VIP 41: Impact of wind on building airtightness test

VALÉRIE LEPRINCE – INIVE

NOVEMBER 8TH– AIVC & TIGHTVENT WEBINAR

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AIVC project: Working Group Impact of Wind on airtightness test

Objective:

- Better understand the uncertainty due to wind on the airtightness test
- Provide a literature review on the subject
- Improve the airtightness test method (inc. calculation) for a better reliability and feasibility.

Output (March 2021):

A "Ventilation Information Paper" published by AIVC : https://www.aivc.org/resources

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Why do we care about wind?

Building airtightness tests have become very common in several countries

- **Tests required** with a target value
  - ⇒ Necessary to have reliable tests
  - ⇒ Not too many limitations on allowable test conditions

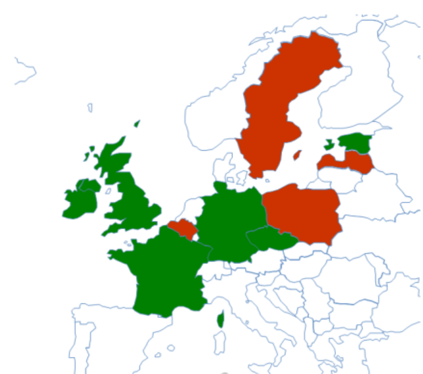
Sources of uncertainty :

- Measurement device (accuracy precision) → Calibration
- Calculation assumptions (regression analysis, model)
- Tester behavior → Training, competent tester schemes
- External conditions (wind, stack effect)
- ⇒ Not properly addressed in ISO 9972

Allowable test conditions:

- The **zero-flow pressure shall not exceed 5 Pa** for the test to be valid.
- In some very windy regions it is difficult to perform a test in accordance with the standard.

> 5Pa



Minimum airtightness requirement included in the regulation (in 2016)

No minimum requirement included

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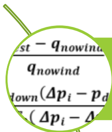
Content

Impact of wind on building airtightness tests



Part 1: The physic

Part 2: Literature review

Part 3: How to limit the impact?

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$$E(q) = \frac{q_{est} - q_{nowind}}{q_{nowind}} = \frac{C_{est}.\Delta p_{ref}^{n} - C_t.\Delta p_{ref}^{n}}{C_t.\Delta p_{ref}^{n}}$$
$$= \frac{C_{up}(\Delta p_i - p_{up})^n + C_{down}(\Delta p_i - p_{down})^n - C_t(\Delta p_i - \Delta p_0)^n}{C_t(\Delta p_i - \Delta p_0)^n}$$

Impact of wind on building airtightness test

PART 1: REASONS BEHIND – THE PHYSIC

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Part 1: The physics behind the impact of wind on the result

At least 4 issues:

- Error due to **wind variation** (between before/after and during the test)
- Impact on the **external pressure** sensor
- Uncertainty due to **wind fluctuations** (wind never steady over the whole test)
- **Model** error

The wind has an impact on the result of the airtightness test despite the zero-flow pressure subtraction

Wind variation

INTERNATIONAL STANDARD **ISO 9972**

5.3.3 Zero-flow pressure difference

Short-circuit the pressure-measuring device and check or adjust the zero reading at the starting of the testing.

Temporarily cover the opening of the air moving equipment and connect the pressure measuring device to measure inside-outside pressure difference. Record the values of the zero-flow pressure difference over a period of at least 30 s (minimum 10 values) and calculate

— the average of the positive values of zero-flow pressure difference, Δp_{01+},

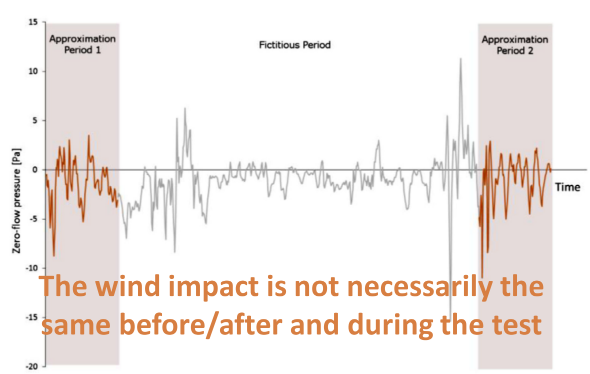
— the average of the negative values of zero-flow pressure difference, Δp_{01-}, and

— the average of all values of zero-flow pressure difference, Δp_{01}.

Repeat this process at the end of the test (to obtain Δp_{02+}, Δp_{02-}, and Δp_{02}).

If the absolute value of Δp_{01+}, Δp_{01-}, Δp_{02+}, or Δp_{02-} is higher than 5 Pa, the test shall be declared not valid. If a test report is produced for such a test, this failure to meet required test conditions shall be stated in the test report.

NOTE The reference pressure value (zero) is outside.



The wind impact is not necessarily the same before/after and during the test

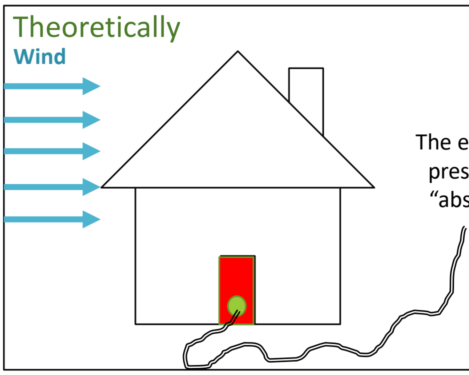
M. Prignon, A. Dawans and S. Altomonte et al./Energy & Buildings 188–189 (2019) 12–24

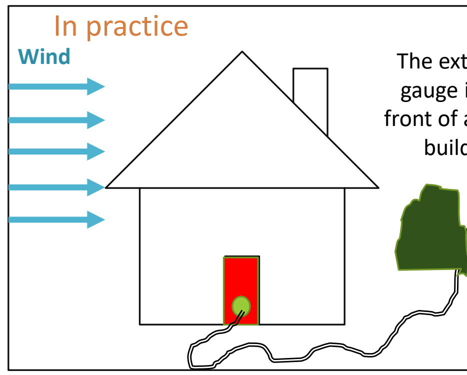
1st issue

Pressure measurement

INTERNATIONAL STANDARD **ISO 9972**

Ensure that interior and exterior pressure drops are not influenced by the air moving equipment. The exterior pressure tap should be protected from the effects of dynamic pressure, e.g. by fitting a T-pipe or connecting it to a perforated box. Especially in windy conditions, it is good practice to place the exterior pressure tap some distance away from the building, but not close to other obstacles.





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Pressure measurement

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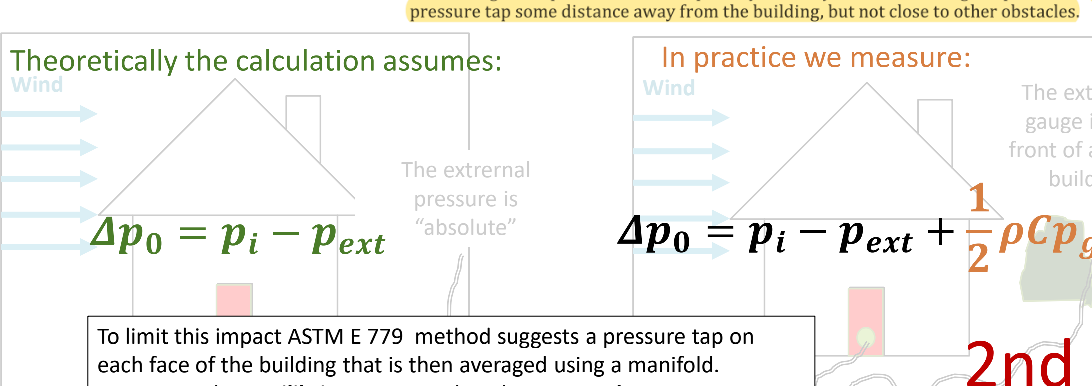
Theoretically the calculation assumes:

$$\Delta p_0 = p_i - p_{ext}$$

In practice we measure:

$$\Delta p_0 = p_i - p_{ext} + \frac{1}{2}\rho Cp_{gauge} U^2$$



To limit this impact ASTM E 779 method suggests a pressure tap on each face of the building that is then averaged using a manifold.
=> It is not the **equilibrium pressure** but the **averaged pressure difference of the building envelope** that is measured in this standard

2nd issue

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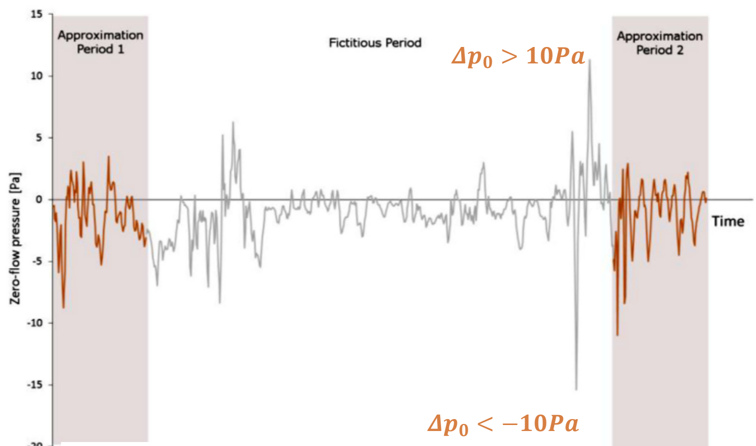
Wind fluctuations



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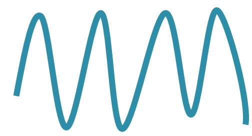
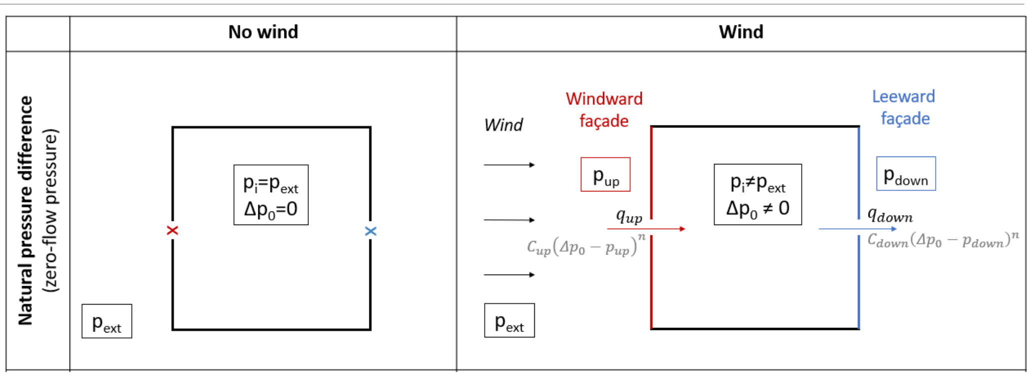


Indoor pressure varies of more than 20 Pa within a few minutes → large induced uncertainty

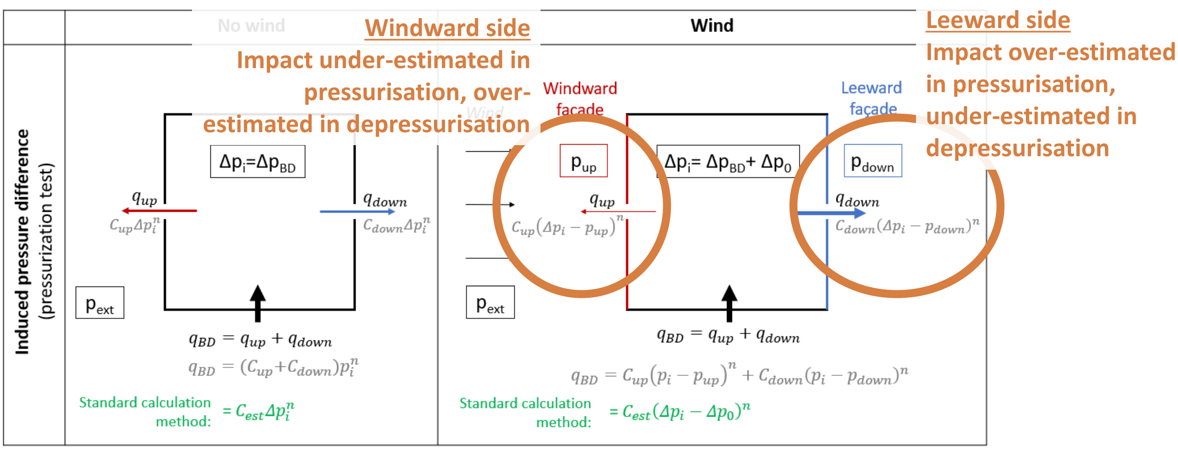
3rd issue

And even in a perfect world, it does not work well (Model error)…



Equilibrium pressure: $\Delta p_0 = p_i - p_{ext} = \dfrac{C_{up}^{\frac{1}{n}} p_{up} + C_{down}^{\frac{1}{n}} p_{down}}{C_{up}^{\frac{1}{n}} + C_{down}^{\frac{1}{n}}}$

… as the problem is not linear (n≠1)



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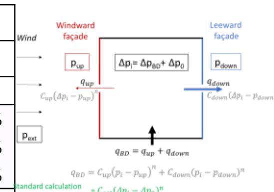
Model error

$$E(q) = \frac{q_{est} - q_{nowind}}{q_{nowind}} = \frac{C_{est}.\Delta p_{ref}^n - C_t.\Delta p_{ref}^n}{C_t.\Delta p_{ref}^n}$$
$$= \frac{C_{up}(\Delta p_i - p_{up})^n + C_{down}(\Delta p_i - p_{down})^n - C_t(\Delta p_i - \Delta p_0)^n}{C_t(\Delta p_i - \Delta p_0)^n}$$

4th issue

U (m/s)	External pressure (Pa)	C_{up}/C_t	Δp_0 (Pa)	Internal pressure $\lvert\Delta p_i\rvert$ 10 Pa			25 Pa			50 Pa			100 Pa		
				p+	p-	av.	p+	p-	av.	p+	p-	av.	p+	p-	av.
3	p_{up}=1,35 p_{down}=-2,7	0,25	-2	-2%	2%	0%	-1%	1%	0%	0%	0%	0%	0%	0%	0%
		0,5	-0,6	0%	-1%	-1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		0,75	0,6	1%	2%	2%	1%	-1%	0%	0%	0%	0%	0%	0%	0%
5	p_{up}=3,75 p_{down}=-7,5	0,25	-4	*1%*	*-14%*	*-7%*	1%	-3%	-1%	1%	-1%	0%	0%	0%	0%
		0,5	-0,8	4%	-14%	-5%	2%	-4%	-1%	1%	-2%	0%	1%	-1%	0%
		0,75	0,6	-5%	-1%	-3%	-1%	0%	-1%	-1%	0%	0%	0%	0%	0%
10	p_{up}=15 p_{down}=-30	0,25	**-7,2**	*18%*	*-267%*	*-125%*	*18%*	*-91%*	*-37%*	*11%*	*-21%*	*-5%*	*6%*	*-9%*	*-2%*
		0,5	-0,9	-14%	-87%	-51%	8%	-48%	-20%	6%	-12%	-3%	4%	-5%	-1%
		0,75	0,6	-86%	-7%	-47%	-16%	-8%	-12%	-6%	2%	-2%	-2%	2%	0%



In some cases, some leakage flow in the opposite direction

If the whole building is pressurized (respect. depressurized) averaging the results of a pressurized and a depressurized test decreases the error.

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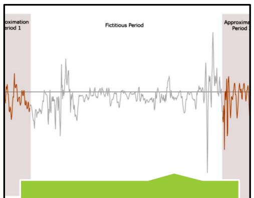
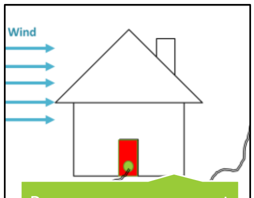
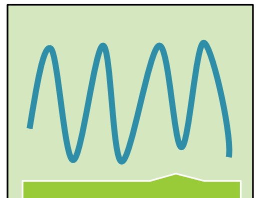
To sum up: 4 main wind issues



Wind variation



Pressure measurement location



Wind fluctuations

$$E(q) = \frac{C_{up}(\Delta p_i - p_{up})^n + C_{down}(\Delta p_i - p_{down})^n - C_t(\Delta p_i - \Delta p_0)^n}{C_t(\Delta p_i - \Delta p_0)^n}$$

Model error

Impact of wind on building airtightness tests

PART 2: QUANTIFICATION, LITERATURE REVIEW

Literature review presented in the VIP

Simulations:
- Impact of **steady wind**
- Impact of **unsteady wind**

Laboratory measurements

On-site measurements

Error due to steady wind:
Very sensitive to leakage distribution
*- **50 Pa**: < **12%** up to 10 m/s;*
< other uncertainties up to 6 m/s
*- **10 Pa**: < **60%** up to 10m/s*
*- **4 Pa**: main uncertainty at 4m/s*
Carrié&Leprince, 2017

Quasi-steady compressible and isothermal models:
- ***Much larger uncertainties** than average wind alone.*
- *Significant impact of **wind frequency***

Carrié&Mélois, 2020

CFD Study:
*The ACH increases from about 100% during a windy day (mean velocity of 5 m/s): **Gusts create a pressure difference around 50 Pa***
Kraniotis et al., 2014

What is needed?
- include the **stack effect**
- simulate **multi-zone** buildings
- A better characterisation of **unsteady winds**
- A better knowledge of **leakages behaviour**

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Literature review presented in the VIP

Simulations:
- Impact of steady wind
- Impact of unsteady wind

Laboratory measurements

On-site measurements

Outdoor measurement with steady artificial wind at 4 Pa:
- ***high wind speeds** (4 m/s – 9.5 m/s) in **one direction** induce **16% to 24% lower results** of air permeability*
- ***wind becomes mostly insignificant under 3.5 m/s***

Zheng et al., 2018

For an indicator at 4 Pa:
- *Leakage mostly leeward side: **ISO 9972 method** more reliable than a 1-point method and a 2-point method, for all wind speeds*
- *Leakage mostly on the windward side: a **1-point analysis** (pressure station at 50 Pa or 100 Pa) gives lower error when the wind is **above 4 m/s**.*

Mélois, 2020

What is needed?
- define how the **wind** shall be **modelled**
- model the **environment**

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Literature review presented in the VIP

Simulations:
- Impact of steady wind
- Impact of unsteady wind

Laboratory measurements

On-site measurements

6000 tests in 6 houses; recommendations :
- **Below 3 m/s, multi pressure point testing ;** about 10% better for a **4 Pa** reference than single-point
- **Above 6 m/s, single point testing at 50 Pa**
- **Averaging pressurization and depressurization** tests reduces the uncertainty by about 12%.

Walker et al., 2013

High-rise building (60m), tests in windy AND not windy condition
- By **averaging the results :** possible to obtain reproducible results
- ***Averaging measured values on 3 sides:*** *reduces wind impact*

Rolfsmeier and Simons., 2019

Test module in open terrain:
- ***Change in wind speed higher impact on uncertainty*** *than change in wind direction*
- *The test becomes even* ***more reliable when wind direction*** *(and therefore pressure distribution)* ***changes a lot*** *during the test.*
- *When the wind blows against the fan, the* ***main source of error*** *is due to this* ***direct flow of wind on the fan*** *(overlaps other source of error due to wind).*

Kraniotis et al, 2020

What is needed?
- More studies to draw general conclusions
- Control some parameters (leakage repartition etc.) for parametric studies

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Minimizing the wind impact on airtightness tests results

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Main recommendations for minimising wind impact

Improve zero-flow pressure measurement

- Increase the **duration and frequency** of the measurements: **30 to 60 s** and **1 data /s (> 10 points/data)**
- Monitor the wind during the entire test to **detect variations**

Choose carefully the location of pressure taps

- Let gauges at the **same location** during the whole test
- Use **T-pieces** and put the pipe some distance away

Use a weighed method for the regression

Adapt the pressure difference sequence

- Average the results of **pressurization and depressurization** tests
- **Single-point test** to estimate a flowrate at **50 Pa or at 4 Pa with wind > 5 m/s** (multipressure-point when < 5 m/s)
- Carry out **similar pressure measurements during the airtightness test than during the zero-flow pressure measurement** (duration and frequency); use an average of the same number of values over the same time interval.