# NUMERICAL EVALUATION OF AIRTIGHTNESS MEASUREMENT PROTOCOLS

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## ABSTRACT

In France, starting January 1st, 2013, the energy performance regulation will impose an airtightness treatment for every new residential building. This translates into several tens if not hundreds of thousands of envelope airtightness measurements a year that will have to be performed. They will have to be performed by a certified operator and according to the NF EN 13829 standard. This ISO standard is being revised under the Vienna agreement to become an EN ISO standard. This revision should include changes in the measurement protocol to reduce the uncertainty for two indicators commonly used: the air change rate at 50 Pa and the air permeability at 4 Pa.

As far as it is quite impossible to determine the real airtighness of a building, the measurement error cannot be estimated only by a numeric protocol. Our approach relies on the simulation of the measurement protocol with the software CONTAM, varying wind conditions and airtightness levels.

This article addresses three issues that impact the uncertainty on these derived quantities: the wind speed, the distribution of the leaks, and the pressure correction with the zero-flow pressure difference. This implicitly entails the investigation of influencing factors such as airtightness level of the building. Based on the analyses of those simulations results, this paper proposes protocols for extracting the air permeability at 4 Pa with better accuracy.

## KEYWORDS

Airtightness, Simulations, measurement protocols, uncertainty

# INTRODUCTION

In France, the new energy performance regulation will start applying for every new residential building starting January 1st, 2013. It will impose an airtightness treatment and each building will have to justify a level for $Q_{4Pa\_Surf}$ (the air permeability at 4 Pa divided by the loss surfaces area excluding basement floor), which will have to be lower than 0.6 $m^3\ h^{-1}\ m^{-2}$ for houses. In most cases, this justification will involve an envelope airtightness measurement. It will have to be performed by a certified operator and according to the NF EN 13829 [1] standard and its implementation guide GA P50-784 [2]. The ISO 9972 [3] is the international standard associated to this European standard.

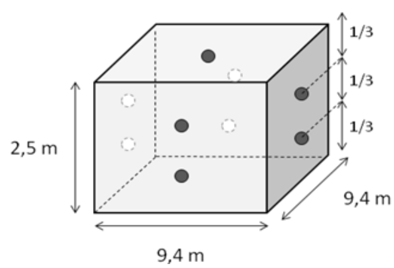
This ISO sets out the airtightness measurement protocol. Since the procedure for the review of this ISO is under way, various publications (e. g. [4] and [5]) look at the uncertainty of this protocol. The uncertainty is a crucial issue as soon as the measured value becomes a requirement. Various research works have shown that the uncertainty could be really important depending on the measurement conditions.

The objectives of this study are to determine the wind impact on the uncertainty of the measurement, and to find out a way to reduce it. So our approach relies on simulations of airtightness tests done with CONTAM[1].

This paper presents the impact of a constant wind during an airtightness measurement, depending on the airtightness level and the leaks distribution. Then, it explains how it is possible to drastically reduce the uncertainty due to the wind. The issue of the pressure correction with zero-flow pressure difference is also discussed.

# METHOD

A numerical study has been carried out using CONTAM as multizone airflow calculation. In order to simulate airtightness measurement, a 1-zone model building has been designed. The simulated building envelope has 9 leaks: 2 leaks on the up-wind facade, 2 leaks on each of the 3 others facades and 1 leak on the roof. The following diagram describes the geometrical properties of the model.




Local wind pressure coefficients:
$C_p$=-0.6 for the roof
$C_p$=0.5 for upwind façade
$C_p$=-0.7 for the three others facades

Figure 1 : Geometrical properties of the model

CONTAM calculates the flow through each leak using the principle of the mass conservation in each zone. For this model, each leak flow's derives from the following equation:

$$q_{mi} = \rho_{air} * C_i * \Delta P^{0.67} \quad (1)$$

with $q_{mi}$= flow through a leak *[$m^3\ h^{-1}$]*, $\rho_{air}$= air density *[$kg\ m^{-3}$]* and $C_i$ = air leakage coefficient *[$m^3.s^{-1}.Pa^{-0.67}$]*

The pressure difference depends on the imposed pressure between the outdoor and the indoor, and the pressure due to the wind:

$$\Delta P = P_{out} - P_{int} - P_{wind} \quad (2)$$

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[1] Multizone Airflow and Contaminant Transport Analysis Software

The wind pressure depends on:

$$P_{wind} = \frac{1}{2} * \rho_{out} * C_p * V_{wall}^{2} \tag{3}$$

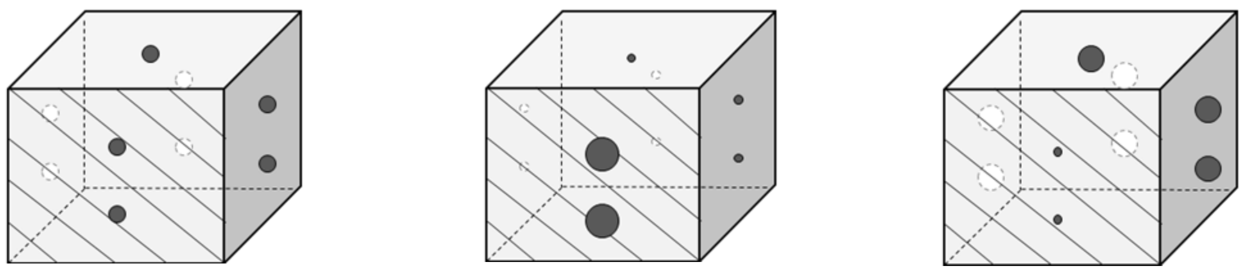
with $C_p$ = local wind pressure coefficient [- ], and $V_{wall}$= Wind speed at the height of the wall [m s$^{-1}$]

The wind speed at the height of the wall depends on the wind speed at 10 m:

$$V_{wall}^{2} = A_0^{2} * \left(\frac{H_{house}}{10}\right)^{2\alpha} * V_{wind}^{2} \tag{4}$$

with $A_0 = 0.60\ and\ \alpha = 0.28$ (coefficients for houses in a suburban area, [6]).

Three different geometric models have been tested. The nine leaks of the first model are all the same, i.e. the size of the "hole" is the same for all of them. For the second model, the size of the two leaks on the upwind side represents 75% of the leakage area. And for the third model, the size of the 2 leaks on the upwind side represents 5% of the leakage area.



Model 1: equal leaks    Model 2: 75% on the up-wind side    Model 3: 5% on the upwind side

Figure 2 : Three different distributions of leaks

Each simulated airtightness measurement consists of 7 measurement points from 10 to 70 Pa for a pressurization test (or from -70 to -10 Pa for a depressurization test). With these 7 points, we made a linear regression according to the ISO9972. The impact of the stack effect is not studied, al the simulated tests are applied under isothermal conditions.

The major objective was to estimate the wind impact depending on the airtightness level. For three airtight levels (0.1 then 0.6 and 3 m$^3$ h$^{-1}$ m$^{-2}$), the wind speed varies from 0 m s$^{-1}$ to 8 m s$^{-1}$ or 9 m s$^{-1}$ (depending on the leaks' distribution).

# RESULTS

## Wind impact

For each leaks' distribution, the simulated measurement of $Q_{4Pa\_Surf}$ evolution depending on the wind speed is represented. For some wind speeds, the relative error between the simulated measurement $Q_{4Pa\_Surf}$ and the $Q_{4Pa\_Surf}$ assumed to represent the real leak, is estimated. The two following graphs show results for the Model 1: "equal leaks". The figure 3 represents the depressurization tests results, and the figure 4 represents the pressurization tests results.

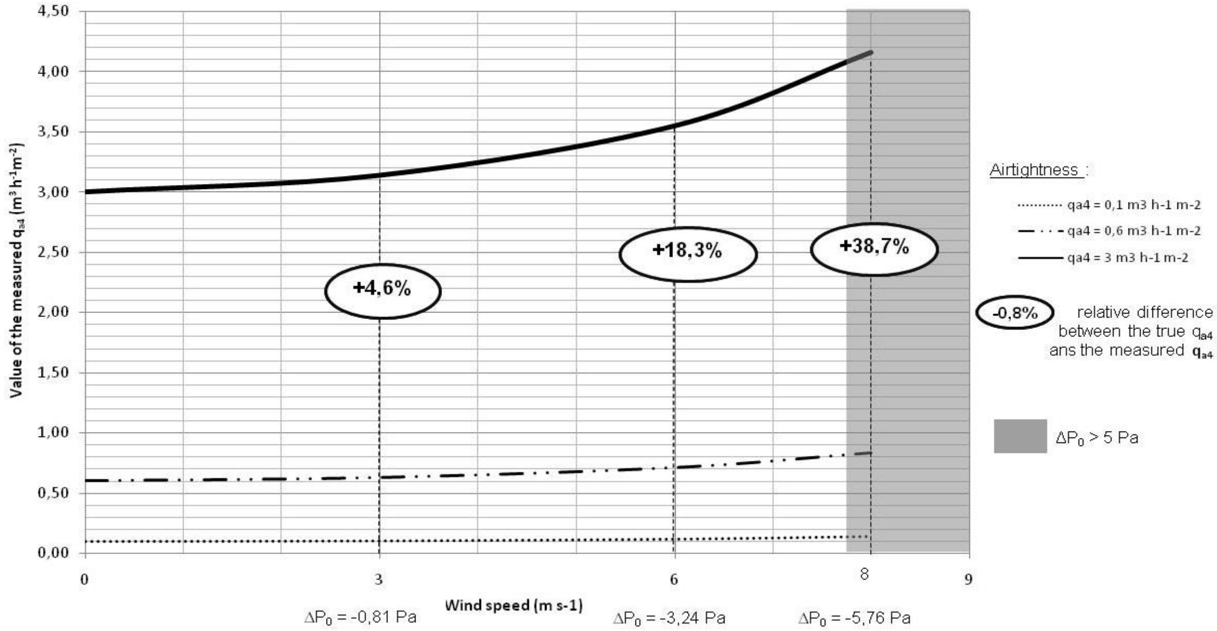



Figure 3: Wind impact on the value of the measured $Q_{4Pa\_Surf}$ for depressurization tests, with 9 indentical leaks

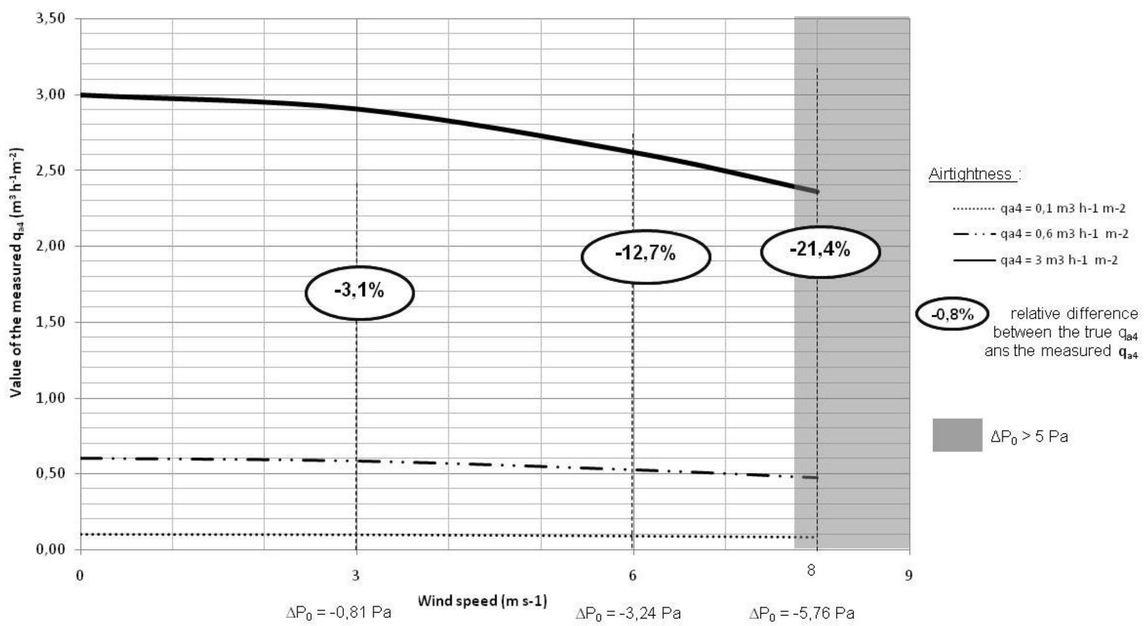



Figure 4: Wind impact on the value of the measured $Q_{4Pa\_Surf}$ for pressurization tests, with 9 indentical

According to the ISO 9972, if the zero-flow pressure difference is greater than 5 Pa, the test is not conform. For the distribution of the model 1, the zero-flow pressure difference exceeds 5 Pa when the wind speed is between 7 and 8 m $s^{-1}$. Thus, for a wind speed lower than 8 m $s^{-1}$, the test is conform (it has been checked that *n* is in range 0.5 to 1 and that $r^2$ is not less than 0.98 for each linear regression).
For the model 1, the relative error for a test declared valid could be more than 20% in pressurization and more than 35% in depressurization. For the three models, the relative error due to the wind is independent of the airtightness level. The following table gives the same key figures for the models 2 and 3.

| | **Model 2** | | **Model 3** | |
|---|---|---|---|---|
| **Wind speed [m $s^{-1}$]** | **Relative error in pressurization** | **Relative error in depressurization** | **Relative error in pressurization** | **Relative error in pressurization** |
| 3 | +1,3% | -0,2% | -0,2% | +1,4% |
| 6 | +3,5% | -1,3% | -1,8% | +3,5% |
| 9 | +6,1% | -3,5% | -4,5% | +8,9% |

Table 1: Relative error due to the wind for models 2 and 3

The zero-flow pressure difference exceeds 5 Pa for wind speed higher than 12 m $s^{-1}$ for the model 2, and for wind speed in range 8 and 9 m $s^{-1}$ for the model 3. For all linear regressions, *n* and $r^2$ respect the ISO 9972 requirements. Table 1 shows that the impact of the wind depends greatly on the leakage distribution on the envelope. It highlights that the error drastically decreases when there is as much leakage on upwind façade ($C_p>0$) as in all others not upwind ($C_p<0$).
For one test, the ISO9972 recommends to make two sets of measurements: for pressurization and depressurization. With those figures, the average of a depressurization set result and a pressurization set results was estimated. The following table gives the relative error in this case for the three models.

| **Wind speed [m $s^{-1}$]** | **Relative error for Model 1** | **Relative error for Model 2** | **Relative error for Model 3** |
|---|---|---|---|
| 3 | +0,8% | +0,6% | +0,6% |
| 6 | +2,8% | +0,3% | +0,8% |
| 8 | +8,7% | -- | -- |
| 9 | -- | -0,9% | +2,2% |

Table 2: Relative error due to the wind for two sets of measurements: for pressurization and depressurization

## The simulated measurement of pressure differences correction with the zero-flow pressure difference

According to the ISO 9972, in order to obtain the induced pressure differences, the average zero-flow pressure difference is subtracted from each of the measured pressure differences. The measured $Q_{4Pa\_Surf}$ calculated without this correction and the measured $Q_{4Pa\_Surf}$ calculated with this correction have been compared. These figures are valid for each tested airtightness level.

| | Wind speed: 3 m s$^{-1}$ | | Wind speed: 6 m s$^{-1}$ | | Wind speed: 9 m s$^{-1}$ | |
|---|---|---|---|---|---|---|
| | **Without correction** | **With correction** | **Without correction** | **With correction** | **Without correction** | **With correction** |
| **Depressurization** | -2,6% | 4,6% | -12,9% | 18,3% | -24,1% | +38,7% |
| **Pressurization** | 3,8% | -3,1% | 13,1% | -12,7% | 22,0% | -21,4% |

Table 3: Impact of the pressure correction on the relative error du to the wind for the Model 1

According to these figures, the pressure correction with the average zero-flow pressure difference has a big influence on the result. Nevertheless, in these geometric models this correction does not decrease the error between the simulated measurement $Q_{4Pa\_Surf}$ and the $Q_{4Pa\_Surf}$ assumed to represent the real leak.

# DISCUSSION

The ISO9972 explains that if the meteorological wind speed exceeds 6 m s$^{-1}$, it is unlikely that the zero-flow pressure difference can be lower than 5 Pa. Nevertheless, there is no wind speed limit. Considering a wind speed of 6 m s$^{-1}$, with the leaks distribution of the model1, the uncertainty of the measured $Q_{4Pa\_Surf}$ could be more than 18%. Moreover, the relative error on $Q_{4Pa\_Surf}$ could be more than 35% if a wind speed for which the zero-flow pressure difference is just under 5 Pa is considered. And none of the validation criteria of the ISO9972 could reject those tests.

These simulated tests have shown that making two sets of measurements in pressurization and depressurization is definitely a way to avoid the wind impact. For each leak distribution, if depressurization tests overestimate the $Q_{4Pa\_Surf}$, then pressurization tests underestimate it (and vice versa), in the same order of magnitude. So, the average of the two results is far closer to the true $Q_{4Pa\_Surf}$. This solution reduces significantly the uncertainty, which is not more than 9% in the worst scenario.

Another significant point of those results is that the uncertainty and the zero-flow pressure difference are independent of the airtightness level. This is true here because the *n* is the same for each leak. However, they depend on the leaks distributions. But, because the *n* of each leak and their distribution are unknown during a test, it is not possible to estimate for each measurement the mistake done because of the wind.

The final important issue raised by this article is the impact of the pressure differences correction. In this model, the impact is important, but does not reduce the relative error. Ideally, the correction should be done with the pressure difference at each leak, but it is not feasible. However, the difference between a result without and with correction shows that a better way to correct the measured pressure differences has to be found.

Those results have been obtained with a numerical study that does not exactly reflect what could happen during a true test. Firstly, the stack effect is not taken into account in those models. Secondly, the model is based on three hypothetical leaks and pressure coefficient distributions, and a flow exponent *n* constant for each leak. And thirdly, the wind speed is supposed constant during a test. Nevertheless, this simple model reveals some interesting results regarding the order of magnitude of the uncertainty due to the wind.

# CONCLUSION

The objectives of this study were to determine the wind impact on the uncertainty of the measurement, and to find out a way to reduce it. Even if the model used to simulate a measurement of the airtightness of a building has some limits, it showed the wind could be responsible of significant errors (in some cases, more than 35%). Doing two sets of measurement in pressurization and depressurization could reduce this deviation in a very important way. This study also showed that the pressure differences correction imposed by the protocol might not be the better one to reduce the measurement error.

Finally, imposing the two sets of measurement and determining another way to correct the pressure differences should lead to reduce the errors during an airtightness measurement.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