Deviation of blower-door fans over years through the analysis of fan calibration certificates

Valérie Leprince[1*], Christophe Delmotte[2], Isabelle Caré[3]

1 PLEIAQ
84 C Av de la Libération
69330 Meyzieu, France
**Corresponding author: valerie.leprince@pleiaq.net*

2 Belgian Building Research Institute
Rue du Lombard 42
1000 Bruxelles, Belgium

3 CETIAT
Domaine scientifique de la Doua, 25 avenue des Arts
69100 Villeurbanne, France

ABSTRACT

Mandatory building airtightness testing has come gradually into force in European countries, mostly because of the increasing impact of building leakage on the overall energy performance of low-energy buildings.
Therefore, because of related legal and financial issues, the reliability of the airtightness test has become a crucial issue and has raised the question of the fan calibration process.
Stake-holders need to find the right balance between cost for testers and test reliability. While some manufacturers recommend a 4 years frequency for calibration, fan calibration is required every year in UK and every 2 years in France. In these 2 countries building airtightness testing are mandatory.
The objective of this paper is to evaluate fan deviation over years. This evaluation has been done through the analysis of calibration certificates issued by certified bodies.
According to these certificates the fan deviation is low but not negligible with 5% of the fan varying of more than 8.5% compared to manufacturer coefficients. It has also been observed that:

- Low-used and well-stored fans deviate less than daily used ones.
- Configurations measuring large flowrate deviate less than configurations that measure small flowrates.
- A significant difference of deviation is observed according to the background test pressure during calibration (30 or 50 Pa);

Besides, conclusions cannot be drawn without taking into account the calibration uncertainty mentioned in the certificates. Therefore this paper is completed by a discussion about the uncertainties stated by the calibration laboratories and the need for an appropriate level in regard with the maximum permissible error when a verification report is required.

KEYWORDS

Airtightness measurement, fan calibration, uncertainty

1 INTRODUCTION

Mandatory building airtightness testing has come gradually into force in European countries, mostly because of the increasing impact of building leakage on the overall energy performance of low-energy buildings.
Therefore, because of related legal and financial issues, the reliability of the airtightness test has become a crucial issue and has raised the question of the fan calibration process.
Stake-holders need to find the right balance between cost for testers and test reliability.

In France and UK the fan calibration is mandatory. However, the 2 countries have 2 different approaches regarding calibration. In UK, the calibration is done every year and fan coefficients are systematically adjusted, while in France the verification is required every 2 years and coefficients are recalculated only if the error exceeds the Maximum Permissible Error. Therefore we have gathered calibration data coming mainly from UK and France.
The objective of this paper is to evaluate fan deviation over years. This evaluation has been done through the analysis of calibration certificates issued by certified bodies.
In the first part of the study we have studied the deviation of fan with the British approach, that is to say by recalculating fan coefficients from the calibration points (systematic adjustment of fan coefficients).
In the second part of the study we have studied the deviation compared to the manufacturer coefficients.
At the end, we have also discussed the impact of the calibration uncertainty and sources of deviations.

2 METHODOLOGY

For the first part of the study, we have recalculated fan coefficients for each configuration with each certificate and calculate the deviation of associated flowrate.
Each fan has up to 10 configurations and may have been calibrated more than twice.
Therefore the number of data from each body used in the statistic study is given in Table 1. In UK fans are calibrated every year, therefore Stromatech has provided C and n coefficients calculated every year for 12 fans, some fans have been calibrated 5 years in a row.

Table 1: Number of data per provider according to the time between calibrations

	1 year	2 years	3 years	4 years	5 years
Stromatech	67	55	43	32	21
Cerema	0	22	0	6	0
Syneole	11	76	10	6	0
BCCA	0	0	0	0	6
Total	78	153	53	44	27

Data provided by the four bodies are quite different. Stromatech (12 fans) is a calibration laboratory in UK. They have provided new calibration coefficients (C and n) but without giving more details (reference flow, pressure difference, uncertainty).

Syneole (13 fans), BCCA (1 fan) and Cerema (5 fans) have provided fan calibration certificates. However, it has to be noticed that Cerema fans are rarely used, well maintained and well stored. While Syneole (trade union of French airtightness testers) has a "classical" use of their fans so their data may be the most representative of the market.
The 2 years results are probably the most representative, as we have data from the three bodies and more than 100 data.

For Syneole, BCCA, and Cerema, verification data (reference flowrate) of the certificate were used to recalculate the coefficients C and n for each configuration: a regression was done from tests points (at least 3) provided in the calibration certificate.
The flowrate at 150 Pa has been calculated and was used to calculate the deviation. The flowrate (Q) through the device according to the pressure difference and the coefficients is

$$Q = C * \Delta P^n \quad (1)$$

The deviation is

$$Deviation = ABS\left(\frac{Q_{new} - Q_{prev}}{Q_{new}}\right) \quad (2)$$

Q_{new} m^3/h Flowrate calculated with new coefficients
Q_{prev} m^3/h Flowrate calculated with coefficients of the previous calibration

For the second part of the study, as far as the deviation was compared to manufacturer data we no longer needed to have 2 calibration certificates, nevertheless new information on calibration were now needed. Therefore, it is another set of data that has been used in this part of the study:

- part of the previous data has been used, when the following information were available:
    - calibration uncertainty
    - reference and device flowrates.
- New fans, for which only one certificate was available, have been added.

As far as the coefficients were not recalculated, every measurement data has been used (3 to 5 checking points per configuration) which means that 1007 data of 325 fan configurations from 62 calibration certificates have been used.
We have included in the analysis the calibration uncertainty, the difference has been made between "reliable" calibration data and all data.
Reliable data are those for which the given calibration uncertainty is maximum a third of the French Maximum Permissible Error (2 m^3/h or 5% the largest) or a third of the observed deviation:

$$U < \max\left(\frac{q_{vd}-q_{vr}}{3}; \frac{0.05\, q_{vr}}{3}; 2\right) \qquad (3)$$

U m^3/h Calibration uncertainty
q_{vr} m^3/h Reference flowrate
q_{vd} m^3/h Device flowrate

In the calibration certificates, the mentioned expanded measurement uncertainty (of the laboratory) is equal to the standard uncertainty multiplied by a coverage factor equal to 2, so as the level of confidence is about 95%.

3 RESULTS

3.1 Part 1: Deviation from calculated coefficient

This part provides the results of the deviation calculated with the British approach, that is to say with the recalculation of fan coefficients at each calibration. The existing deviation (with coefficients of the previous adjustment) and the new deviation (with coefficients of the new adjustement) are cumulated. Therefore, it is important to keep in mind that the observed deviation not only include the deviation of fan but also:

- calibration uncertainty
- the error due to the linear regression for the calculation of coefficients.

There is also no guarantee that these last points are not significant compared to the accuracy of the fan.

Also, we have noticed that the value of the pressure for which the flowrate through fan is calculated (here 150 Pa) has an important impact on the observed deviation: the smaller the fan pressure the larger the deviation. 150 Pa is the average fan pressure in studied calibration certificates.

Observed deviation according to the time between calibrations

These results use the absolute value of the relative deviation.

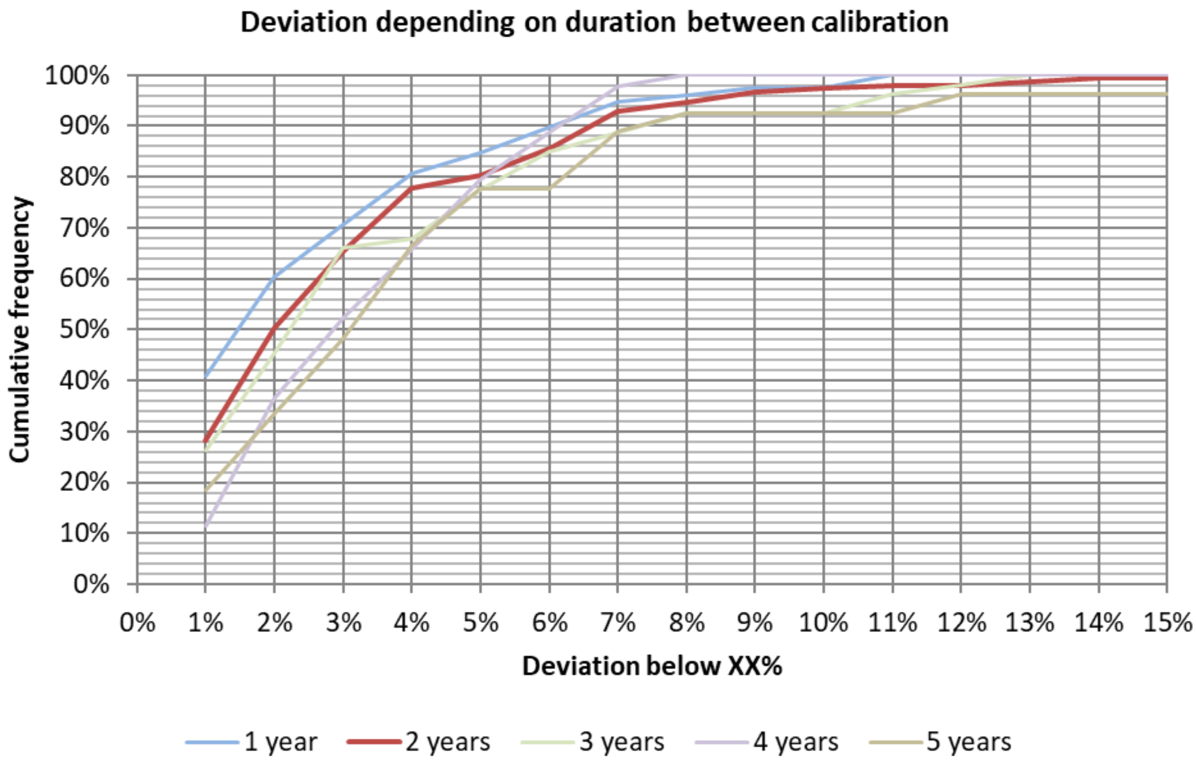

Figure 1: Deviation depending on time between calibrations

The graph presents the deviation of fan over 1 to 5 years. The 2 years line is drawn thicker as it is the one with the largest amount of fans and gathers data from three different bodies.
It shows that **10% of fans deviate of more than 6.5% after 2 years, and 5% of more than 8%.** Table 2 gives the median, average, minimum and maximum deviation according to the time between calibration.
If the calculation of the flowrate is done at 50 Pa instead of 150 Pa, the results are that 10% of fans deviate of more than 10% and 5% more than 14%.

Table 2: Statistics on the deviation

	Time between calibrations				
	1 year	**2 years**	3 years	4 years	5 years
Median	1.5%	**1.9%**	2.2%	2.5%	3.1%
Average	2.4%	**2.9%**	3.3%	3.1%	3.8%
Minimum	0.0%	**0.0%**	0.0%	0.1%	0.1%
Maximum	10.9%	**22.4%**	12.9%	7.9%	15.5%

Positive and negative deviation

The following graph gives the value of the deviation when taking into account the sign.

$$Deviation = \left(\frac{Q_{new} - Q_{prev}}{Q_{new}}\right) \quad (4)$$

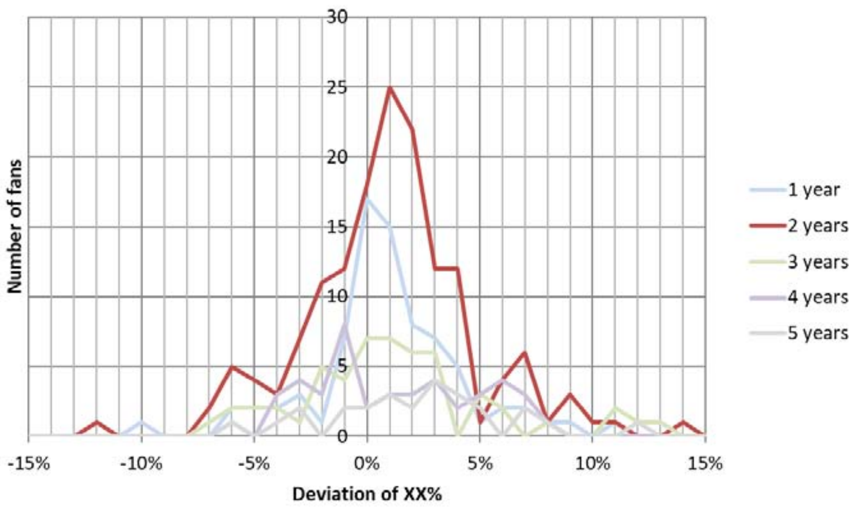

Figure 2: Value of the deviation

The following table gives average, median, minimum and maximum when the sign is considered.

Table 3: Statistics on the deviation when the sign is considered

	Duration between calibration				
	1 year	**2 years**	3 years	4 years	5 years
Median	0.4%	0.5%	0.6%	0.2%	2.3%
Average	0.5%	0.6%	0.7%	0.7%	2.1%
Minimum	-10.1%	-12.5%	-7.7%	-6.3%	-6.3%
Maximum	10.9%	22.4%	12.9%	7.9%	15.5%

Observed deviation according to various parameters

The observed deviation according to the data provider is given in Figure 3. It shows a smaller deviation of fan coming from CEREMA (well stored little used) than others.

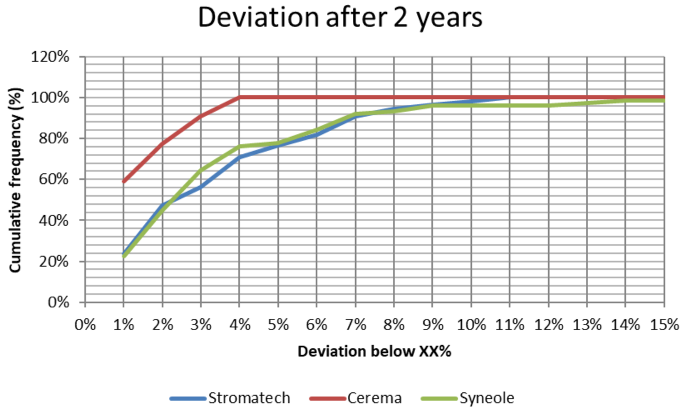

Figure 3: Deviation after 2 years according to the data provider

In the following graph we have studied the variation according to the flowrate of the configuration.

We have considered as "large flowrate" :

- Minneapolis model 4 configurations Open and A
- Retrotec model 3000 configurations Open, A and B

- Retrotec model 6000 configurations Open, A and B8

as "Medium flowrate":

- Minneapolis model 4 configurations B and C
- Retrotec model 3000 configurations C8, C6, C4, C2
- Retrotec model 6000 configurations B4 and B2

as "Small flowrate":

- Minneapolis model 4 configurations D and E
- Retrotec model 3000 configurations C1, L4 and L2
- Retrotec model 6000 configurations B1, B74, B47 and B29

Minneapolis Ductblaster and Retrotec Model 300 have not been taken into account in this part of the study has they only cover small and very small flowrate.
The following table gives the number of data per year and per flowrate:

	1 year	2 years	3 years	4 years	5 years
Large	2	30	3	4	2
Medium	69	86	47	36	23
Small	2	27	3	4	2
Total	73	143	53	44	27

Table 4: Number of data according to the flowrate of the configuration

To have enough significant data only 2 years variations have been considered for this part of the study.
The following graph gives the deviations after 2 years according to the flowrate of the configuration.

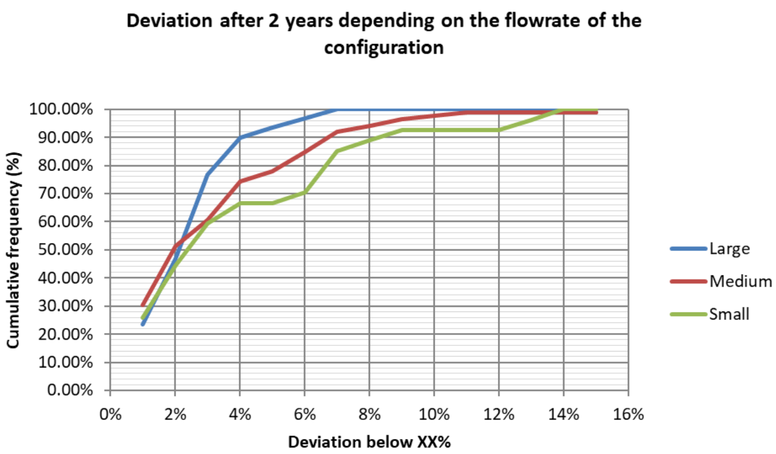

Figure 4: Deviations depending on the flowrate of the configuration

3.2 2nd part of the study, deviation compared to manufacturer coefficients

For the 2nd part of the study we have studied the deviation compared to manufacturers coefficients according the following parameters:

- The measurement capability index
- The flowrate
- The background test pressure
- The fan pressure

On the 1007 data only 235 have a measurement capability index above 3 and are named "reliable" in the following graph.

Observed deviation compared to manufacturer default coefficient

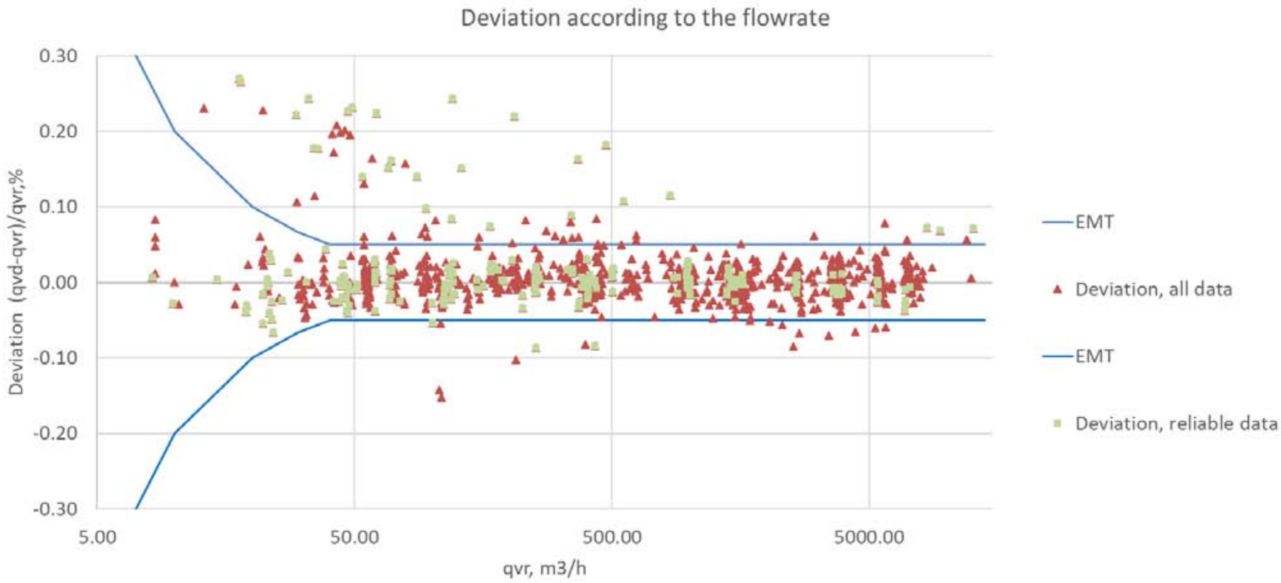

Figure 5: Observed deviation compared to manufacturer default coefficients according to the flowrate, "reliable data" are in green

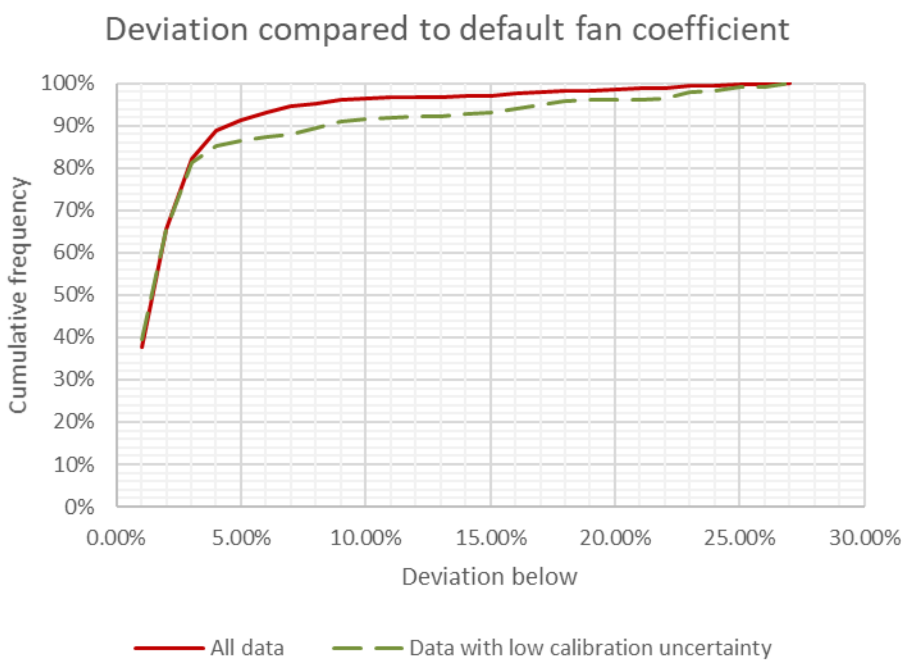

Figure 6: Cumulative frequency of observed deviation compared to manufacturer coefficients

If we look at all data 10% deviate of more than 4.5% compare to manufacture coefficients and 5% of more than 8.5%.

If we only look at calibration with small uncertainty (1/4 of the data) 10% deviate of more than 8.5% and 5% of more than 13.5%.
However, as the French standard requires a maximum of 5% of deviation or 2 m^3/h, only 65 data out of the 1007 are non-compliant (6.5%)

Deviation according to the flowrate
For this part of the study the following assumptions have been made:

- Small flowrate is below 500 m^3/h
- Medium flowrate is between 500 and 2000 m^3/h
- Large flowrate is above 2000 m^3/h

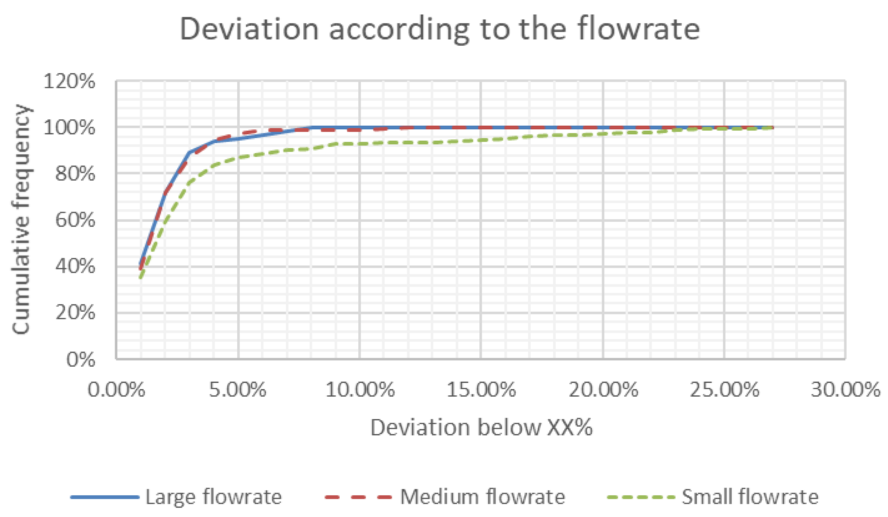

Figure 7: Cumulative frequency of observed deviation compared to manufacturer coefficients according to the flowrate

As in section one the deviation is larger for small flowrates, which is expected as the relative Maximum Permissible Error is higher (2 m^3/h or 5% the biggest). In this case, the large and medium flowrate deviation is similar and quite low: only 4% deviate of more than 6%.

Deviation according to the data provider

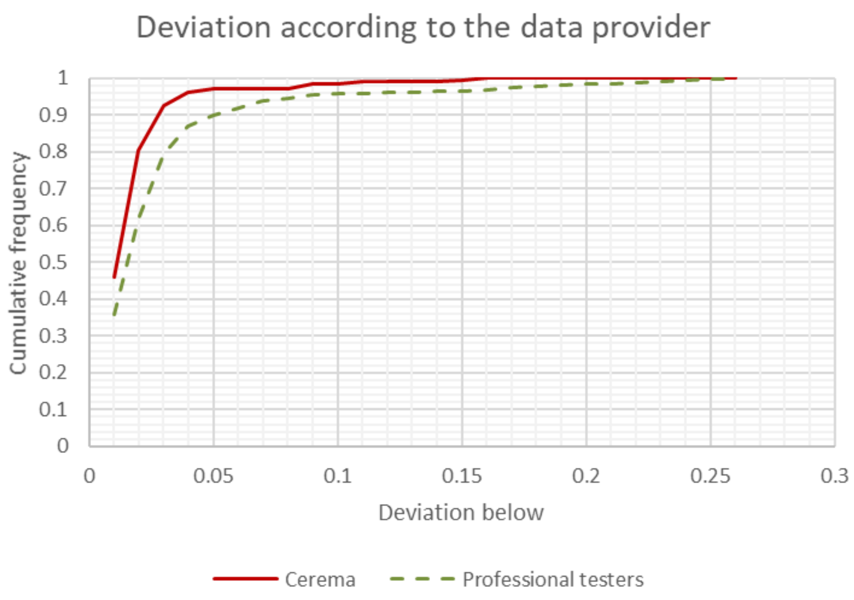

Figure 8: Cumulative frequency of observed deviation compared to manufacturer coefficients according to the data provider

Cerema has provided 204 data out of the 1007. Low used and well-stored fans deviate less than daily used ones. However, this statistic is slightly biased by the fact that Cerema is only using one type of device and has not calibrated its instruments in all the seven laboratories.

Deviation according to the background test pressure

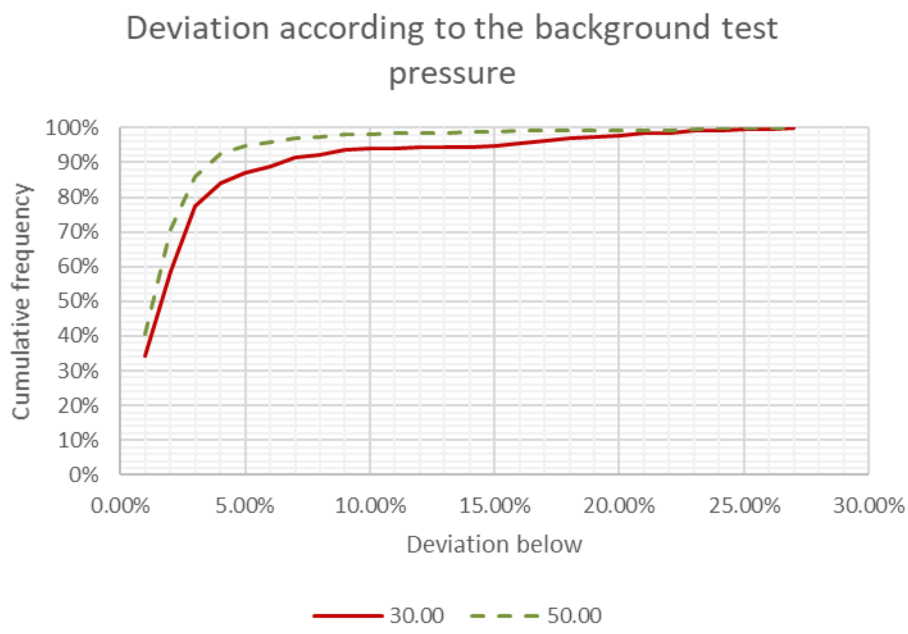

Figure 9: Cumulative frequency of observed deviation compared to manufacturer coefficients according to the background pressure (30 and 50 Pa)

Significant difference of deviation according to the background test pressure is observed.

- With a 50 Pa background pressure 10% deviate of more than 3.5% and 5% of more than 5% which is very low

- With a 30 Pa background pressure 10% deviate of more than 5.5% and 5% of more than 15%.

Deviation according to the fan pressure

Figure 10 shows the deviation of calibration points according to the pressure at fan. Calibration points have been split in three categories:

- Small fan pressure : less than 100 Pa,
- Medium fan pressure: between 100 and 300 Pa,
- Large fan pressure: over 300 Pa.

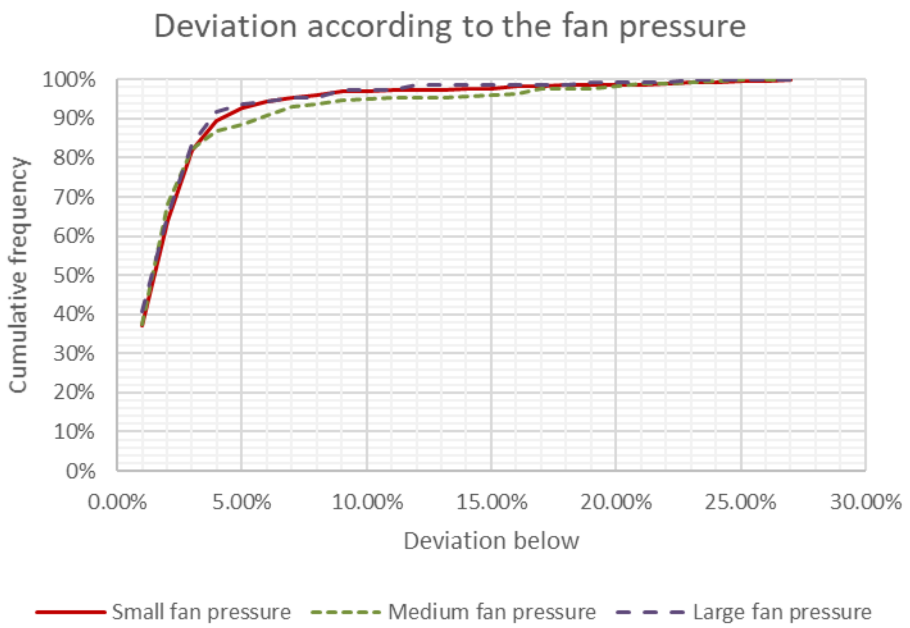

Figure 10: Cumulative frequency of observed deviation compared to manufacturer coefficients according to the fan pressure

Contrary to the first part of the study there is almost no impact of the fan pressure on the deviation.

3.3 Uncertainty of calibration

The following figures provide the calibration uncertainty according to the flowrate and the measurement capability index (Cm) which is the ratio between the Maximal Permissible Error and the calibration uncertainty (JCGM 106:2012).

If the measurement capability index is high, the probability of conformity of the verification is low. It is commonly accepted that a measurement capability index of at least 3 provides good probability of conformity, 2 is low and 1 is not acceptable. If the Cm is below 1 it means that the reference device is less accurate than what the measuring device under calibration is supposed to be.

Most laboratories have a probability of conformity between 1 and 3. Some laboratories get value above 6. In this case it is unclear whether the uncertainty is correctly estimated in the certificates, and whether or not it includes both uncertainties (pressure and flowrate).

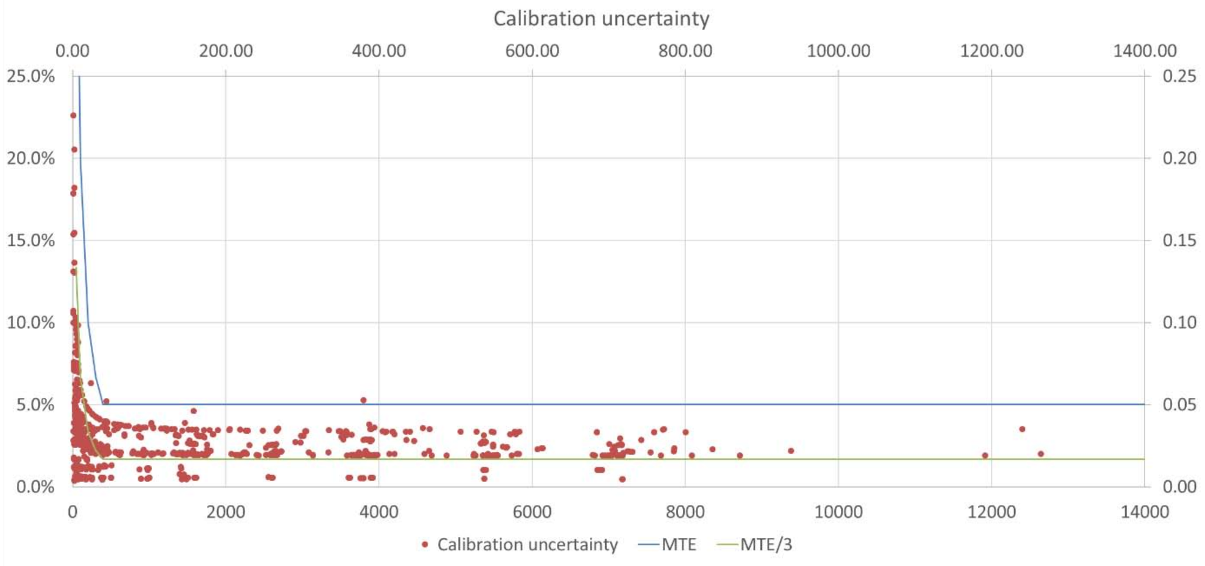

Figure 11: Calibration uncertainty according to the flowrate

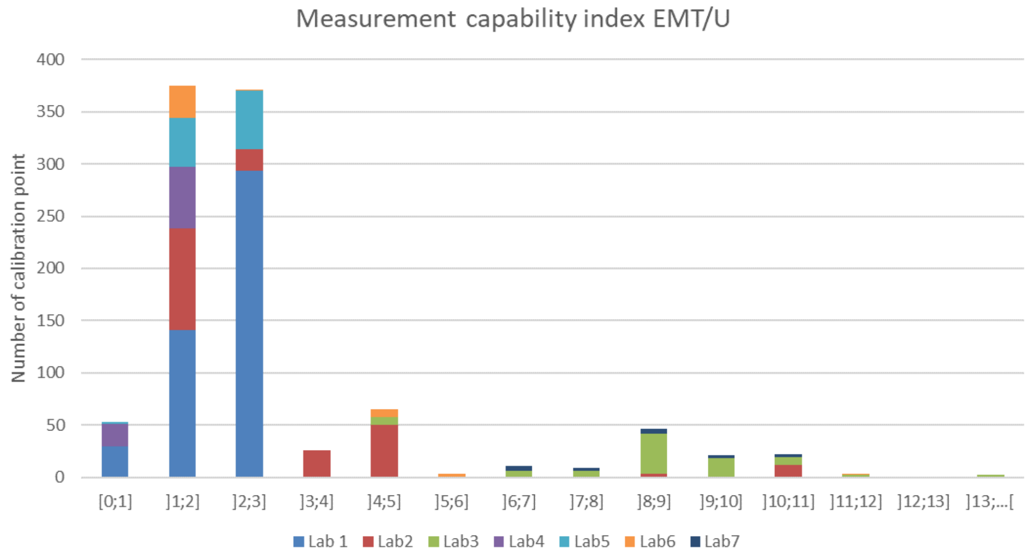

Figure 12: Distribution of measurement capability index per calibration laboratory

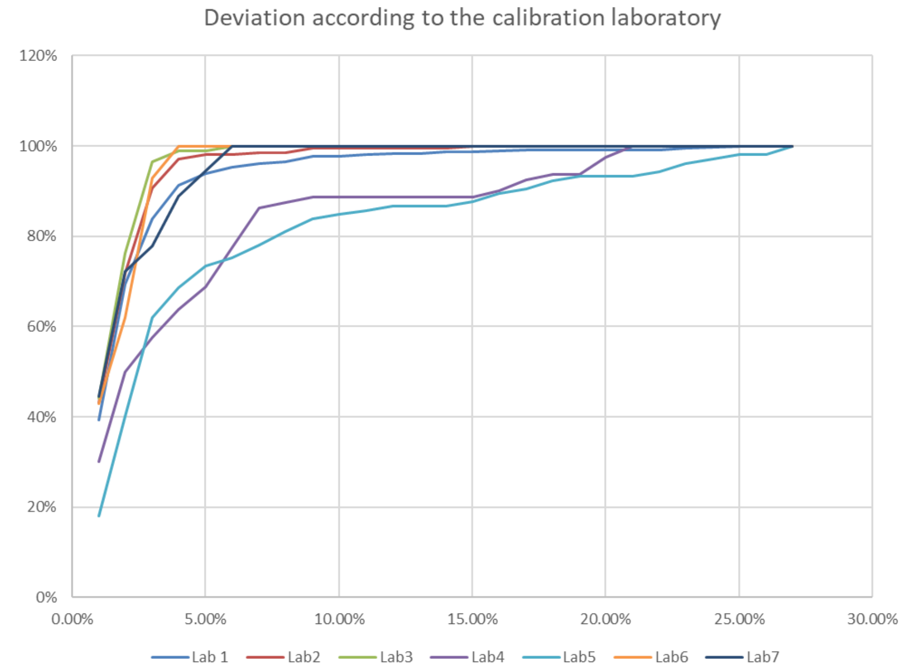

Figure 13: Cumulative frequency of observed deviation compared to manufacturer coefficients according per laboratory.

Laboratories which have low measurement capability index also have a higher deviation, therefore the observed deviation may not be an actual deviation of the device but may be due to calibration uncertainty. However, it has to be kept in mind that these results may be biased by the fact that these laboratories may also check only certain kind of products.

4 DISCUSSION

The observed deviation is quite similar in the first and in the second sections. Table 5 summarizes the results.

Table 5: Comparison of the results for the two parts of the study

	Part 1: recalculation of coefficients	***Part 2: comparison with manufacturer coefficient***
10% vary of more than	6.5%	4.5 %
5% vary of more than	8 %	8.5 %

This deviation is low but not negligible as 4 configurations on 60 do not comply with the French requirements.
The two parts of the study cannot be compared to decide whether the British or the French approach is more appropriate as they don't cover the same sample of data. However, the first part of the study has shown that the pressure used to calculate the flowrate has a large impact on the observed deviation. This is probably because the calibration does not always cover the full range of pressure of the fan, therefore the linear regression leads to extrapolation outside the calibrated range and coefficient are less reliable than manufacturers ones.
Note: This paper does not cover the issue of linear regression but the ordinary least squares method is not always applicable to calibration. See ISO/TS 28037 for more information.
Therefore, it can be concluded that if a recalculation of coefficient is done, the calibration shall:

- cover the full range of possible pressure of the device

- probably be done on more than three points
- use a proper regression method.

Both the first and the second part of the study have shown that low-used and well-stored fans (as those from CEREMA) deviate less than daily used ones (as those from Syneole for example).

The study taking into account the sign of the deviation shows that the median and average of the deviation are close to 0% (0.5%) which means that the flowrate measured by fans tends to increase very slightly but vary mostly randomly.

Configurations measuring large flowrates deviate much less than configurations that measure small flowrates (in the 2 parts of the study). The second part has shown that medium and large flowrate remain conform to the regulation in 96% of cases.

In the second part of the study a significant difference of deviation is observed according to the background test pressure. This means that manufacturer fan coefficients are probably calculated for 50 Pa and vary when the background pressure changes. This means that, when performing a multiple test point on-site, the uncertainty due to the variation of the fan coefficient shall be added to the global uncertainty calculation (if not already included in the device uncertainty). This would need further investigation.

Even if the deviation is low, this study shows that calibration is necessary to establish the appropriate coefficients. However it does not stress the need of an high-frequency one. The first calibration is probably the most important one.
However, if a requirement is set on calibration or verification, first it shall define whether a calibration or verification of calibration has to be performed. It shall also include requirements on laboratories performing the calibration/verification such as:

- Provide at least the following data (in accordance with ISO 17025)
    - Both for calibration and verification of calibration:
        - Reference flowrate
        - Uncertainty on the reference flowrate
        - Device flowrate (calculated with fan coefficients)
        - Fan pressure
        - Uncertainty of fan pressure
        - Background pressure
        - Uncertainty on background pressure
        - Measurement error
        - Uncertainty on measurement error
    - In addition for verification of calibration
        - Maximal permissible error of the device
        - Probability of conformity
        - Measurement capability index
        - Decision rule
        - Conformity assessment
    - In addition for adjustments:
        - calibration function, calibration diagram, calibration curve, or calibration table with associated measurement uncertainty
- Having a measurement capability index above 3

Nevertheless, this study has not shown a significant difference of observed deviation for laboratory with high uncertainty and those with low uncertainty.
In addition to the calibration, it is good practice to check the state of the fan (fan position, vacuity of pressure taps, distortion of the case, broken elements, etc.) on a regular basis.

5 CONCLUSIONS

This study has shown that the fan deviation is low but not negligible with 5% of the fan varying of more than 8.5% in the second part of the study.
Therefore, calibration is necessary but this study does not stress the need of a high frequency calibration/verification nevertheless it insists on the importance to perform an accurate one. A requirement on calibration/verification shall include requirement on the laboratories performing this calibration.
The two parts of the study has not highlighted a large difference between the two approaches (calibration in UK and verification of calibration in France) when comparing results at an average fan pressure of 150 Pa for calibration. However, it seems that new calculated coefficients are less reliable than manufacturers ones on a large scale of pressure. Therefore, when only few points are available, a verification seems more relevant than a calibration. The observed deviation is randomly positive or negative so it is probably not due to the apparition of leakage in the device.
However, statistics have shown that the deviation is correlated with the use of the fan and with the flowrate, highly used fan and small flowrates configurations deviate more than others.
A significant difference of deviation is observed according to the background test pressure (30 or 50 Pa) further investigations are needed to explain it.

6 ACKNOWLEDGEMENTS

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