On the contribution of steady wind to uncertainties in building pressurisation tests

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ABSTRACT

This paper analyses the contribution of a steady wind to the uncertainties in building pressurisation tests, using the approach developed in another paper (Carrié and Leprince, 2016). The uncertainty due to wind is compared to the uncertainties due to other sources of uncertainty (bias, precision and deviation of flow exponent).
The main results of this study are:

- The model error due to the wind on the estimated airflow rate is relatively small at the high pressure point (12% at 10 m/s), but it can become very significant at the low pressure point (60% at 10 m/s);
- At the high pressure point, the uncertainty due to wind remains smaller than that due to other sources of uncertainties up to 6 m/s, whereas when a two-point pressurisation test is performed to calculate flowrate at 4 Pa, the impact of wind may become dominant at 4 m/s;
- Having a constraint either on the zero-flow pressure or on wind speed seems effective to control uncertainty (provided these quantities can be adequately measured);
- Averaging results between pressurisation and depressurisation is mostly beneficial at intermediate wind speed (around 4 m/s) when a reference pressure of 4 Pa is used;
- The uncertainty due to steady wind is mostly critical for single-sided dwellings or zones tested alone;
- For single-sided dwellings or zones, to estimate flowrate at 4 Pa, it is better to perform:
    - up to 5 m/s, a 2-point test and extrapolate with a calculated flow exponent;
    - above 5 m/s, a test at 50 Pa and extrapolate with a default flow exponent.

KEYWORDS

Airtightness; building; pressurisation test; infiltration; measurement; error; uncertainty

INTRODUCTION

With the increasing pressure of energy performance of buildings regulations, building pressurisation tests become more and more common. Yet, there remain unanswered questions regarding the quantification of uncertainties in practice. The sources of uncertainties include model error due to wind, model error due to the deviation of the flow exponents, precision and bias error.
The objective of this study is to assess the impact of steady wind on airtightness testing uncertainty and compare it to other sources of uncertainty. This paper uses the modelling approach proposed by (Carrié, et al., 2016). The reader should refer to that paper for equations and demonstrations which are not repeated here.

1 APPROACH

This analysis assumes that:

- the building can be represented by a single zone separated from the outside by 2 types of walls: walls on the windward side of the building which are subject to the same upwind pressure; and walls on the leeward side which are subject to the same downwind pressure;
- the test is performed in isothermal conditions ; and

- the airflow rate through the leaks of the envelope is given by a power-law with the same flow exponent.

To estimate combined uncertainty, we use a similar approach to that proposed by (Sherman, et al., 1995), which includes:

- the standard uncertainty due to precision errors, $u_{precision}$;
- the standard uncertainty due to bias errors, u_{bias};
- the standard uncertainty due to model errors, u_{model}, which is assumed to be due both to the wind effect on the pressure seen by the leaks and the guess or deviation of n over a range of pressure.

We have compared the model error due to wind with the combined expanded uncertainties due to other sources.

We have estimated the maximum error for a one-point measurement at 10 and 50 Pa and for a two-point measurement with determination of flowrate at reference pressure 4 and 50 Pa. Constraints were applied to perform a test valid according to ISO 9972:2015. However, we have also plotted results without the constraint on the zero-flow pressure (named "constraint D") to see its impact. We assessed the uncertainties when averaging results of pressurisation and depressurisation tests. We analysed separately the maximum error likely to happen when testing a building zone with facades exposed to wind:

a) both upstream and downstream such as a detached house. In such cases, the leakage distribution, which is represented in our model by the ratio of the leakage coefficient upstream and downstream, is likely to have values contained in a “restricted range” between 2 and 8 ;
b) either upstream only or downstream only, for instance, in single-sided dwellings. In such cases, there is no reason to assume that the leakage distribution would be restricted. Therefore, we should consider the “full range” of leakage distribution.

2 RESULTS

The results are summarised in Figure 1 to Figure 4 and Table 1.

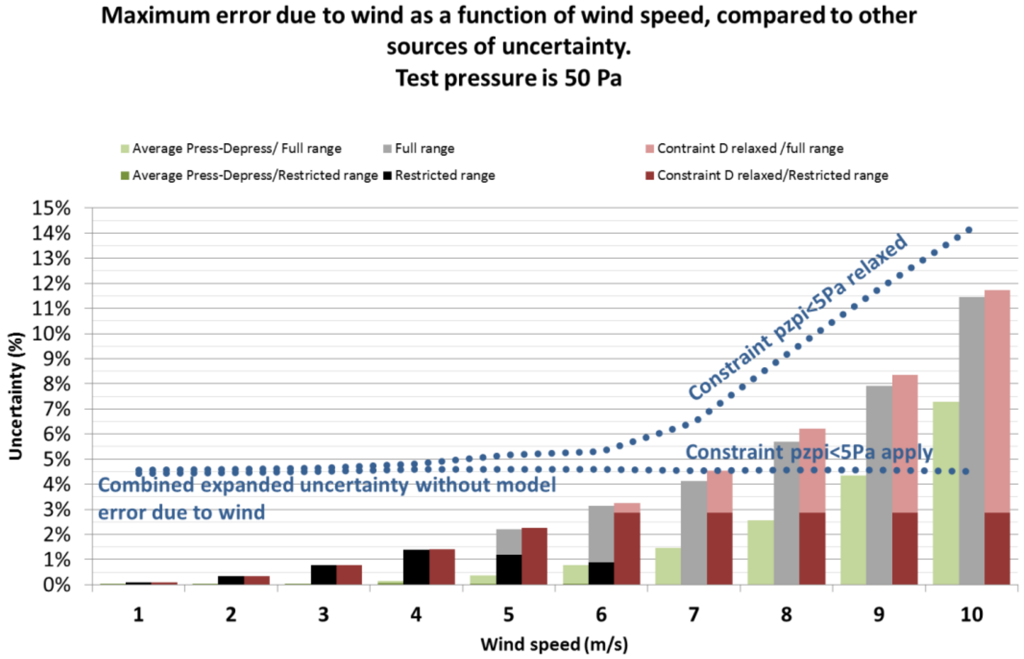

Figure 1: Model error due to wind at 50 Pa, one point measurement

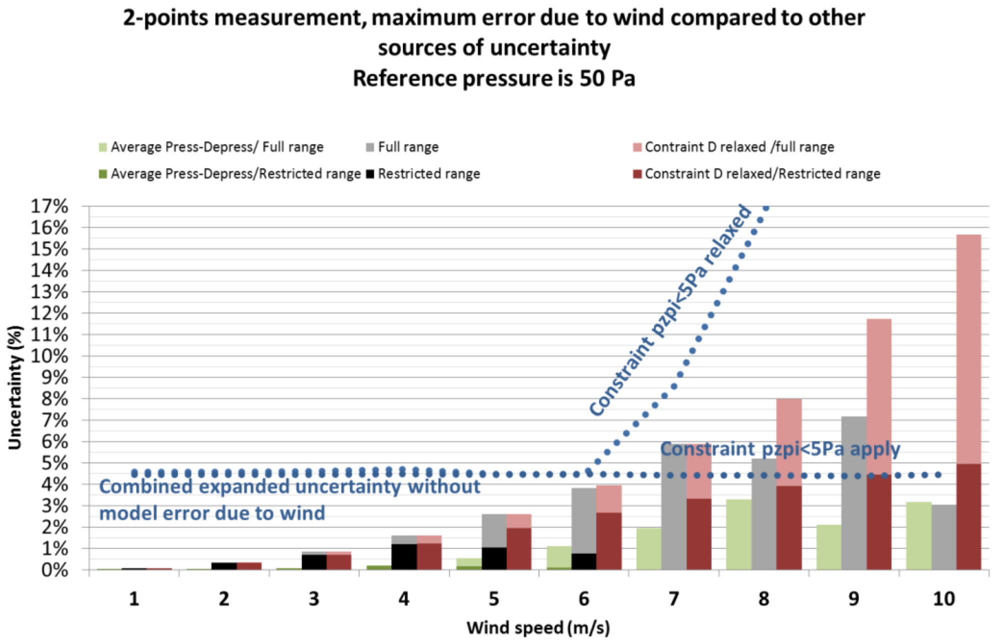

Figure 2: Model error due to wind at a reference pressure of 50 Pa with 2-points measurements

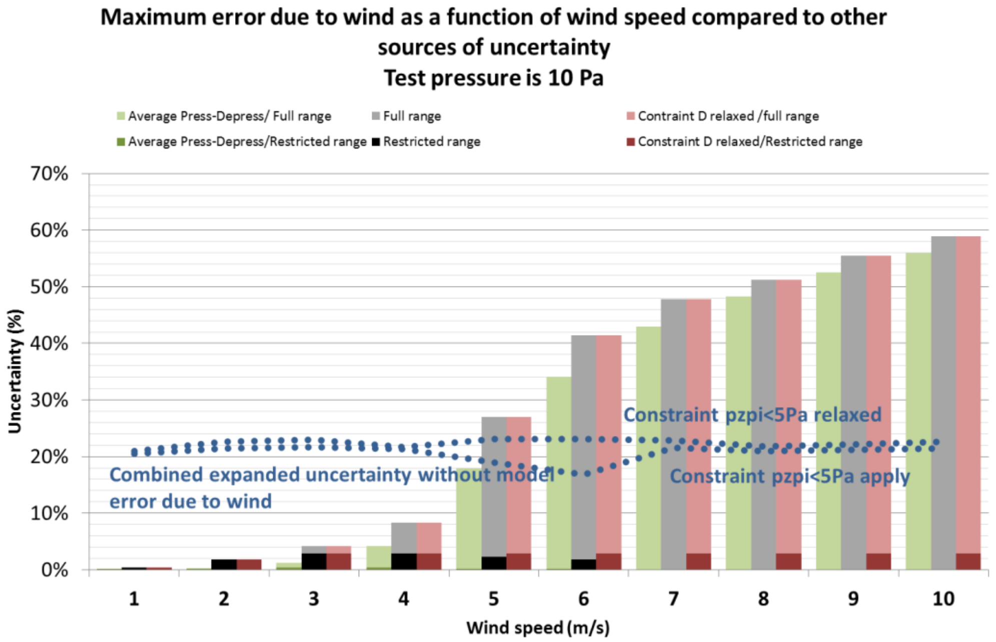

Figure 3: Model error due to wind at 10 Pa, one-point measurement

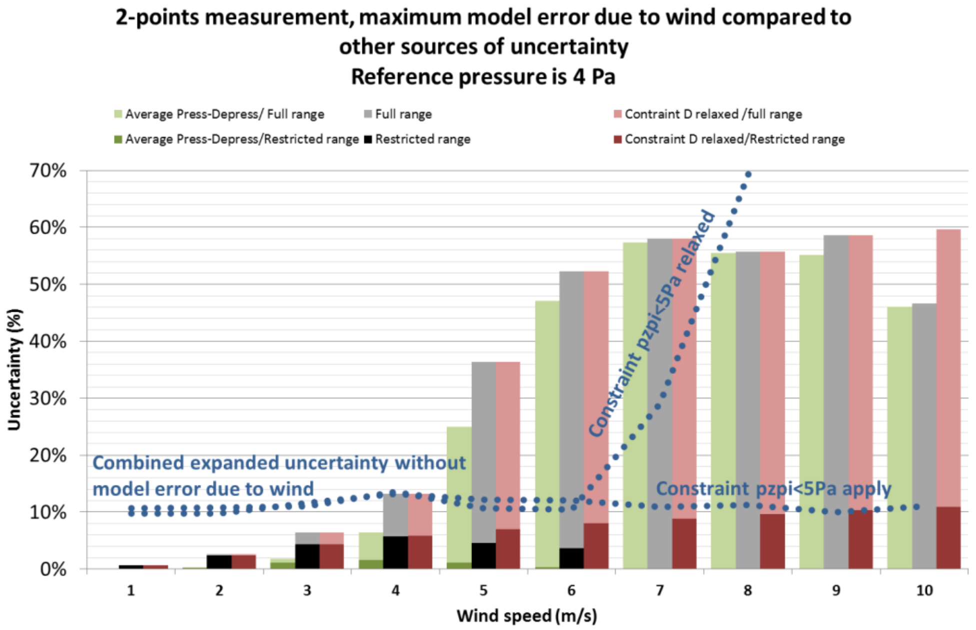

Figure 4: Model error due to wind at a reference pressure of 4 Pa with 2-point measurements

		At 4 Pa				At 50 Pa			
		Constraint D		No constraint D		Constraint D		No constraint D	
	Range of z	Full	Restr.	Full	Restr.	Full	Restr.	Full	Restr.
1-point	6 m s-1	3%	1%	3%	3%	3%	1%	3%	3%
	10 m s-1	11%		12%	3%	11%		12%	3%
1-point combined	6 m s-1	32%	30%	33%	32%	6%	5%	6%	6%
	10 m s-1	34%		45%	44%	12%		15%	14%
2-point	6 m s-1	52%	4%	52%	8%	4%	1%	4%	3%
	10 m s-1	47%		60%	11%	3%		16%	5%
2-point combined	6 m s-1	53%	15%	53%	42%	6%	5%	6%	5%
	10 m s-1	48%		151%	139%	5%		44%	39%

Table 1: Summary of result: maximum error due to steady wind

3 DISCUSSION

One key result is that alone, the model error due to the wind on the estimated airflow rate is relatively small for the high pressure point, but it can become very significant with a low pressure point. While the error lies within 12% for wind speeds up to 10 m s^{-1} at 50 Pa, it can reach 60% at the low pressure point (10 Pa).

However, there are other sources of uncertainty that are not taken into account in this study such as:

- wind fluctuations
- leaks that have different flow exponents
- the linear regression
- thermal draft
- uncertainty on building preparation.

3.1 What happens over 6 m/s?

At 50 Pa, up to 6 m/s uncertainty due to wind remains below "other combined uncertainty". Therefore the uncertainty due to wind has almost no impact on the quadratic sum. It is seen on one- and two-point measurement graphs.
The uncertainty due to wind becomes dominant at 5 m/s for 10 Pa (Figure 3) and at 4 m/s for 2-point test extrapolated at 4 Pa (Figure 4).
Therefore, 6 m/s is a relevant limit value for the high pressure station (50 Pa), but is too high for low-pressure measurements.

3.2 Can we relax the zero-flow pressure constraint ("constraint D" on graphs) to allow testing in windy places?

The difference between with and without the zero-flow pressure constraint is the difference between the grey/black and the red bars on figures 1 to 4. Up to 6 m/s there is not much difference between with and without applying this constraint. Constraint D limits the wind speeds for which the test can be performed to about 6.2 m s^{-1} with a restricted range of leakage distribution (see Figure 1, Figure 2, Figure 3, Figure 4) which is consistent with ISO 9972:2015 stating that constraint D is unlikely to be met above 6 m s^{-1}. Relaxing the constraint on the zero-flow pressure would allow one to perform a test above 6 m/s in detached houses.
In detached houses (restricted range of leakage distribution), the uncertainty due to wind remains low even with wind speeds up to 10 m/s and without constraint on zero-flow pressure. However, for 2-point tests above 6 m/s, the combined uncertainty without wind increases rapidly without constraint D; it passes over 10% at 7 m/s for a reference pressure at 50 Pa.
These results suggest it is necessary:

- either to have a constraint on wind speed (maximum 6 m/s); or
- to have a constraint on zero flow pressure (maximum 5 Pa)

3.3 Does averaging pressurisation and depressurisation have a significant impact on results?

The difference between green and grey bars in figures 1 to 4 shows the effect of averaging pressurisation and depressurisation tests. This averaging can decrease the uncertainty due to wind up to 5 percentage points. At low wind speed, when averaging, the uncertainty due to wind is negligible; therefore other sources of uncertainties dominate.
At high wind speed, averaging is not enough to make uncertainty due to wind in the same range of other sources of uncertainties.
Averaging is mostly beneficial at intermediate wind speed (around 4 m/s) when reference pressure is 4 Pa. It keeps the error due to wind far below the "other" combined uncertainty.

3.4 Is the uncertainty different between tests in detached houses and single-sided dwellings?

The maximum uncertainty in detached houses (restricted range) is given by dark bars in the figures, and the maximum uncertainty without restriction on the leakage distribution is given by light bars. The uncertainty in detached houses remains below 12% even for wind speeds up to 10 m/s with constraint D relaxed at 4 Pa, whereas for a single-sided dwelling the uncertainty due to wind may reach 60% at high wind speed. Therefore, the uncertainty due to wind is mostly critical for single-sided buildings or zones.

3.5 To calculate the infiltration air flowrate is it better to have test results at 4 Pa or to have test result at 50 Pa and estimate flowrate at 4 Pa with a constant n of 2/3?

According to ((Carrié, et al., 2016) ; figure 6), the uncertainty for a reference at 4 Pa (with *n* =2/3) when testing at a single pressure station of 50 Pa remains between 31 and 34% up to 10

m/s when constraint D applies. When constraint D is relaxed, it increases from 5 m/s to reach 47% at 10 m/s.
Comparing this result with Figure 4 suggests that up to 5 m/s, it is better to perform a 2-point test and extrapolate with a calculated flow exponent and above 5 m/s it is better to perform a test at 50 Pa and extrapolate with a default flow exponent.
For detached houses, Figure 4 suggests that a 2-point test is preferable up to 7 m/s (whether constraint D is relaxed or not).

3.6 What is the impact of steady wind on uncertainty compared to other sources of uncertainty?

On figures 1-4, for detached houses (restricted range), the impact of steady wind is quite low compared to the other sources of uncertainty, but for a single-sided building (full range), it is important to check wind speed and/or pressure difference at zero flow to perform a reliable test.

3.7 Should tests be performed with one or several pressure stations?

If the reference value is 50 Pa, there is much less uncertainty due to wind if the test is performed at only one pressure point close to 50 Pa. If the test reference is 4 Pa, a 2-point test is better for low wind speeds and a one point test better for high wind speeds.
As expected, the low-pressure point is more sensitive to bias and precision errors. At a reference pressure of 50 Pa, these effects are not counterbalanced by better determining the flow exponent with the two-point analysis. Still, it may be useful to test envelopes at multiple pressure stations to identify suspicious results, e.g. due to moving valves.

4 CONCLUSION

This study has shown that the impact of steady wind remains reasonable as long as the wind speed remains below 6 m/s. In detached houses, our results suggest that the impact of wind is always below the other sources of uncertainty considered in this paper; this is not true when testing single-sided zones. Testing at 50 Pa and using the same reference pressure (50 Pa) seems effective at limiting the uncertainty for wind speeds up to 9m/s (below 10%). These results apply only to tests performed according to ISO 9972:2015 protocols.

5 REFERENCES

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