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Trends in building and ductwork airtightness in France

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1 General introduction

There exists a large body of literature showing that air leaking unintentionally through building cracks can severely affect the energy performance of a building, and that the energy impact of poor airtightness is proportionally greater in energy-efficient buildings. This is why building airtightness, which had been introduced in some energy performance regulations since several decades, is now taken into account in the regulations of most member states of the European Union [1].

The French energy performance regulation for buildings has been updated in depth 6 times since its first introduction in 1974. With regard to envelope airtightness, the 1982 and 1988 versions already accounted for leakages through specific components (some vents, windows, roller shutter casings). The 2000 version used the air permeability consistently with ISO 9972:1996 as an input parameter for the energy performance assessment. However, these changes proved to be inefficient to drive the market towards better practice regarding building airtightness, probably because the calculated energy savings for better airtightness were small compared to the risk of choosing a better value than the default value (which by definition, can be used without any justification of the actual airtightness level attained).

Concerning ductwork airtightness, this subject has drawn comparatively less attention although it is also considered as an input parameter in the French EP calculation since 2000. Besides, unstructured feedback from the field suggests that much progress can be made to significantly reduce the permeability of duct systems for both energy savings and indoor air quality. This is the reason why measures have been progressively introduced since 2013 to push for better ductwork airtightness.

This paper presents the regulatory context, the control procedures, and the results analysis of buildings and ductworks airtightness in France. It details the different limit values, the testers qualification schemes and the analysis of databases.

2 Building airtightness

2.1 Introduction

An important step was the 2005 regulation (RT 2005) as it introduced a significant reward on the overall building energy performance assessment when justifying a better-than-default value for the air permeability of the envelope. A second very important step was taken with the introduction of a minimum requirement in the 2012 regulation (RT 2012) for residential buildings. This means that for every new residential building, the actual envelope airtightness has to be justified, either by a measurement, or by the application of an airtightness quality management approach (QMA). In the continuity of RT2012, the new regulations RE2020 which came into force on January 1, 2022 strengthen the requirements for the air permeability of residential buildings by adding penalties for measurements by sampling or when tests are performed before the completion of all work impacting the envelope air permeability.

Therefore, gradually, many professionals have called into question their previous methods for implementing and controlling building airtightness to comply with the regulation or to be able to use a better airtightness value than the default value or the minimum requirement. The default values were defined on the basis of the results of the first air permeability measurements carried out in France in the 1980s and 1990s on a few hundred dwellings and a few dozen non-residential buildings.

This section focuses on French regulation requirements since 2012, the control procedures and the field results.

2.2 Airtightness indicator

The French indicator for the building envelope airtightness is $Q_{4PaSurf}$[1], which is the airflow rate at 4 Pa divided by envelope surface area (excluding lowest floor). It is an input data for the calculation which affects the overall energy performance assessment. The reference pressure of 4 Pa was chosen because it corresponds to the order of magnitude the pressure difference under natural conditions. Concerning the reference surface considered for the calculation of the indicator, it was initially planned to use the surface of the envelope in contact with the outside, the unheated spaces, the crawl space and the attic. However, as a majority of buildings in France are built with a slab on the ground, it was decided to exclude the surface of the lowest floor from the reference surface.

2.3 Requirements and drivers

2.3.1 Building airtightness requirements in the regulation

In the 2012 version of the French EP regulation (called “RT 2012”), the airtightness level of residential building envelope must not exceed:

- 0.6 $m^3.h^{-}1.m^{-2}$ at 4 Pa for single-family buildings;
- and 1 $m^3.h^{-1}.m^{-2}$ at 4 Pa for multi-family buildings.

These airtightness levels were minimum requirements which must be justified. Note that better values could be also used provided that they were justified.

For non-residential buildings, there was no minimum requirement but the airtightness was taken into account either by the default value (1.7 $m^3.h^{-1}.m^{-2}$ or 3 $m^3.h^{-1}.m^{-2}$ depending on the building use), or by a better-than-default value. The better-than-default value had to be justified.

With the new French EP regulations RE2020, the requirements remain unchanged. However, penalties are applied when the tests are carried out under the following conditions:

- A multiplying factor of 1.2 in case of measurement by sampling;
- An increase by 0.3 $m^3.h^{-1}.m^{-2}$ when the test is performed before the completion of all work impacting the envelope air permeability.

[1] The order of magnitude of the French indicator $Q_{4Pa\text{-}surf}$ regarding q_{E50} and n_{50} (n = 0.67) are the following:

- All buildings: $q_{E50} \sim 5.4^* Q_{4Pa\text{-}surf}$
- Single-family houses: $n_{50} \sim 4.2^* Q_{4Pa\text{-}surf}$
- Multi-family dwellings: $n_{50} \sim 1.7^* Q_{4Pa\text{-}surf}$
- Non-residential buildings: $n_{50} \sim 2.4^* Q_{4Pa\text{-}surf}$

2.3.2 Incentive for Building airtightness

In France, the reinforcement of buildings envelope airtightness has been pushed at first by the BBC-Effinergie label, which has imposed, since 2008, limit values and mandatory justification for residential buildings.

More recently, the EP-labels of French association Effinergie (BEPOS, and BEPOS+ Effinergie 2017) set higher requirements for residential buildings:

- 0.4 $m^3.h^{-1}.m^{-2}$ at 4 Pa for single-family buildings;
- 0.8 $m^3.h^{-1}.m^{-2}$ at 4 Pa for multi-family buildings in case of measurement by sampling, and 1 $m3.h^{-1}.m^{-2}$ at 4 Pa in case of measurement on the whole building.
- No target value for non-residential buildings, but an airtightness test is compulsory for all non-residential buildings of less than 3,000 m².

2.3.3 Building airtightness justifications

The French EP regulation gives two options to justify the building airtightness level used as an input in the EP calculation:

- Either with an airtightness test of each building (with sampling rules for apartments in multi-family buildings and housing developments described in FD P50-784 [2]), performed by a qualified tester;
- Or by the application of a certified quality management approach (QMA) on the building airtightness (Annex VII of the regulation), that allows to test only a sample of buildings. The underlying basis of an airtightness QMA is to implement a scheme that lasts from the genesis of the building project to its commissioning and that ensures that the building airtightness will not exceed a limit value. This limit value must be better or equal than regulatory requirements. The QM approach is based on a precise description of "who-does-what-when-and-how". In addition, each step must be traceable and traced. Since 2012, the justification has been compulsory for residential buildings. This obligation led to a more systematic use of certified QMA [3].

In both cases, airtightness tests must be performed by a third-party tester, qualified by the certification body, Qualibat.

2.3.4 Sanctions

The ministry in charge of construction appoints trained sworn-in civil servants to undertake checks on a sample of the yearly production of buildings. The controls are ordered by the ministry as a judiciary police mission. By law, they can be performed on site within 3 years after the building is declared finished by the owner.

Non-compliance with regulation is an offense and controllers' reports are sent to national authorities. By law, the building owner is liable for the compliance of his building with the regulation; however, in turn, the responsibility usually bears on the persons "skilled in the art" (architects, contractors, etc.). In case of non-compliance, the attorney general can give financial penalties—in theory, up to 45.000 €, and, in case of repeat offence, 75.000 € with 6 month imprisonment—or ban professionals from practicing. In practice, these penalties are very rarely applied; however, the owner is usually compelled to apply remedial actions to comply with the regulation.

2.4 Building airtightness in the energy performance calculation

2.4.1 Calculation

The building airtightness is an input of the energy performance calculation of the French EP regulations. A network zonal model is integrated in the calculation method to estimate the air change rates induced by air infiltration and ventilation in each zone of the building and hence, the associated heat losses. Regarding the air infiltration, the building envelope airtightness $Q_{4PaSurf}$, which is the airflow rate at 4 Pa divided by envelope surface area (excluding lowest floor), is used as input. For each zone, the method considers two leakages on the leeward walls (at 0.25 and 0.75 of the ceiling height of the zone), two leakages on the windward walls (at 0.25 and 0.75 of the ceiling height of the zone), and one leakage on the ceiling (at the ceiling height). The flow coefficient of each leakage is estimated from $Q_{4PaSurf}$ with an exponent coefficient of 2/3 in proportion to the wall surface in relation to the total surface of the envelope.

The method is fully described in the decree of August 4, 2021[2].

2.4.2 Default values

For residential buildings there are no default values but minimum requirements that need to be justified.

For non-residential buildings, there is no minimum requirement but the airtightness is taken into account either by the default value ($1.7\ m^3.h^{-1}.m^{-2}$ or $3\ m^3.h^{-1}.m^{-2}$ depending on the building use), or by a better-than-default value. The better-than-default value has to be justified.

2.5 Building airtightness test protocol

2.5.1 Qualification of Airtightness testers

In order to justify the building airtightness value used in the EP calculation, airtightness tests must be performed by a third-party tester, qualified by the certification body, Qualibat. To be qualified, a tester has to:

- Undergo state-approved training,
- Pass the training examination (the theoretical part, with a state-approved multiple choice questionnaire; and the practical part, with a real test performed with a qualified tester);
- Provide proof of sufficient testing experience with a minimum of 10 tests performed.

Once qualified, every tester is subjected to yearly follow-up checks, organized by the certification body. The follow-up checks include an analysis of some reports to verify their compliance with applicable standards and guidelines.

The certification body can check the testers based on the documentation sent every year, but also on site, in particular, in case of complaints or doubts about their work. A committee involving stakeholders is in charge of delivering qualification, re-issuing qualification or handling complaints. The follow-up checks require provision of a professional standard form giving information on all airtightness measurements performed within the year (the professional measurement register).

As of December 2021, 842 testers were qualified.

2.5.2 National guidelines

The French EP-regulations require that each airtightness test has to be performed by a qualified tester according to EN ISO 9972 [4] and the national guideline FD P50-784 which is an application guide of the standard EN ISO 9972. Therefore, the fan pressurisation method is the only method used in France to test building airtightness.

Moreover, FD P50-784 requires that measurements shall be performed according to method 3 of EN ISO 9972and specifies how the building must be prepared. More specifically, only the ventilation openings included in the EP-calculation are sealed, and all windows, doors, and trapdoors on the envelope are closed. The preparation method is in accordance to the EP-calculation method that accounts to the heat losses related to the ventilation system. FD P50-784 also gives the sampling method for multi-family buildings of more than 500 m²:

- 3 dwellings for buildings with less than 30 dwellings
- 6 dwellings for buildings with more than 30 dwellings.

Dwellings from the sample must be located on the first level, on one intermediate level and on the higher level, depending in the dwellings floor areas. The sampling method has been defined based on the results of MININFIL project that included air permeability

[22] https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000043936431

measurements on ten multi-family buildings [5].

2.5.3 Requirements on measuring devices

Besides the requirements of ISO 9972 regarding the equipment, FD P50-784 gives additional requirements for the calibration and the verification of equipment (calibration range, periodicity, maximum permissible error).

2.6 Building airtightness Tests performed

2.6.1 Tested buildings

The mandatory requirement of the French Energy Performance (EP) regulation requires a minimum airtightness level for all 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, EP labels have helped to strengthen airtightness requirements.

Since 2015, thanks to the mandatory requirement of the French regulation RT2012, around 30% of all new constructed houses, and 6% of all new constructed multi-family dwellings are being tested each year. Logically, the share of tested multi-family dwellings measured is lower as the measurement by sampling is widely used in multi-family buildings.

As there is no mandatory requirement for non-residential buildings (when the default value is used), very few non-residential buildings are tested. In 2018, around 3,000 non-residential buildings were tested.

2.6.2 Database

The French database of building airtightness was created in 2007 following the implementation of a national qualification scheme for building airtightness measurement. Each qualified tester is required to register all test results in a formatted table and send this register table to the certification body Qualibat every year. The database is fed annually by these tables. The structure of the table is presented by [6]. Collected registers are annually compiled in the national database which is composed of 39 data fields as follows:

- general building information: owner, location, use (single-family for a building with one or two apartments, multi-family for a building with more than two apartments, several subcategories for non-residential buildings such as schools and office buildings), year of construction, year of rehabilitation;
- special requirements: label, certification;
- main building characteristics: main material, construction type (frame structure, bearing walls, combined or lightweight facade), insulation type, ventilation system, heating system;
- measurement protocol: operator, date of measurement, measurement device, time of measurement (construction phase of the building), method;
- measurement input data: envelope area (excluding low floors), floor area, volume;
- measurement results: air leakage coefficient CL, flow exponent n, $Q_{4PaSurf}$, n50, uncertainties (the uncertainties are calculated according to Annex C of ISO 9972. FD P50-784requires that the uncertainty on qa4 is below 15%);
- detected leakage locations: leakages being classified into 46 standardized categories.

Currently, more than 440,000 tests have been recorded in the database. It includes all the measurements that were performed by certified testers till the end of 2019. Data from around 63,000 tests are expected each year. However, it takes about 2 years to collect registers and perform data analysis.

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 minimum airtightness level for new residential buildings (Figure 1). Also low-energy labels have helped to strengthen airtightness requirements.

Residential buildings account for almost all of measurements (68% for single-family dwellings with 140,542 measurements, and

28% 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" EP-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.

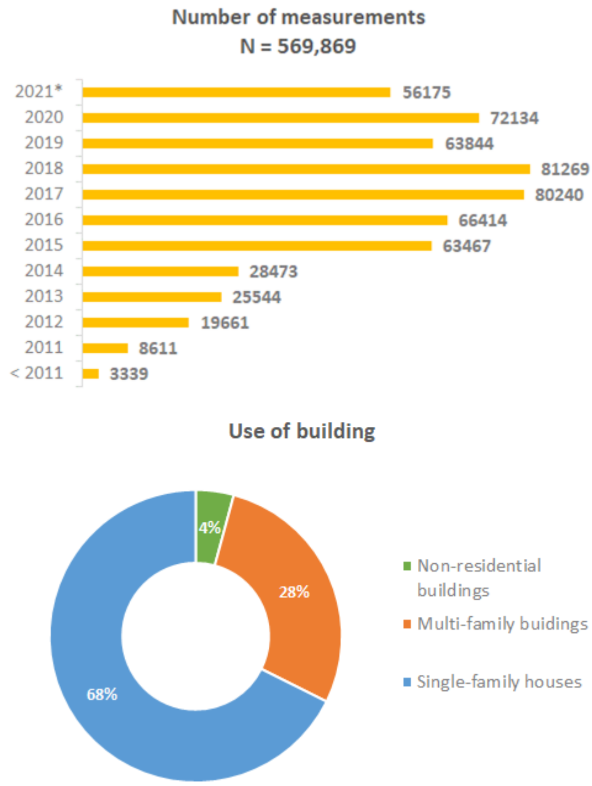

*Figure 1: Evolution of the number of building airtightness measurements in France (top) and percentage of measurements depending on the use of the building (*The data for 2021 is not complete and corresponds to measurements made by around two-thirds of qualified measurers. The rest will be implemented later)*

2.6.3 Evolution of the airtightness level

The figures which follow present the annual evolution of the number of tests and the average value of the air permeability for single-family, multi-family and non-residential buildings.

For residential buildings, single-family (Figure 2) and multi-family buildings (Figure 3), results show a fast increase in the number of airtightness tests 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 tests 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 0.63 $m^3.h^{-1}.m^{-2}$ in multi-family buildings. The slight increase of air permeability 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. As mentioned above, the EP-regulation requires that $Q_{4PaSurf}$ is below 0.6 $m^3.h^{-1}.m^{-2}$ for single-family houses and 1 $m^3.h^{-1}.m^{-2}$ for multi-family buildings. Measurements from 2015 can thus be considered as representative of new French residential buildings.

For non-residential buildings (Figure 4), the number of tests is much lower due to the absence of a mandatory requirement. 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 around 0.5 $m^3.h^{-1}.m^{-2}$ in 2017. In addition, this value is similar for buildings with or without an EP-label. Despite the absence of a mandatory requirement, airtightness of non-residential buildings continues to improve, but only for those who have decided to care about it. Therefore, these results cannot be considered as representative of new French non-residential buildings.

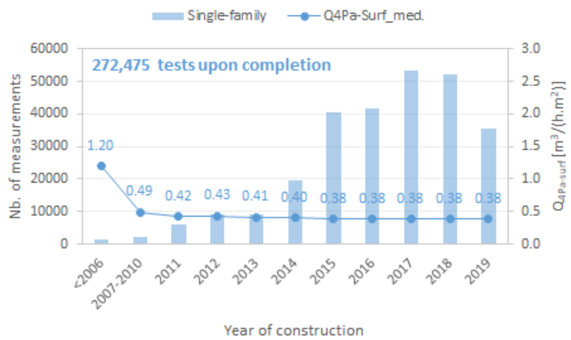

Figure 2: Evolution per year of construction of the number of measurements and the mean air permeability in single-family buildings

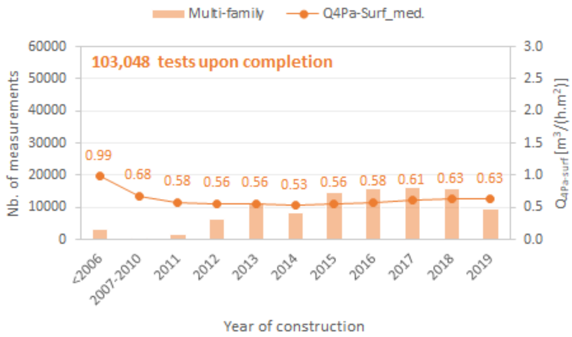

Figure 3: Evolution per year of construction of the number of measurements and the mean air permeability in multi-family buildings

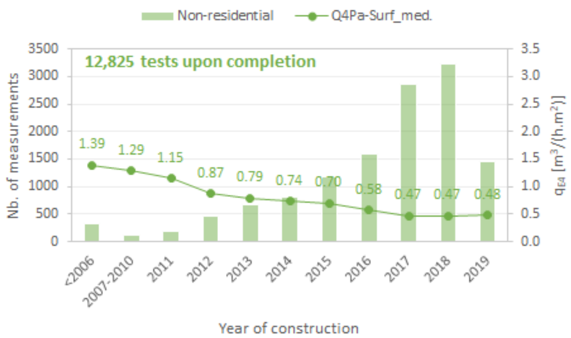

Figure 4: Evolution per year of construction of the number of measurements and the mean air permeability in non-residential buildings

2.7 Guidelines to build airtight

Design and implementation guide for the attention of designers, craftsmen and construction companies were elaborated in 2010 to account for the airtightness during building design and construction. The guide describes how to design the air barrier. For each junction in the building envelope, it gives the airtightness application drawing that illustrates the treatment of airtightness, specifying the sealing products to be used and the craftsmen involved in the implementation [7].[3]

2.8 Conclusion

Undoubtedly, the regulatory measures and control procedures have profoundly changed the building airtightness market in France. Within a few years, they have led to significant improvements in airtightness test results. Note however that this change is the result of a number of measures and procedures that have been implemented, including:

- Minimum requirement for residential buildings and substantial reward for better-than-default values for non-residential buildings;
- Compulsory justification for residences and better-than-default values with 2 routes: systematic testing or application of a certified QMA;
- Mandatory qualification of testers and certification of QMA to justify airtightness values;
- Follow-up of test results, including statistical analysis to monitor the impact of the regulation.

In addition, the BBC-Effinergie label in 2006 has been a fundamental step both to raise awareness and to experiment measures to revise the regulation. Given the number of simultaneous changes, the impact of each one is difficult to isolate from the others.

The overall approach has produced very positive results with regard to its original objectives; however, several points merit further attention, in particular:

- Testers are under pressure to please their clients with the present third-party testing requirement. They are also under time pressure, which may affect the quality of their measurements. This calls for dissuasive controls by the scheme holder. Improvements have been done by Qualibat to strengthen control of testers.
- Tests performed at commissioning do not reflect the airtightness during the buildings' lifetime, especially when last-minute corrections are implemented to meet the target value. Durability issues are considered thanks the research project Durabilit'Air that concluded that airtightness of houses may deteriorate mainly during the first two years (a mean increase of around +20% in the air

[3] https://programmepacte.fr/points-de-divergence-entre-les-carnets-mininfil-et-les-regles-de-lart-synthese-de-letude-rapport

permeability observed from two samples of 30 low energy houses each) [8].

Now with the latest regulation RE2020, the French authorities focus on ventilation requirements in order to ensure that new dwellings are ventilated right. It includes mandatory requirements to control ventilation systems in new residential buildings based on what has been done for building airtightness (tester qualification scheme, national database).

2.9 Key documents

[1] AIVC. 2012. Achieving relevant and durable airtightness levels: status, options and progress needed. Proceedings of the international workshop held on 28-29 March 2012, Brussels.

[2] FD P50-784. Thermal performance of buildings - Implementation guide for NF EN ISO 9972, 2016.

[3] Charrier, S., Ponthieux, J., 2015, Airtightness Quality Management Approaches in France: end and birth of a scheme. Previous and new schemes overview and analysis. In: 36th AIVC Conference "Effective ventilation in high performance buildings", Madrid, Spain, 23-24 September 2015.

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[5] Moujalled, B., Richieri, F., Carrié, R., Litvak. A., 2011. Evaluation of selection criteria of an air tightness measurement method for multi-family buildings. In Proceedings of 32nd AIVC Conference "Towards Optimal Airtightness Performance". Brussels, Belgium.

[6] Mélois, A.B., Moujalled, B., Guyot, G., Leprince, V., 2019. Improving building envelope knowledge from analysis of 219,000 certified on-site air leakage measurements in France. Building and Environment 159, 106145. https://doi.org/10.1016/j.buildenv.2019.05.023

[7] POINTS DE DIVERGENCE ENTRE LES CARNETS MININFIL ET LES RÈGLES DE L'ART - SYNTHÈSE DE L'ÉTUDE – RAPPORT, 2014. AQC, Paris. Available on : https://programmepacte.fr/sites/default/files/pdf/rapport-rage-points-divergence-carnets-mininfil-et-regles-de-lart-2014-10_0.pdf

[8] Moujalled, B., Leprince, V., Berthault, S., Litvak, A., Hurel, N., 2021. Mid-term and long-term changes in building airtightness: A field study on low-energy houses. Energy and Buildings 250, 111257. https://doi.org/10.1016/j.enbuild.2021.111257

3 Ductwork airtightness

3.1 Introduction

The introduction of mandatory ductwork airtightness tests for the EP-labels "Effinergie+" and "BEPOS Effinergie 2013" (and related subside) in 2013, and thus the creation of the testers scheme qualification dedicated to ductwork airtightness, has been one of the main drivers to sensibilize to the importance of this issue. With the new regulation RE2020, the performance of the ventilation systems, especially for dwellings, is taken into account with mandatory inspection and measurements at air terminal devices. As for the previous regulation, the ductwork airtightness measurements are not mandatory in this new regulation, but they are identified as a mean to check the quality of the work, especially during the construction phase, in order to ensure the good performance of the ventilation system at the commissioning phase.

3.2 Airtightness indicator

The ductwork airtightness indicator is the airtightness classes according the air leakage flowrates defined in the EN standards 12237 [9], 1507 [10] and 13403 [11]. There are 4 classes: class A (the leakiest class), B, C and D (the most airtight class). These classes are defined from an air leakage limit: this limit varies with a factor 3 between class A and class B, then between class B and class C and between class C and class D.

3.3 Requirements and drivers

3.3.1 Ductwork airtightness requirements in the regulation

The ductwork airtightness class is an input value of the ventilation system in the EP calculation of the EP regulation. The default value of "2.5xclass A" is used in the calculation which corresponds to an air leakage rate equal to 2.5 times the air leakage rate defined by the class A.

Any other class used in the EP calculation has to be justified (see §3.3.3).

3.3.2 Incentive for Ductwork airtightness

The Effinergie labels accompany EP regulation by introducing reinforced requirements in order to anticipate future regulatory requirements. They are the most popular labels for new buildings in France. Effinergie has promoted the quality of the ventilation systems since many years, and has included requirement regarding ventilation in 2012 with the "Effinergie+" label. This label requires a visual inspection of all the components of the ventilation system and a class A for ductwork airtightness that must be justified by measurement.

3.3.3 Ductwork airtightness justifications

As for building airtightness, the French EP regulation gives two options to justify a better than default class of the ductwork airtightness in the EP calculation. It must be justified:

- Either by a ductwork airtightness measurement, performed by a certified tester;
- Or by the application of a certified quality management approach (QMA) on ductwork airtightness, that allows to test only a sample of buildings.

In both cases, ductwork airtightness tests must be performed by a third-party tester, qualified by the certification body Qualibat, according to national guide FD E51-767 [12].

3.4 Ductwork airtightness in the energy performance calculation

3.4.1 Calculation

In the EP-calculation, the airtightness of the ductwork influences the total air change rate of the internal volume as it is taken into account in the calculation of the ventilation flow rate, and thus has an impact on the heating and/or cooling needs.

Equation (1) defines the leakage rate through all duct leaks Q_{leaks} for a pressure difference ΔP:

$$Q_{leaks} = 3600 * K_{res} * \Delta P^{0,667} * A_{duct} \quad (1)$$

K_{res} [$m^3.s^{-1}.Pa^{0.667}.m^{-2}$] depends on the airtightness class of the network
A_{duct} [m²] is the surface of the air duct, which can be estimated as a percentage of the floor area

For example, the final extraction flow rate due to ventilation is calculated according to equation (2):

$$Q_{ext} = Q_{ext,dep} + K_{hv} * Q_{ext,leaks} \quad (2)$$

K_{hv} *[-]* describes the part of the exhaust duct in the heated volume (from 0 to 1)
$Q_{ext,\,dep}$ [$m^3.h^{-1}$] is the extraction flow calculated from regulatory airflow and including additional airflow due to potential dysfunctions of the system due to design.

3.5 Ductwork airtightness test protocol

3.5.1 Qualification of ductwork Airtightness testers

To be qualified, a tester has to:

- Undergo a qualifying State approved training;
- Pass the training examination (the theoretical part, with a State-approved multiple-choice questionnaire; and the practical part, with a test performed in situ with a certified tester),
- Provide proof of sufficient testing experience with a minimum of 10 tests performed.

Once qualified, testers are subjected to yearly follow-up checks, organised by the certification body Qualibat. The follow-up checks include an analysis of some reports to verify their compliance with applicable standards and guidelines. The certification body can control the testers based on the documentation sent every year, but also on site, in particular, in case of complaints or doubts about their work. A committee involving stakeholders is in charge of delivering qualification, re-issuing qualification or handling complaints. The follow-up checks require provision of a professional standard form giving information on all ductwork airtightness measurements performed within the year (the professional register). Data are checked to ensure their accuracy, completeness, and reliability regarding the specifications of EN standards and FD E51-767.

The competent tester scheme started in 2014. As of March 2022, 133 testers are qualified by Qualibat.

3.5.2 National guidelines

Tests have to comply with the European standards EN 12237, EN 1507, EN 13403 and EN 12599, and the French technical report FD E 51-767. Whenever a test is performed, either for a certified QMA or for a systematic test, it must be performed after any works that could impact the final ductwork airtightness. FD E 51-767 specifies the reporting format. The report specifies if the ductwork airtightness complies with the input class used in the EP calculation.

The FD E51-767 gives requirements regarding the sampling procedure:

- 100% of the ductworks for single family houses
- For multi-family dwellings and non-residential buildings: the test can be performed by sampling if:
  - The sample is continuous
  - The sample is representative of the dimensions, shapes, accessories and materials of the ductwork
  - For a network with a distribution by floor: at least one complete floor from the most distant air terminal device to the fan up to the connection of the fan. The sample area shall represent at least 20% of the ductwork area, and if possible, at least 10 m².
  - For a network with a distribution by column: at least one column of the ductwork, from the most distant air terminal device to the fan up to the connection of the fan. The sample area shall represent at least 20% of the ductwork area, and if possible, at least 10 m².
  - The test can be performed by section, each section area shall be at least 10 m².

The FD E51-767 also proposes rules to select a sample of houses among a group of houses, and a sample of ductworks for buildings than include more than 5 fans (the sampling applied to fans).

The FD E51-767 gives requirements regarding the preparation of the ductwork, especially for dampers, connections at air terminal devices (ATD), connection at the fan, plenums and air handling units (AHU).

The FD E51-767 defines the reference pressure difference of the test depending of the type on building: ± 80 Pa for single-family houses, ± 160 Pa for multi-family dwellings and ±250 Pa for non-residential buildings. If the design pressure difference is higher than the reference given in this text by more than 50 Pa, a second test shall be performed at the design pressure difference.

The FD E51-767 defines the different correction that shall be applied for the following situations:

- Corrections to obtain result in standard environmental conditions,
- If one element of the ductwork (the connection to the fan, one or several plenums or one or several air handling units) is not including in the tested ductwork, the measured air leakage rate shall be corrected by the application of a penalty
- For single-family houses, if the tested ductwork includes the fan, a correction is proposed to subtract an air leakage rate corresponding to leaks due to the fan.

3.5.3 Requirements on measuring devices

The FD E51-767 recommends to use measurement devices that respect the following characteristics:

- Pressure measurement: accuracy less or equal to MAX(±3 Pa; ±2.5 ΔP_{test}), calibrated every 2 years
- Air leakage rate: accuracy less or equal to MAX(0.000 012 m^3s^{-1} ; ±7% $q_{measured}$), calibrated every 2 years

- Temperature: accuracy equal to ±1°C in the range [-15°C; +35°C], calibrated every 4 years
- Barometric pressure: accuracy equal to ±200 Pa in the range [90,000 Pa; 110,000 Pa], calibrated every 4 years

3.6 Ductwork airtightness Tests performed

3.6.1 Tested Ductwork

As ductwork airtightness test is not mandatory, only few buildings are concerned by this measurement, either because:

- it is a requirement from a label or certification
- for security/safety reasons (for example in some part of hospitals),
- it is a voluntary approach from the building owner.

All tests performed by a qualified tester in France are included in the national database. In 2020, 1323 tests were performed (Figure 5). Among all tests recorded in the database, 63% of them are performed at commission stage.

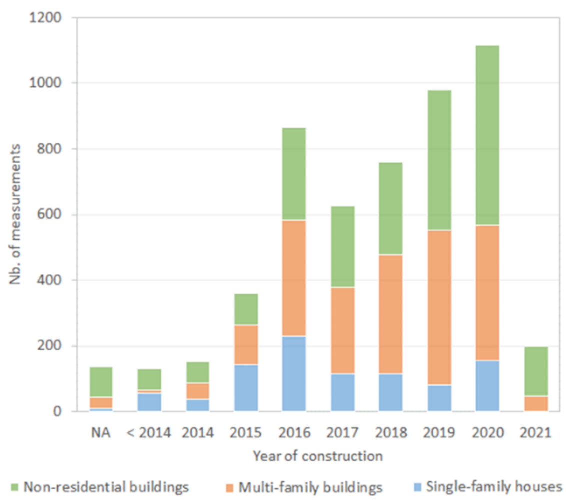

Figure 5: Evolution of the number of ductwork airtightness tests performed in French building each year – Source: Bassam Moujalled, BEPOSTIVE 2021, Lyon, France, December 2021.

More than half of the tests are performed on residential buildings: 40% on multi-family dwellings and 18% on single-family dwellings. The other tests are mainly performed on office buildings, school and hospitals (Figure 6).

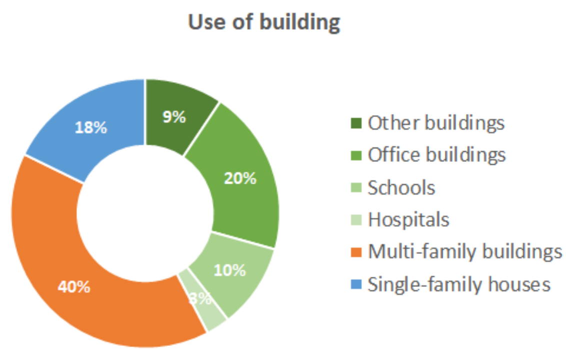

Figure 6: Type of buildings in the ductwork air leakage test database - Source: Bassam Moujalled, BEPOSTIVE 2021, Lyon, France, December 2021.

3.6.2 Database

Qualified testers are required to fill in a database with all test results and provide this database to the certification body every year for the follow-up of their certification. Then, the public agency Cerema collects all the data and perform yearly analyses of the database. This database includes all the tests performed in France by a qualified tester in a regulatory or Effinergie certification context. It is supposed that many tests performed during the construction phase are not filled in this database, and that only final tests may be recorded.

Figure 7 presents the distribution of ductwork airtightness measured classes depending on target classes. The class "2.5*A" is the default value of the French EP-regulation. It can be used in the EP calculation without any justification. More explanations of these results are presented by [13].

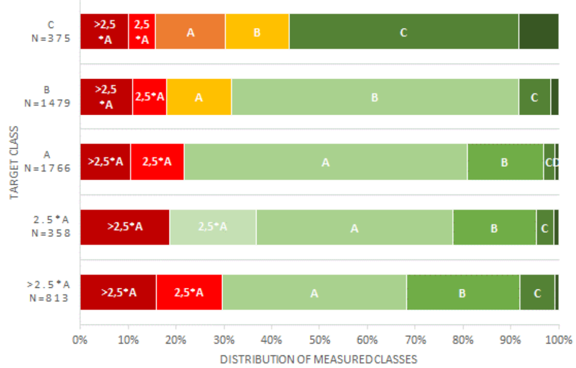

Figure 7: Distribution of ductwork airtightness measured classes depending on target classes - Source: Bassam Moujalled, BEPOSTIVE 2021, Lyon, France, December 2021.

3.6.3 Evolution of the ductwork airtightness level

The evolution of the ductwork airtightness level has not been analysed yet.

3.7 Guidelines to build airtight ductwork

The DTU 68.3 is a national standard that provides rules for design and installation of ventilation systems in buildings. Its application it not mandatory regarding regulatory context, but it is very widely required by building owner for insurance purposes. Regarding ductwork airtightness, DTU 68.3 gives recommendations with technical drawings.

3.8 Conclusion

The Effinergie certifications, with their mandatory tests of ductwork airtightness since 2013, have participated in France to the development of the ductwork airtightness tests with the creation of the tester's scheme qualification and the database. The possibility to use in the EP-calculation a class better than default (A, B or C) and thus, advantage airtight ductwork regarding energy performance of the buildings, is also a driver for the ventilation performance.

With the new regulation RE2020 and the mandatory inspection and measurements of the ventilation systems in residential buildings, the ventilation system is finally identified in the construction process and we can hope that the quality of the ductwork will improve, even if the airtightness test is not mandatory. A dedicated observatory will be developed, gathering all inspections and measurements regarding ventilation systems. It will be on-line and will be directly filled by the testers: some analyses will be public and the data will be automatically updated.

3.9 Key documents

[9] NF EN 12237. Ventilation for buildings – Ductworks – Strength and leakage of circular sheet metal ducts, 2003.

[10] NF EN 1507. Ventilation for buildings – Sheet metal air ducts with rectangular section – Requirements for strength and leakage, 2006.

[11] NF EN 13403. Ventilation for buildings – Non-metallic ducts – Ductwork made from insulation ductboars, 2003.

[12] FD E51-767: Ventilation des bâtiments — Mesures d'étanchéité à l'air des réseaux, 2017.

[13] B. Moujalled, V. Leprince, A. Bailly Mélois, Statistical analysis of about 1,300 ductwork airtightness measurements in new French buildings: impacts of the type of ducts and ventilation systems, in: Proc. 39th AIVC Conf. Smart Vent. Build., Antibes Juan-Les-Pins, France, 2018.

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