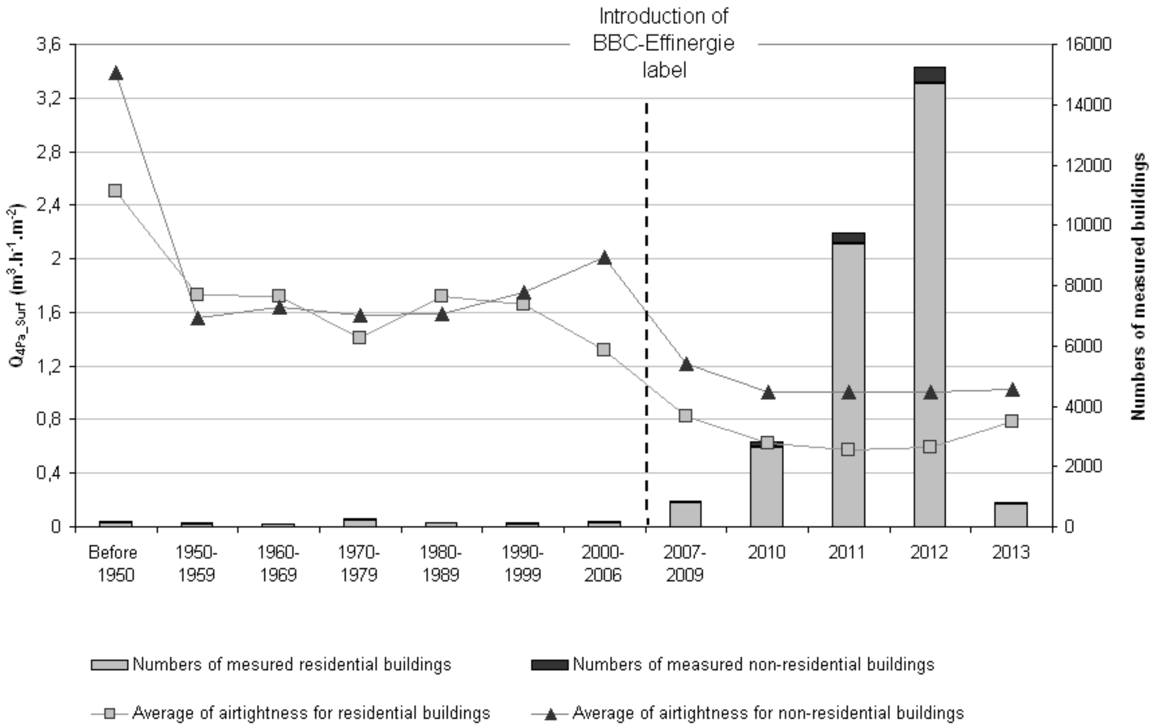


Figure 1: Distribution of measured buildings in France

The database includes non-residential buildings (about 1250 records) and residential buildings (about 29 000 records); mainly new constructions, with very different volumes, uses and structures. The following figures give the distribution of those buildings.



For example, measured buildings include 852 buildings built between 2007 and 2009: 809 residential buildings for which the average airtightness is 0.82 $m^3.h^{-1}.m^{-2}$, and 43 non-residential buildings for which the average airtightness is 1.21 $m^3.h^{-1}.m^{-2}$.

Figure 2: Airtightness performance depending on the construction year of measured buildings

Most of the measurements have been done on recent buildings: figure 2 shows that more than 97 % of them have been built since 2000 (94 % since 2010). These figures should be analysed regarding the two last EP regulation years: 2000, and 2005 (applied for constructions built from 2007). Even if they did not include airtightness requirement, good air leakage measurement results may be rewarded in the EP-calculation. Furthermore, during these years, labels have encouraged to reinforce the envelope airtightness (BBC-Effinergie label: 2007).

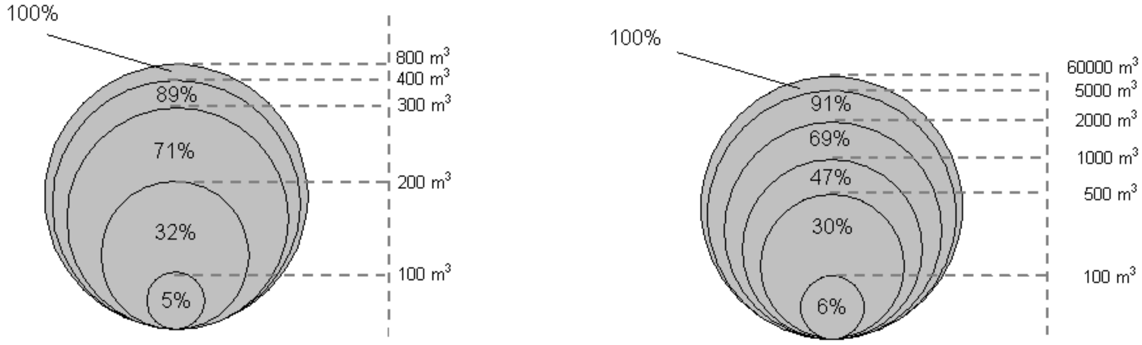
Figure 2 shows that buildings are more and more airtight until 2011. The average airtightness is a bit higher in 2012 and still increases in 2013 for residential buildings. It is explained by the part of single-family houses and multi-family dwellings in this sample.

Table 1: Selection of residential buildings samples for the last few years

Construction year of residential buildings	**2010**	**2011**	**2012**	**2013**
Part of single-family houses	84%	77%	60%	44%
Part of multi-family dwellings	16%	23%	40%	56%

The measured buildings built in 2012 include 40% of multi-family dwellings, 56% in 2013. This kind of building has not the same requirement than single-family houses, which explains why the average of residential building airtightness is higher in 2012 and 2013.

Figure 3 represents the distribution of buildings measured volumes for residential and non-residential constructions.



(a) (b)

Figure 3: Distribution of measured volumes for residential (a) and non-residential buildings (b)

A blower-door can generally provide between 7 000 and 8 000 $m^3.h^{-1}$. With this kind of equipment, measuring a non-residential building of more than 2 000 m^3 (n_{50} must be lower than about 3.5 h^{-1}) could be very difficult: it could require rare and more expensive material, or several blower-doors. This limit can explain why most of measured non-residential buildings (about 70%) are below 2 000 m^3. On the other hand, residential buildings should be more airtight so it should be possible to measure large volumes with a “Blower Door”. Nevertheless, the regulation authorizes sampling measurements for multi-family dwellings. This method is often easier and so, few entire buildings are measured.

The following paragraph describes the distributions of measured buildings by uses and kind of principal material. Residential buildings include two groups: single-family houses and multi-family dwellings. These categories are distinguished into the French EP regulation, which imposes distinct target values for them. Figure 4 shows the distribution of the main materials used in France to build these two kinds of constructions. For both, the market share of concrete and brick are important. However, 17% of the single family houses measured have used wood as their main material, whereas wood constructions represent only about 10% of the new single-family houses in France, in 2011 [2].

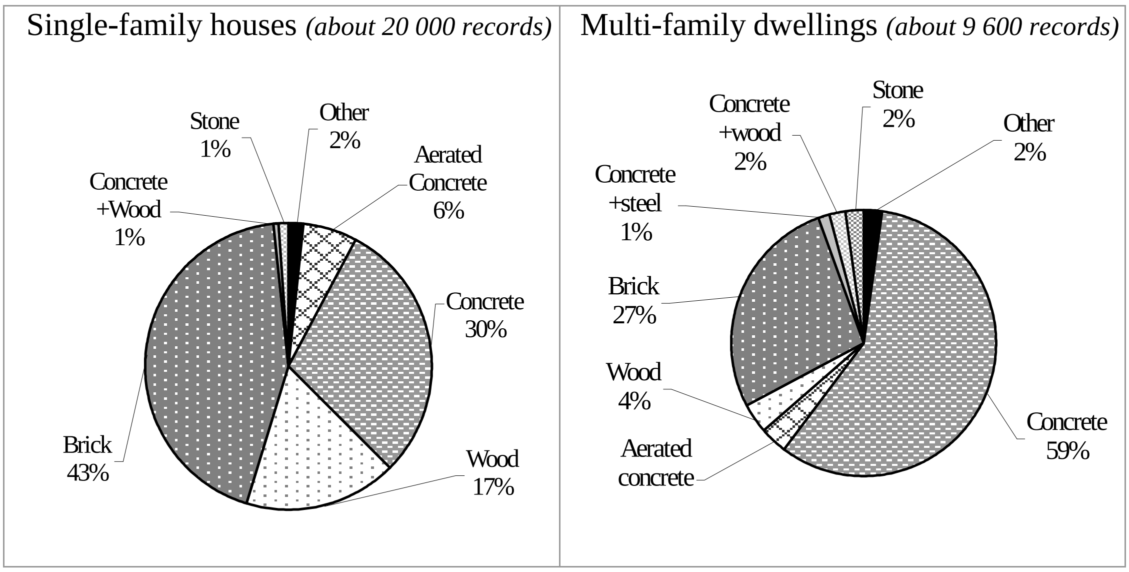


Figure 4: Distribution of main materials for measured residential buildings

Therefore, there is a bias in the database. Indeed, 79% of the measured houses were applicant for a BBC-Effinergie label, whereas the market share for this label was about 13% in 2012 for new single-family houses. For multi-family dwellings, wood constructions represent only 4% of the measured buildings, which is consistent with the French market, even if 88% of the database applied for a BBC-Effinergie label (against 70% for the national market).

The next figure describes the distribution of non-residential buildings into the database. In 2011, some data were analysed [3], describing the distribution of 188 measured non-residential buildings. In 2013, the database includes about 1250 measurement results. The distributions are similar, with a majority of office buildings and schools. Concrete is still the main used material, and wood is the second one. In France, the market share for wood in constructions is less than 5%. Like for houses, the greater use of wood in this sample is explained by the important part of buildings applying for a label in this database (74%).

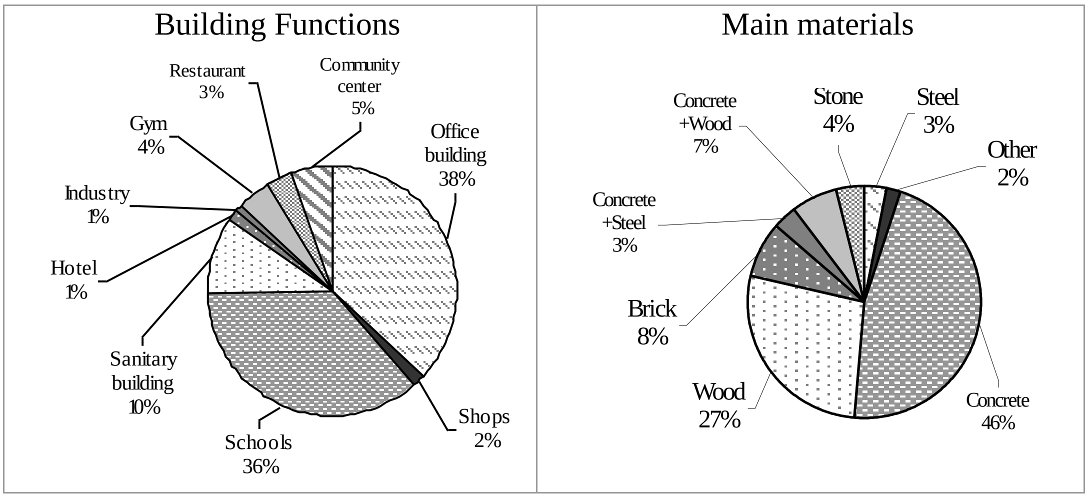


Figure 5: Distribution of measured non-residential buildings

2.2 The airtightness performance of the French buildings

The first figure of this part shows airtightness performance of all database measurements depending on the main material of buildings. According to last graphs, concrete and brick are the main material of most buildings: respectively 39% and 34% of the sample. Their airtightness performance is quite good: the airtightness of 63% of concrete buildings and 76% of brickwork buildings is lower than 0.6 $m^3.h^{-1}.m^{-2}$, like 74% of wooden buildings. For this three construction systems, between 76% and 86% of buildings have been applying for a label. This is an important bias in this result: for example, buildings built with stone present the worse airtightness performance, but only 52% on them (in the database sample) have been applying for the BBC-Effinergie label. The BBC-Effinergie label importance for residential buildings is the next point of this paper.

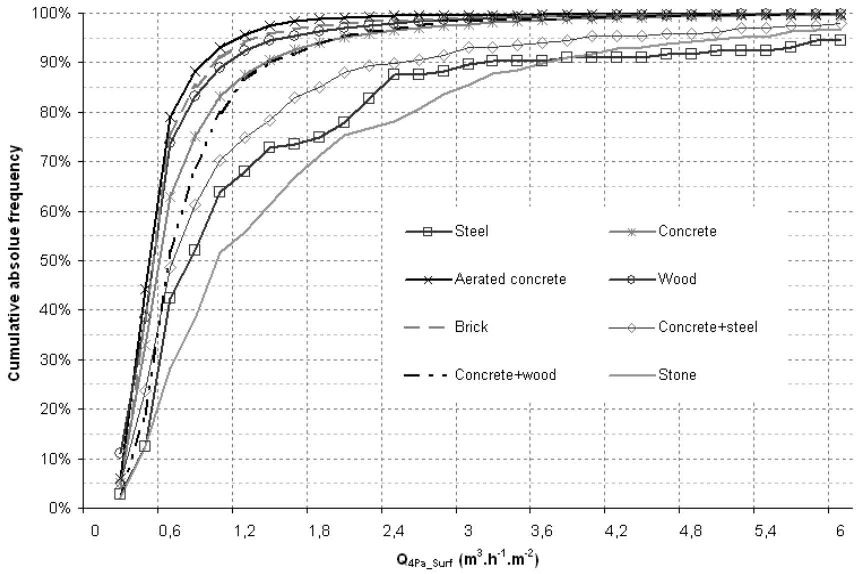


Figure 6: Airtightness performance of French buildings depending on main material

Residential Building

The average airtightness for single-family houses is 0.57 $m^3.h^{-1}.m^{-2}$, and 0.81 $m^3.h^{-1}.m^{-2}$ for multi-family dwellings. The figures 6 and 7 distinguish three different cases: buildings applying for a BBC-Effinergie label, constructions applying for other label (such as Passiv'Haus and Minergie,), and buildings without a label candidacy.

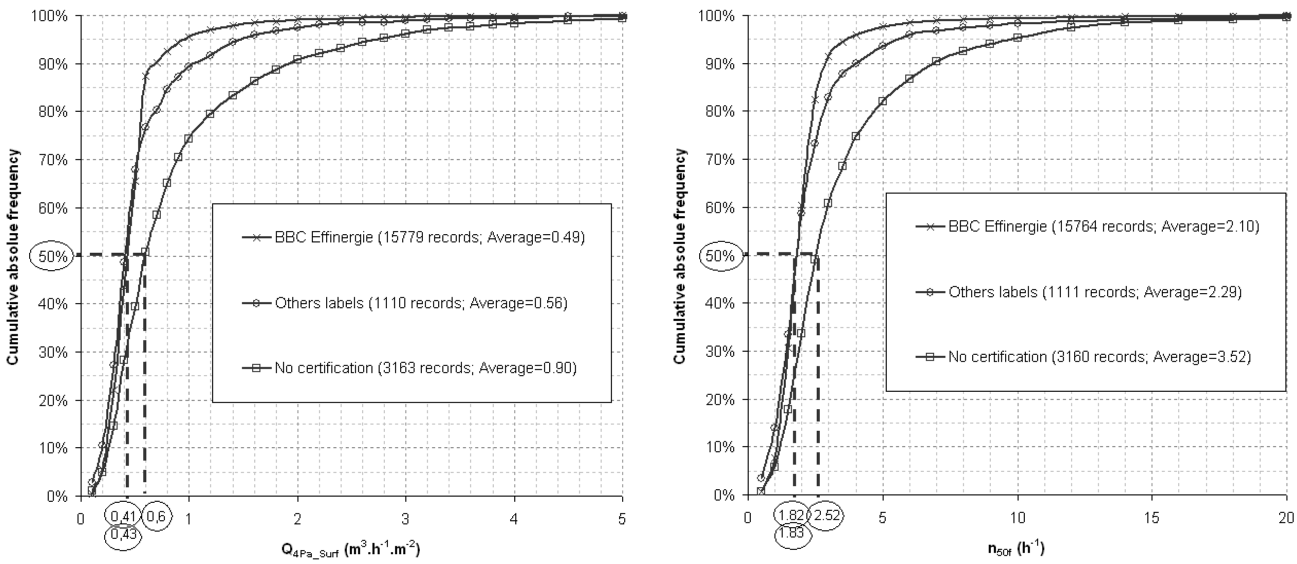


Figure 7: Airtightness performance of single-family houses

Those figures show that the average airtightness for houses applying for a label is under the limit value of the RT2012 (0.6 $m^3.h^{-1}.m^{-2}$), like for others labels. However, the average of "usual" houses is 0.9 $m^3.h^{-1}.m^{-2}$. This average is expected to decline for the next few years to respect the EP regulation. They also show that airtightness of 95% of houses applying for BBC Effinergie is lower than 1 $m^3.h^{-1}.m^{-2}$ against 89% of houses applying for an other label, and only 74% for houses without any label candidacy.

The interaction between airtightness envelope building performance and mechanical ventilation systems directly impact on energy consumptions due to air exchange and indoor air quality. The next figure shows the airtightness performance for the three main ventilation systems: balanced ventilation, simple-exhaust ventilation and natural ventilation.

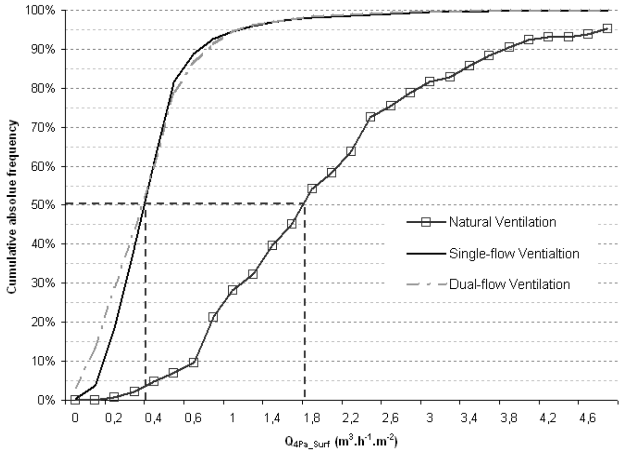


Figure 8: Airtightness envelope of single-family houses depending on ventilation system

As Guyot et al (2010) [4] have explained, the balanced ventilation generalization in European Nordic countries is mainly responsible for a long-standing airtightness interest. Figure 8 shows that for 50% of houses with either single-flow ventilation or dual-flow ventilation, the airtightness is lower than 0.44 $m^3.h^{-1}.m^{-2}$, and for about 80%, it is lower than 0.6 $m^3.h^{-1}.m^{-2}$. These systems are widely used in recent constructions, whereas natural ventilation is very difficult to install in order to respect label and new regulation requirements [5]. Therefore, results of this system mostly correspond to older houses, which may explain that 50% of measured houses airtightness is higher than 1.88 $m^3.h^{-1}.m^{-2}$.

Non-residential Buildings

A similar study has been conducted for non-residential buildings. The main figures are included in Table 2. The BBC-Effinergie buildings represent 32% of the non-residential constructions in this sample, and 12% was applying for an other label. Even if there is no airtightness requirement for most of those labels, it is assumed that a low-energy consumption building may have better airtightness performance than buildings without this kind of certification, which explains the following figures.

Table 2: Main figures for non-residential buildings airtightness

	BBC-Effinergie	**No certification**
Q_{4Pa_Surf} ($m^3.h^{-1}.m^2$)		
Average	1.05	2.0
Standard deviation	1.78	2.63
Median	0.74	1.15
n_{50} (h^{-1})		
Average	2.68	3.73

Standard deviation	3.03	4.05
Median	1.86	2.32

The non-residential sample includes many different building uses; next figure describes the airtightness performance depending on the building function. The five building functions represented in this figure were chosen using the size of the sample (more than 50 records).

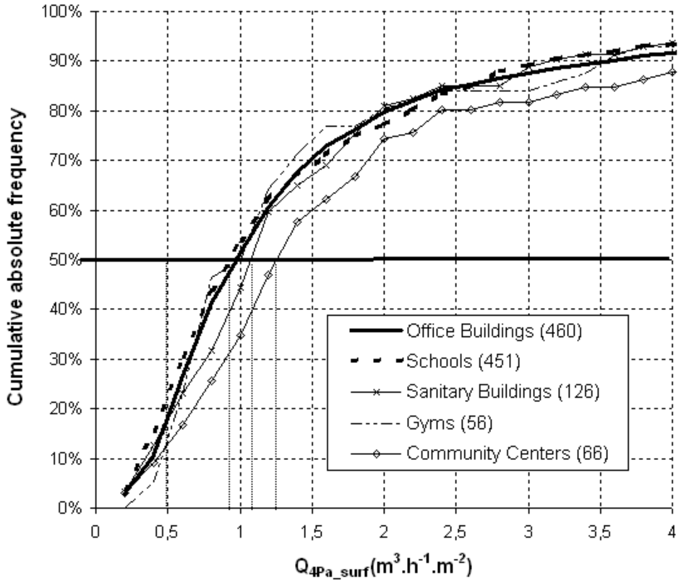
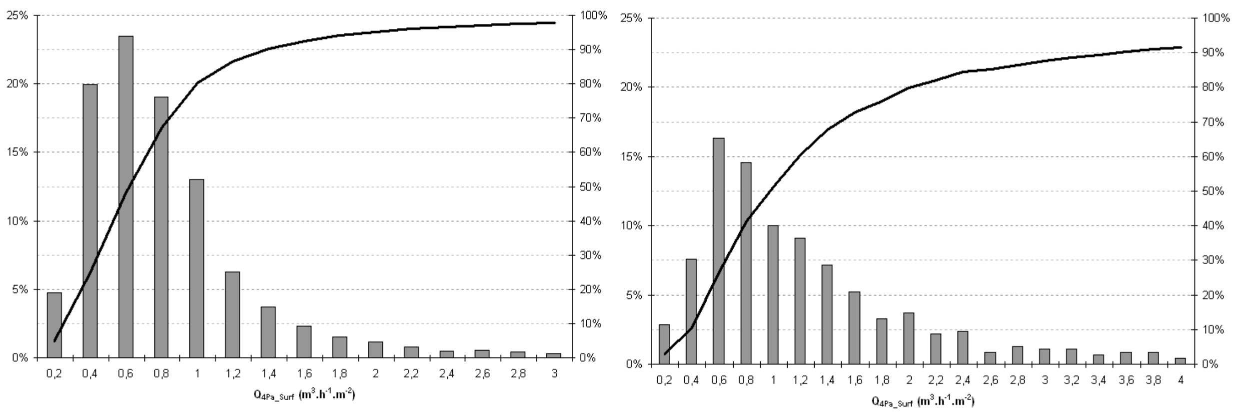


Figure 9: Distribution of measured airtightness for the main groups of non-residential buildings

The median airtightness is quite close for the five groups of non-residential buildings: the airtightness of 50% of the office buildings is lower than 1 $m^3.h^{-1}.m^{-2}$, and lower than 1.3 $m^3.h^{-1}.m^{-2}$ for community centers. Nevertheless, the curves are different: office buildings curve is more concave than community centers curve, which shows better knowledge and implementation of airtightness treatment for office buildings.

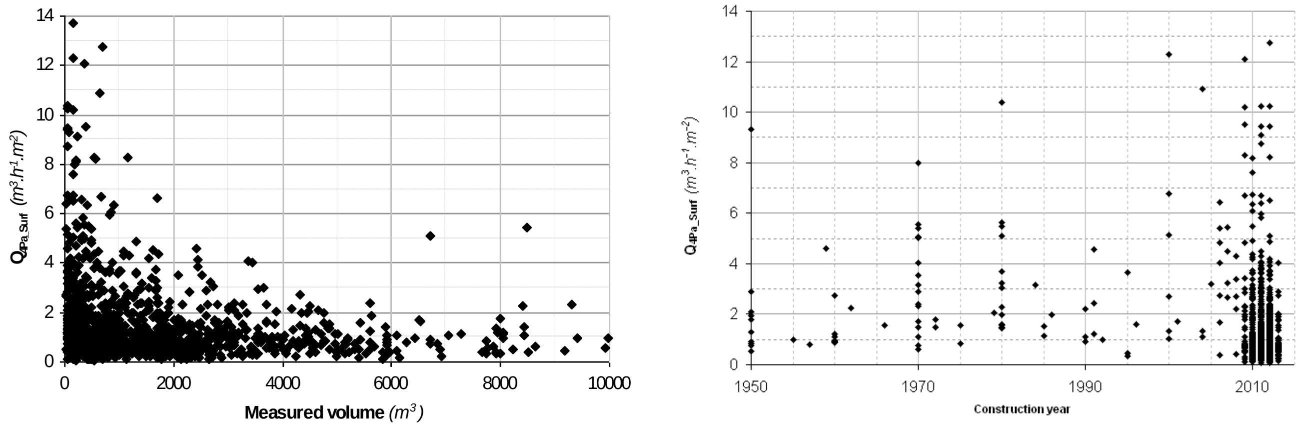
The two next graphics illustrate the airtightness performance for office buildings and multi-family dwellings, two comparative kinds of construction.



(a) (b)

Figure 10: Multi-family dwellings and office buildings (b) airtightness performance

The multi-family dwellings yield courses is smoother, with about 9 600 records (against 460 records for office buildings). As it was expected, multi-family dwellings are more airtight (average=1.01 $m^3.h^{-1}.m^{-2}$) than office buildings (average=1,73 $m^3.h^{-1}.m^{-2}$). But these figures also show that good airtightness performance is more often respected by multi-family dwellings: most of their airtightness results (80%) are under 1 m^3.h^{-1}.m^{-2}, whereas about 30% of office buildings measured results are more than 1.6 m^3.h^{-1}.m^{-2}. Nevertheless, there is not airtightness requirement for offices building, which explain the difference performance.



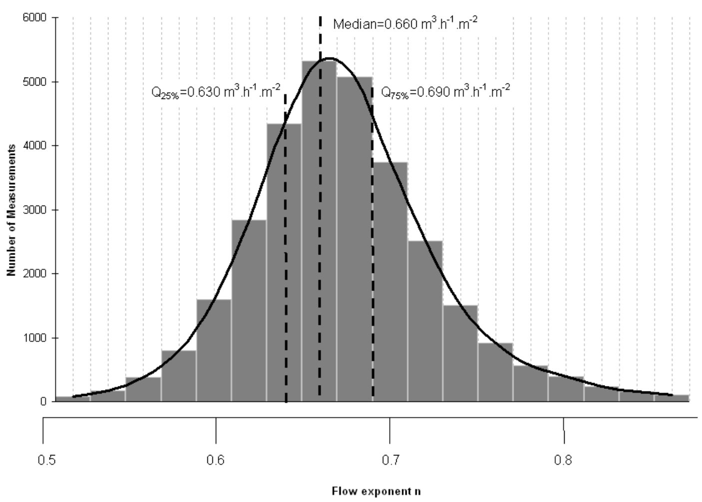
(a) (b)

Figure 11: non-residential buildings airtightness depending on the measured volume and construction year

Figure 11 describes the airtightness performance of non-residential buildings depending on their volume and construction year. It shows that airtightness could be treated as well for large buildings than for smaller. Even if the airtightness level is still high (25% of the non-residential buildings airtightness exceed 1,8 m^3.h^{-1}.m^{-2}), large volumes do not seem to be the worst.

2.3 Additional results

The database could provide further analysis, including airtightness coefficients. Last figure represents the distribution of the air flow exponent (n) or pressure exponent for the 31 000 measurements of the database.



The average exponent is 0.663 $m^3.h^{-1}.m^{-2}$ with a standard deviation of 0.060 $m^3.h^{-1}.m^{-2}$. Those figures match the commonly used default value (n=0.67) and previous studies results [6].

Figure 12: Distribution of air flow exponents from about 31 000 airtightness measurements

3 CONCLUSIONS

This objective of this study was to realize a state of the art of French airtightness buildings through analysis of more than 31 000 results of air leakage measurement. The database has been developed in recent months. Moreover, thanks to the new French EP-regulation, about 100 000 measurements are expected to be performed each year. Statistical studies should be conducted, more diverse and reliable.

This data tool is a main source to monitor the buildings airtightness performance, including the impact of the new EP-regulation. It will also allow us to analyse air leakages distribution and occurrence, in order to understand how to reinforce buildings envelope airtightness. Then, it will be an important trusted way to estimate the feasibility to add new requirements on airtightness for next labels and EP-regulation.

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The sole responsibility for the content of this publication lies with the author. It does not necessarily reflect the opinion of the Ministry.
On January 1st, 2014, the CETE de Lyon will merge to become the CEREMA.

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