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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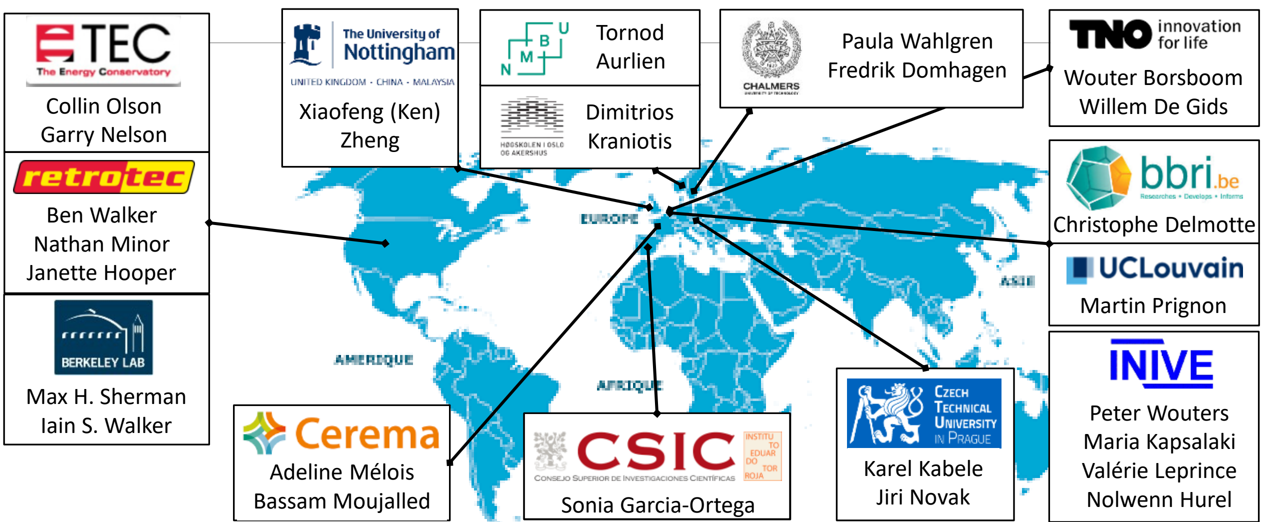
Participants of the WG



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Why do we care about wind?

Building airtightness tests have become very common in several countries

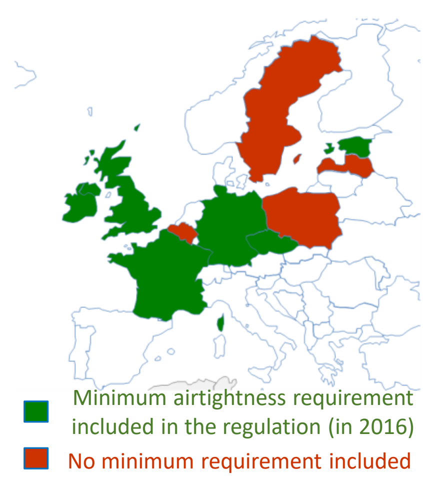
- **Tests required** with a target value
  - ⇒ Necessary to have reliable tests
  - ⇒ Not too many limitations on allowable test conditions

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.



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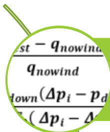
Content

Impact of wind on building airtightness tests



Part 1: The physic

Part 2: Literature review

Part 3: How to limit the impact?

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

Impact of wind on building airtightness test

PART 1: REASONS BEHIND – THE PHYSIC

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+},

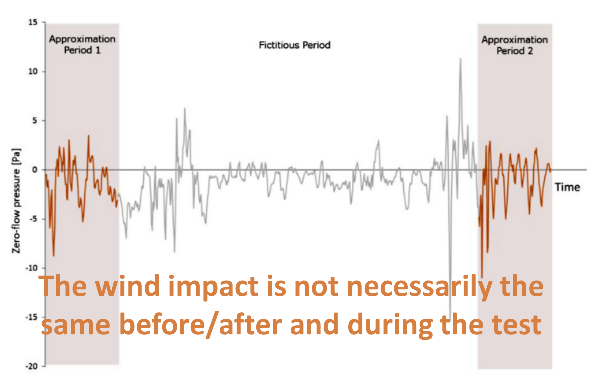
— the average of the negative values of zero-flow pressure difference, Δp_{01-}, and

— 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.

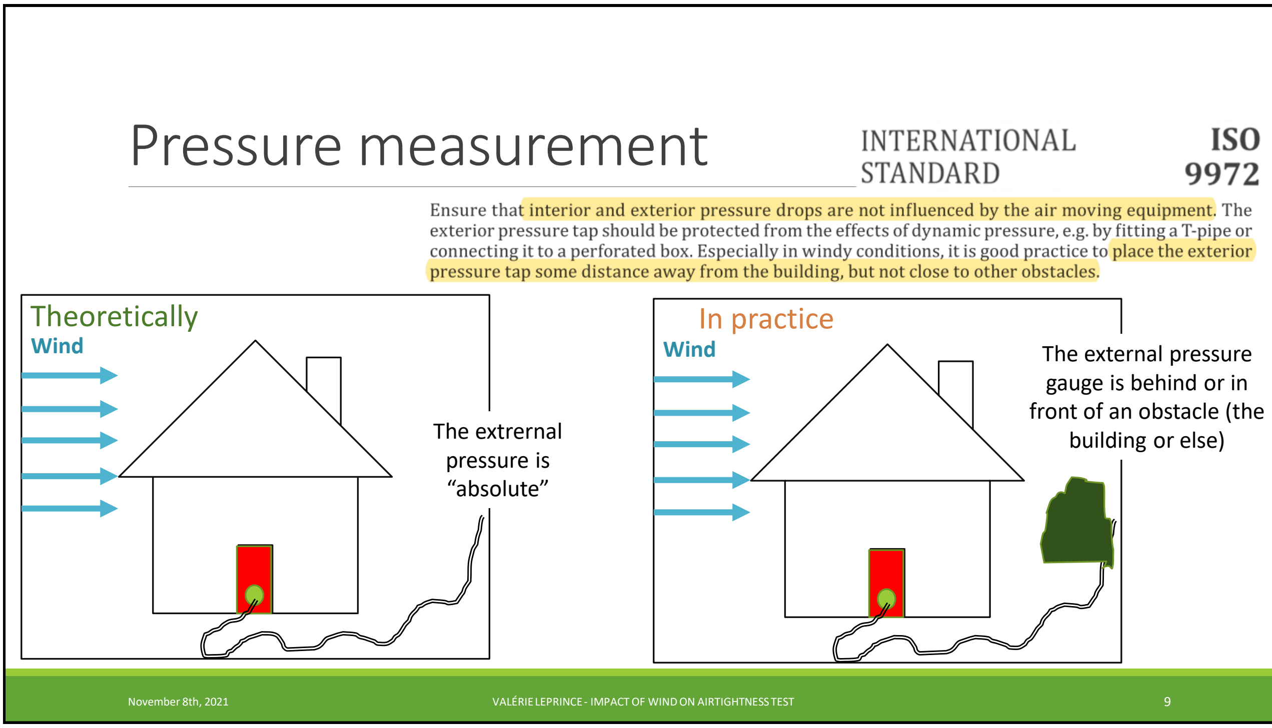
NOTE The reference pressure value (zero) is outside.



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.
Theoretically
Wind
The extrernal pressure is "absolute"
In practice
Wind
The external pressure gauge is behind or in front of an obstacle (the building or else)
November 8th, 2021
VALÉRIE LEPRINCE - IMPACT OF WIND ON AIRTIGHTNESS TEST
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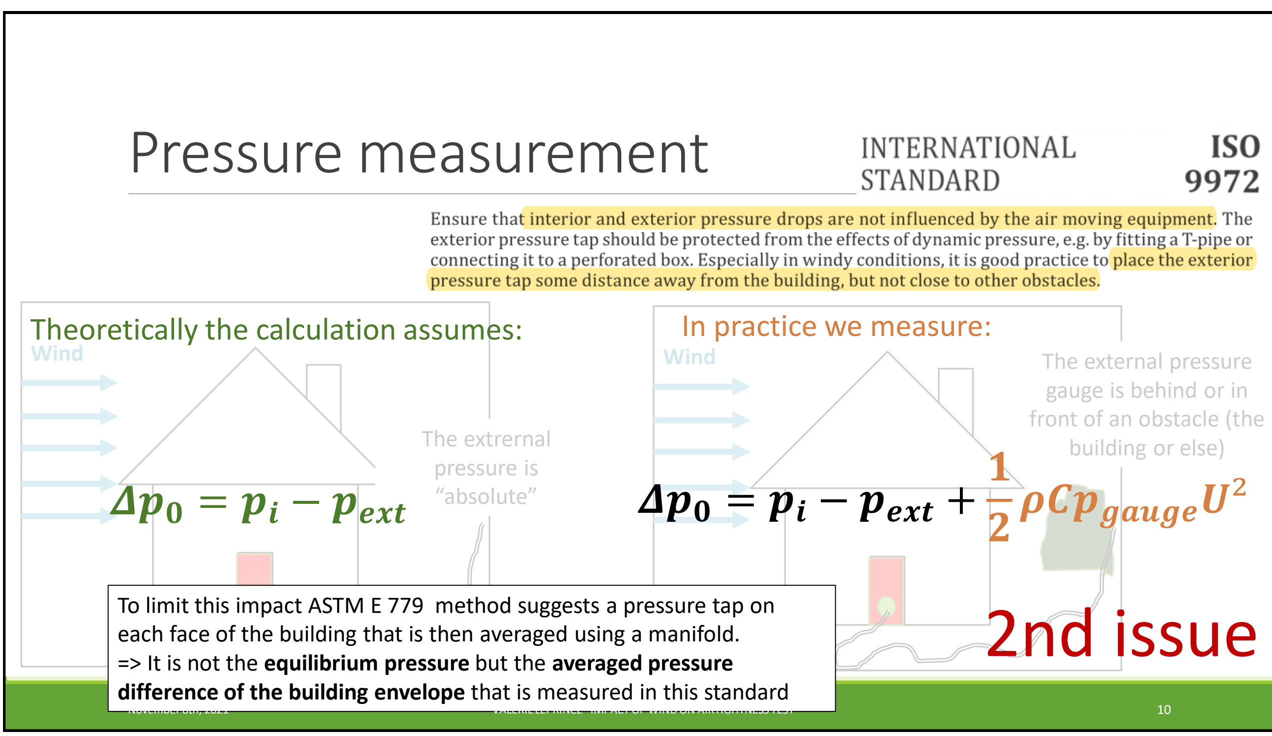

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Theoretically the calculation assumes:
$\Delta p_0 = p_i - p_{ext}$
The extrernal pressure is "absolute"
In practice we measure:
$\Delta p_0 = p_i - p_{ext} + \frac{1}{2}\rho Cp_{gauge} U^2$
The external pressure gauge is behind or in front of an obstacle (the building or else)
2nd issue
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
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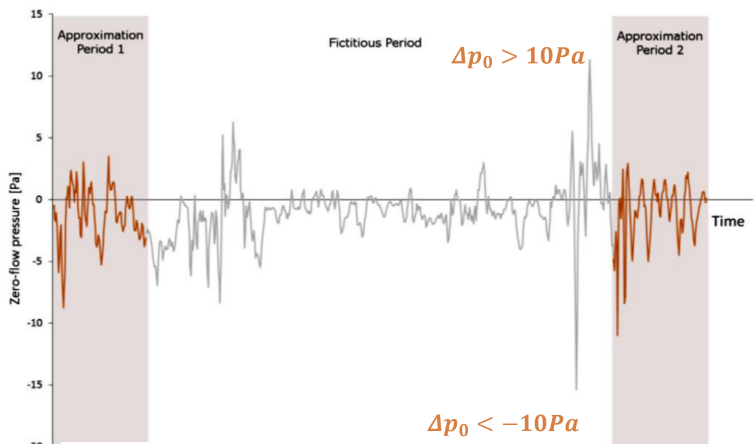
Wind fluctuations



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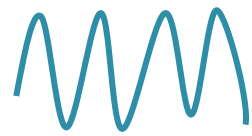

Indoor pressure varies of more than 20 Pa within a few minutes → large induced uncertainty

3rd issue

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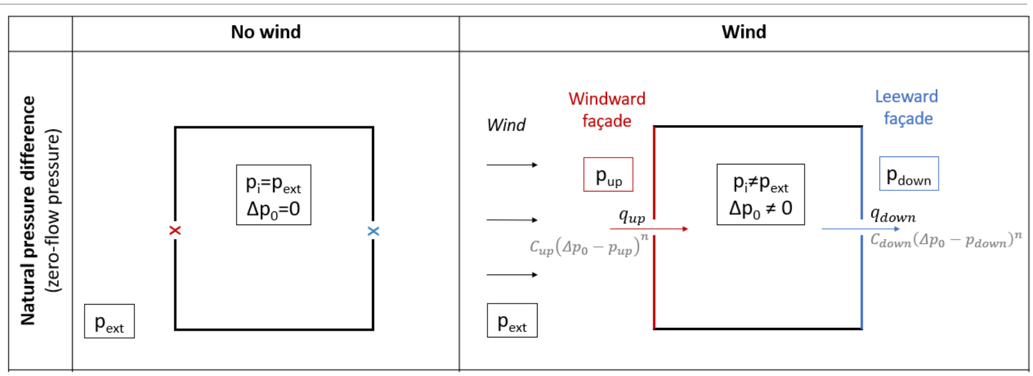
And even in a perfect world, it does not work well (Model error)…



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

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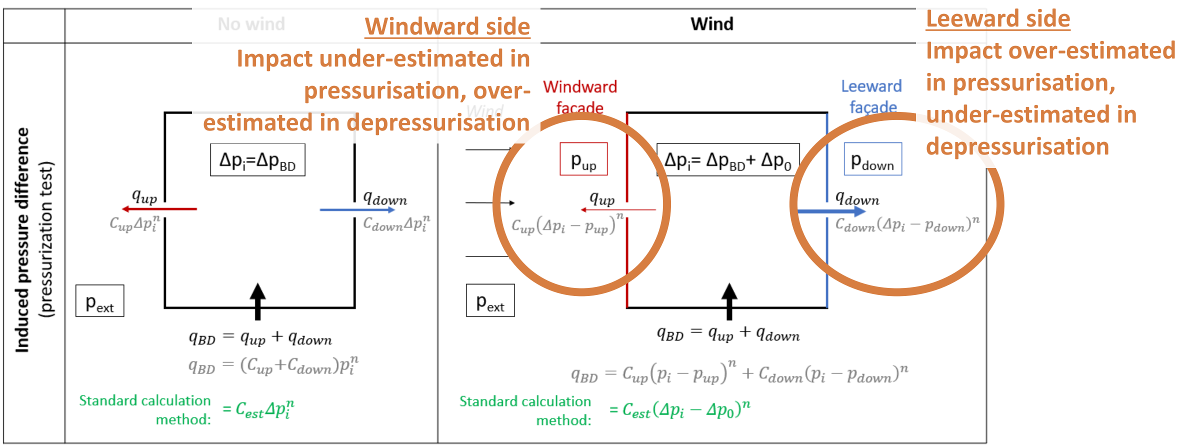
… as the problem is not linear (n≠1)



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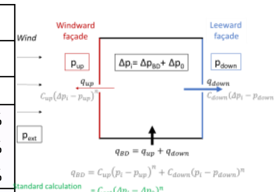
Model error

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

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

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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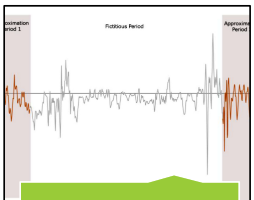
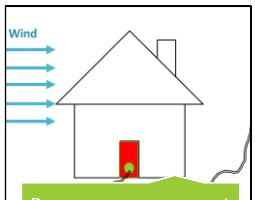
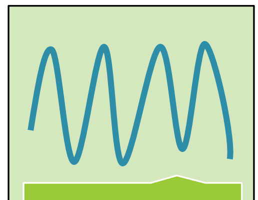
To sum up: 4 main wind issues



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

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Impact of wind on building airtightness tests

PART 2: QUANTIFICATION, LITERATURE REVIEW

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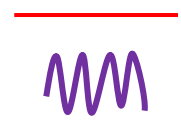
Literature review presented in the VIP

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

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



Laboratory measurements

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

On-site measurements

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

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

Laboratory measurements

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

On-site measurements

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

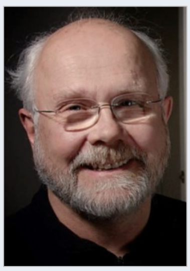
- Let gauges at the **same location** during the whole test
- Use **T-pieces** and put the pipe some distance away

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.

THE ENERGY CONSERVATORY



Improving Air Tightness Measurements in Windy Conditions

With Gary Nelson

T E C - THE ENERGY CONSERVATORY

Introduction

THE ENERGY CONSERVATORY

Gary Nelson

- Founder of TEC – The Energy Conservatory
- Physicist and Engineer
- Inventor of the Minneapolis Blower Door™, Minneapolis DuctBlaster® and TrueFlow® Grid
- Recognized member of global building science community

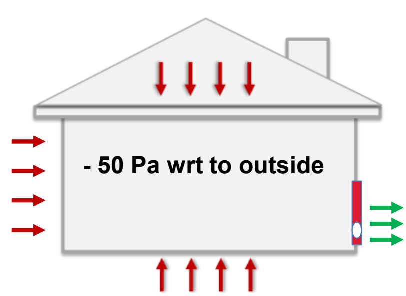
Agenda

- **Improving Air Tightness Measurements in Windy Conditions**
  - Results from testing several outdoor tap locations and designs simultaneously
- **Testing very tall buildings**
  - Outdoor pressure measurements testing a 35-story building

T·E·C

What Happens During a Blower Door Test?

- A blower door test is typically done at an induced pressure difference of 50 Pascals.
- The blower door fan is adjusted to change the pressure difference between inside and outside the building by 50 Pa and the flow is measured.
- The induced pressure difference (in a single zone building) will be the same everywhere (Pascal's principle), so it should not matter where you measure.
- However, wind fluctuations create noise and we want to select the measurement location to minimize this noise

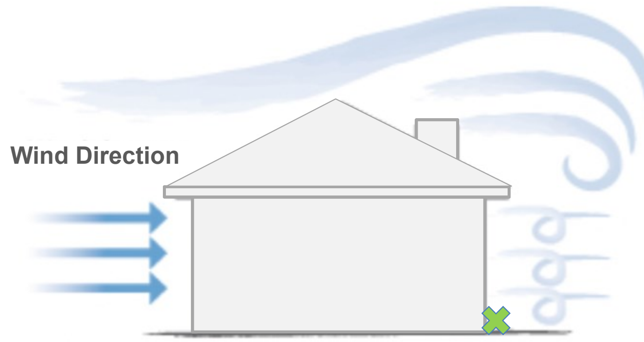


A Blower Door Test induces a pressure difference between inside and outside.

T·E·C

Blower Door Test in Windy Conditions

- TEC's historic advice has been to measure at ground level on leeward side for best results
- Others have recommended to measure far away from the house
- Ensure measurement duration is extended to 30 seconds or more.
- Recent work by Prignon, et al has suggested optimal measurement periods of 60 to 120 seconds in windy weather.

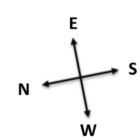


Steady measurement of house to outdoor pressure is important to minimize impact of wind

Where and How Should Outdoor Pressure be Measured?

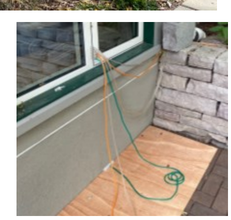
T·E·C

Testing Outdoor Pressure Locations



Tested 8 locations at the same time

- Used TECLOG software collecting extended data (hours) at 1 sec averages
- To compare performance of each location, calculated standard deviation of (20) sets of 30 second data (10 minutes)
- The lower the standard deviation, the better the technique, as previously discussed in AIVC papers by Christophe Delmotte, Martin Prignon and others
- Gary's House: n50 = 1, Volume = 850 m^3



Testing Outdoor Pressure Locations

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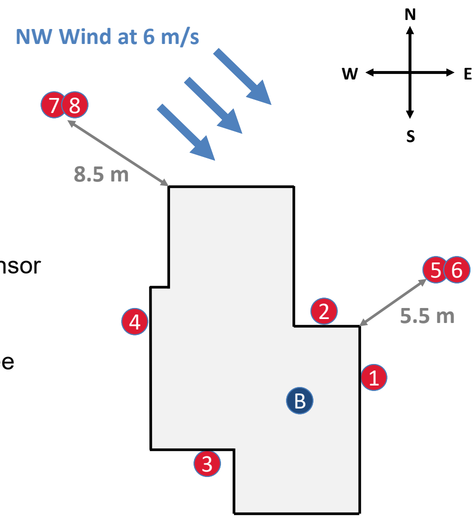


1 **East side**, ground level with tee

2 **North side**, ground level with tee

3 **South side**, ground level with tee

4 **West side,** ground level with tee

5 **East of house by 5.5m**, 2 m above ground with Dwyer sensor

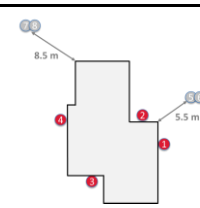
6 **East of house by 5.5m**, ground level with tee

7 **Northwest corner of property**, 2 m above ground with tee

8 **Northwest corner of property**, ground level with tee

B Indoor barometric pressure (Paroscientific barometer)

Testing Outdoor Pressure Locations



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7 **Northwest corner of property**, 2 m above ground with tee

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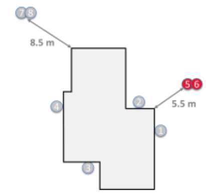
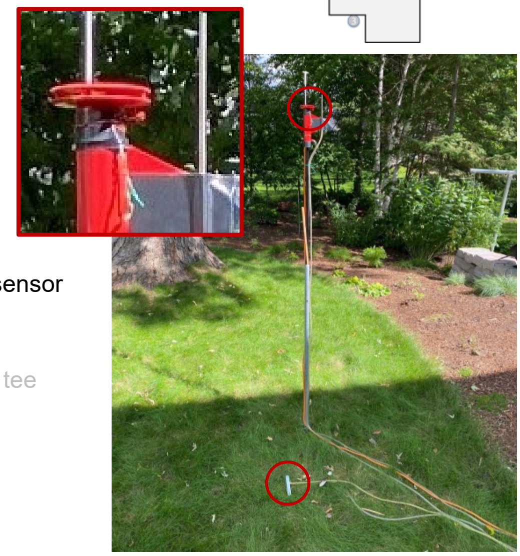
B Indoor barometric pressure

Testing Outdoor Pressure Locations



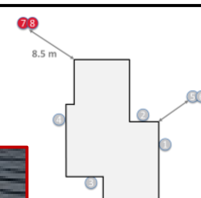
Tested 8 locations at the same time



1. East side, ground level with tee
2. North side, ground level with tee
3. South side, ground level with tee
4. West side, ground level with tee
5. **East of house by 5.5m**, 2 m above ground with Dwyer sensor
6. **East of house by 5.5m**, ground level with tee
7. Northwest corner of property, 2 m above ground with tee
8. Northwest corner of property, ground level with tee

B. Indoor barometric pressure

Testing Outdoor Pressure Locations



Tested 8 locations at the same time

1. East side, ground level with tee
2. North side, ground level with tee
3. South side, ground level with tee
4. West side, ground level with tee
5. East of house by 5.5m, 2 m above ground with Dwyer sensor
6. East of house by 5.5m, ground level with tee
7. **Northwest corner of property**, 2 m above ground with tee
8. **Northwest corner of property**, ground level with tee

B. Indoor barometric pressure

Method for Collecting and Analyzing Data

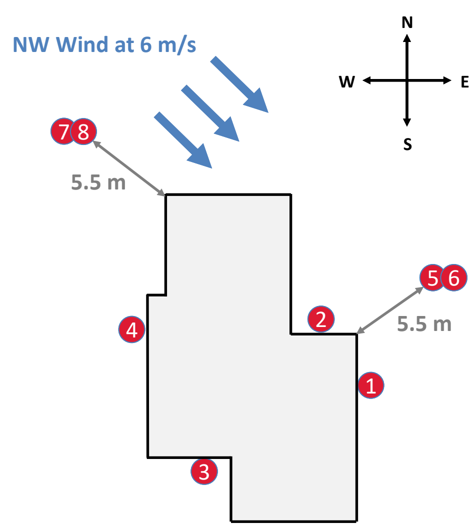
- Logged data from each location for several hours
    - Raw data collected with 1 second averages
- Selected several 10-minute periods which had high wind
    - Split 10-minute periods into twenty 30-second averages to approximate normal measurement durations needed for a multi-point test
- Calculated the standard deviation of the twenty averages to allow comparison of the various locations and designs

Testing Outdoor Pressure Locations

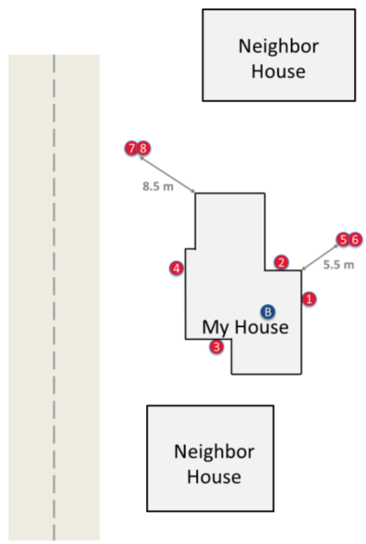
Data Summary

	Channel	Avg (Pa)	Std Dev (Pa)
1	**East Side, tee**	**-5.58**	**0.52**
2	North Side, tee	-4.7	0.81
3	South Side, tee	-6.79	1.25
4	West Side, tee	-5.44	1.05
5	5.5 m East, Dwyer 2m up	-4.52	0.69
6	5.5 m East, ground w/tee	-5.55	0.87
7	NW Corner, 2m up w/tee	-2.85	1.59
8	NW Corner, ground w/tee	-4.19	1.03

Generally, Leeward side appears best.
Example of one data set on one building.



The Goal is to Find A Quiet Location



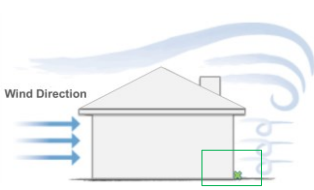
Location of Adjacent Buildings can Impact Rules of Thumb

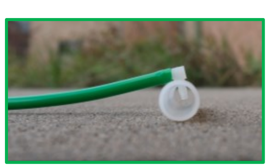
Recommendations to Minimize Effect of Wind

Wind Speed	Outdoor Pressure Tap Location	Measurement Duration
< 2.2 m/s	More than 2 m from fan	10+ seconds
2.2 – 4.5 m/s	Leeward side, more than 2 m from fan	10+ seconds
> 4.5 m/s	Leeward side, more than 2 m from fan	30+ seconds

Place Outdoor Tap in Quiet Location

- Place at joint between wall & ground, as low as possible
- Use a Tee, protected from rain
- For higher winds, leeward side of the building



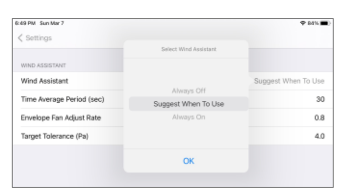


Measurement Duration

- In windy conditions, extend measurement duration to at least 30 seconds

AutoTest - Wind Assistant™

When turned on, Wind Assistant monitors data during a baseline, automatically adjusts baseline & POR duration (and other settings) to reduce uncertainty in data



Next Steps: Looking into Performance of Outdoor Tap Designs

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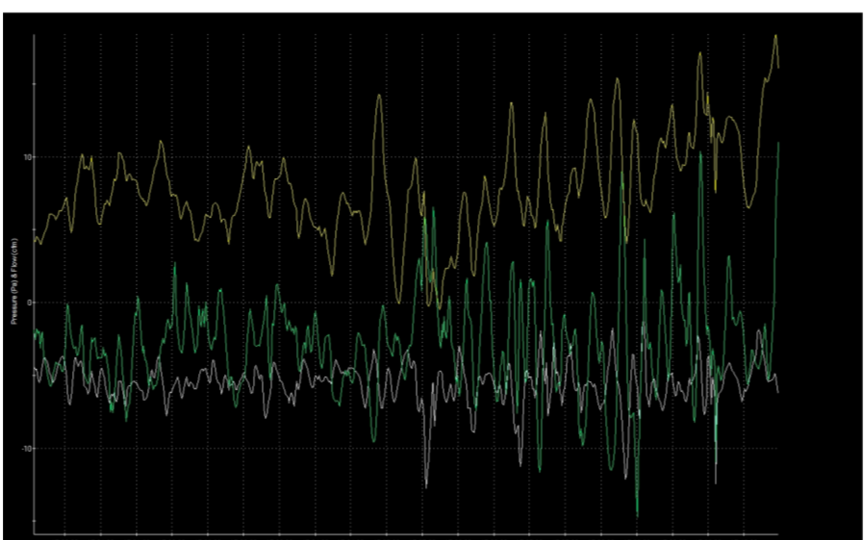
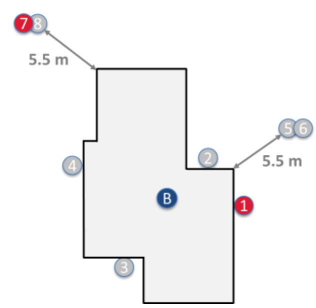
Indoor Barometric Pressure Variation





Indoor Barometric Pressure
Std Dev = 2.21 Pa

East Side, ground w/tee
Std Dev = 0.52 Pa

NW Corner, 2 m up, w/tee
Std Dev = 1.59 Pa

16

Agenda

- Best practices for minimizing the effects of wind
    - Results from testing several methods simultaneously
- Testing very tall buildings
    - Outdoor pressure measurements testing a 35-story building

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Luftdurchlässigkeitsmessung in einem 125 m hohen Gebäude

Airtightness Test in a 125 m high Building

Projektleitung
- **Emanuel Mairinger,** Dr. Ronald Mischek, ZT GmbH, Wien

Partner
- **Johannes Neubig, Thomas Gayer,** MA39, Stadt Wien

Unterstützung
- **Gary Nelson, Collin Olson,** The Energy Conservatory
- **Stefanie Rolfsmeier,** BlowerDoor GmbH

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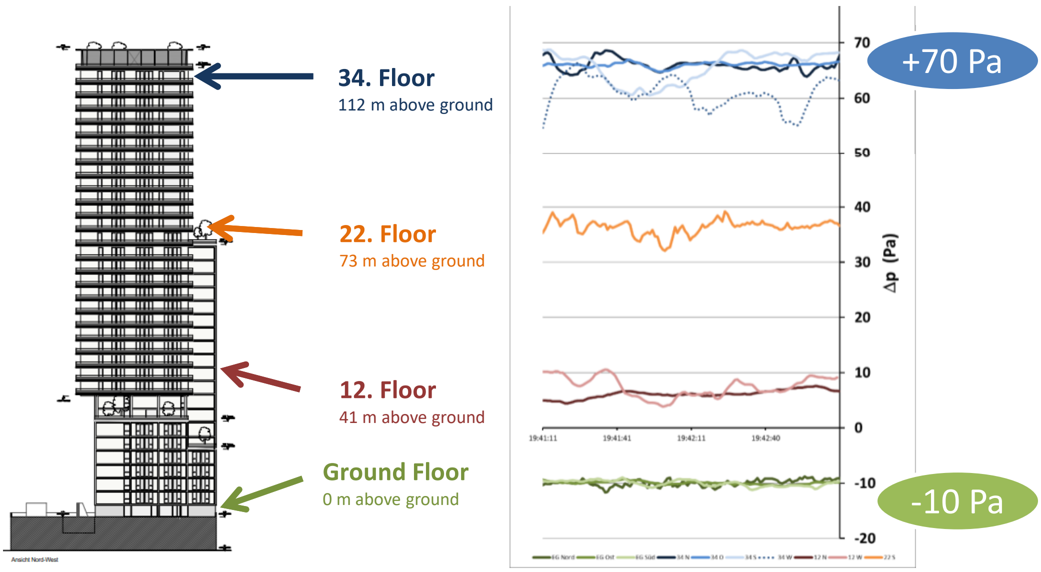
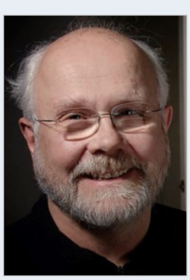
Nat. Gebäudedruckdifferenzen / *nat. building Pressure*



THE ENERGY CONSERVATORY

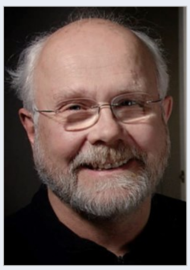


Improving Air Tightness Measurements in Windy Conditions

With Gary Nelson

T E C - THE ENERGY CONSERVATORY

THE ENERGY CONSERVATORY



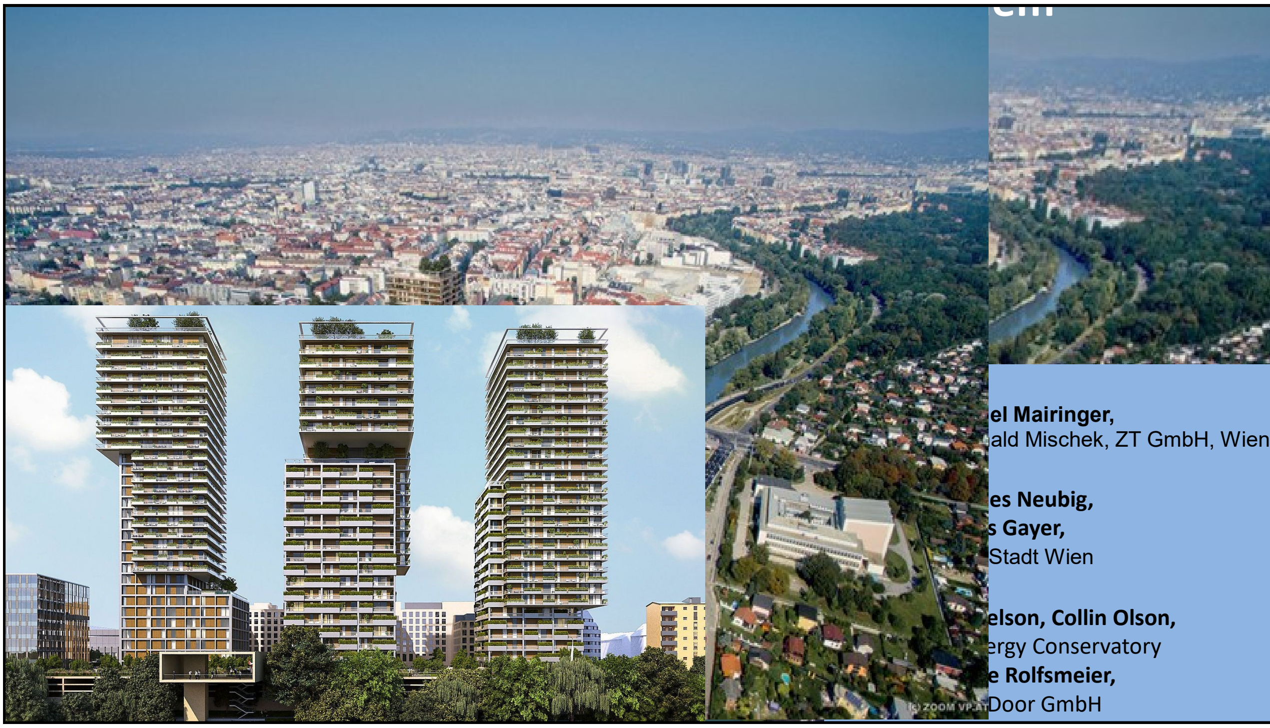
Minimizing the Effect of Wind on Air Tightness Tests

With Gary Nelson

How Does Wind Impact Blower Door Measurement

- If the wind is perfectly steady, it would not cause an issue. It is the fluctuation of the wind that causes noisy measurements.
- To minimize the impact of fluctuating wind we take measures to reduce the amplitude of the noise as well as extending the time period for the measurement.
- The measurement of zero flow pressure (or "baseline pressure") is impacted by the wind and causes an uncertainty in the calculated air tightness. This uncertainty is not currently considered in standards.

Question: Where should we measure outdoor pressure?



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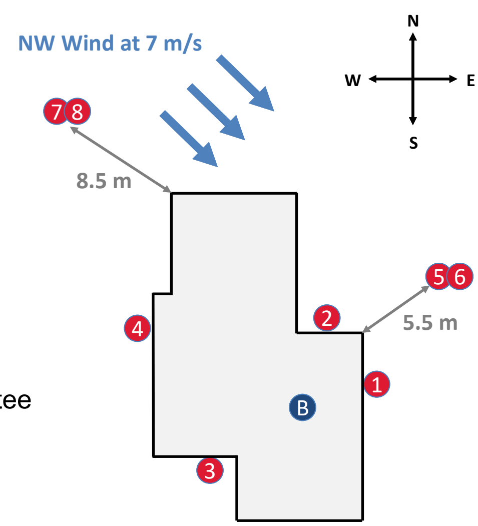
Testing Outdoor Pressure Locations

Tested 8 locations at the same time

1. East side, ground level with tee
2. North side, ground level with tee
3. South side, ground level with tee
4. West side, ground level with tee
5. 5.5 m East of house, 2 m above ground, Dwyer static pressure sensor
6. 5.5 m East of house, ground level with tee
7. Northwest corner of property, 2 m above ground with tee
8. Northwest corner of property, ground level with tee

B. Indoor barometric pressure



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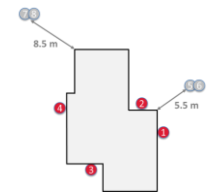

Testing Outdoor Pressure Locations

Tested 8 locations at the same time

1. East side, ground level with tee
2. North side, ground level with tee
3. South side, ground level with tee
4. West side, ground level with tee
5. East side 5.5 m away from building
6. East side on stand
7. Northwest corner of property, up 2 m
8. Northwest corner of property, ground

25

Testing Outdoor Pressure Locations

Tested 8 locations at the same time

1. East side, ground level with tee
2. North side, ground level with tee
3. South side, ground level with tee
4. West side, ground level with tee
5. East side 5.5 m away from building
6. East side on stand
7. Northwest corner of property, up 2M
8. Northwest corner of property, ground

26

Testing Outdoor Pressure Locations

Tested 8 locations at the same time

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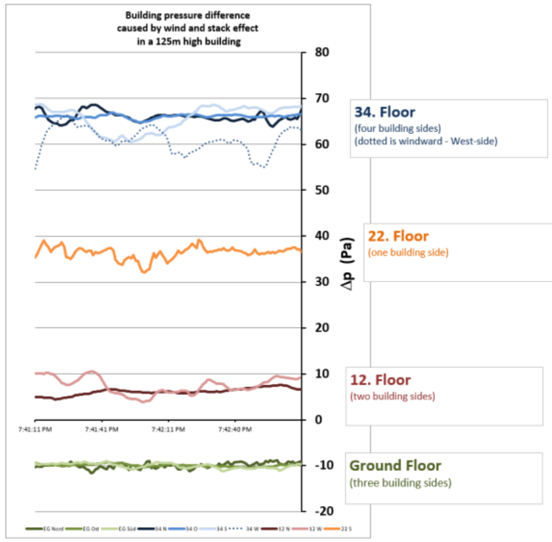
2. North side, ground level with tee
3. South side, ground level with tee
4. West side, ground level with tee
5. East side 5.5 m away from building
6. East side on stand
7. Northwest corner of property, up 2M
8. Northwest corner of property, ground

27

28

Test in Vienna run in 2021 by: Steffi, Thomas, etc.

Building Pressures in Very Tall Buildings



Conclusion: Measure Outdoor Pressure at Ground Level

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Best Practices to Minimize Effect of Wind

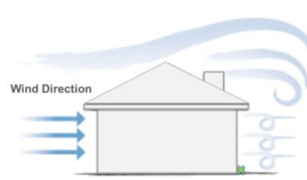
Place outdoor tap in quiet location

- > 2M from the exit of the fan, away from obstructions.
- Place at the joint between the wall and the ground as low as possible
- Use a Tee at the end of the hose
- Ensure end of hose is protected from rain
- For higher winds, ensure outdoor tap is on leeward side of the building

Extend Baseline & POR readings

- Average 10 seconds or more on calmer days
- Average 30 seconds or more on windier days

Wind	P_{out} Location, POR Duration
< 2.2 m/s	Outside > 2M from fan, average 10+ sec
2.2 – 4.5 m/s	Leeward side, > 2M from the fan, average 10+ sec
> 4.5 m/s	Leeward side, > 2M from the fan, average 30+ sec



AutoTest - Wind Assistant™

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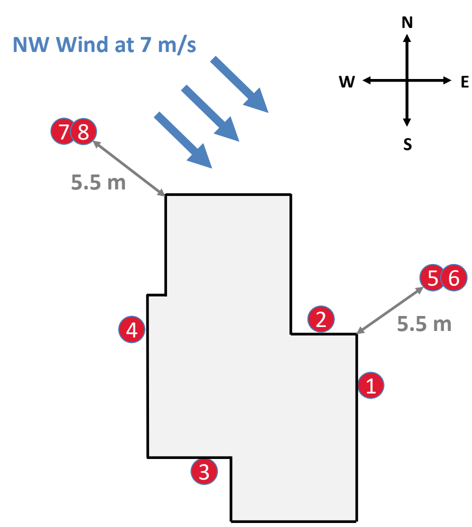
Agenda

- Best practices for minimizing the effects of wind
  - Results from testing several techniques simultaneously
- Testing very tall buildings
  - Outdoor pressure measurements testing a 35-story building

Testing to Confirm Best Approach

Data Summary

	Channel	Avg	Std Dev
1	**P1 East Side**	**-5.58**	**0.52**
2	P6 North Side	-4.7	0.81
3	P8 South Side	-6.79	1.25
4	P2 West Side	-5.44	1.05
5	P7 (5.5M East, Ground)	-5.55	0.87
6	P4 (5.5M East, Dwyer)	-4.52	0.69
7	P3 (NW Corner, 2M Up)	-2.85	1.59
8	P5 (NW Corner, Ground)	-4.19	1.03



Testing to Confirm Best Approach

Data Summary

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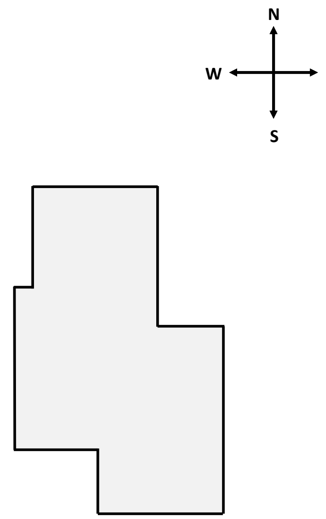
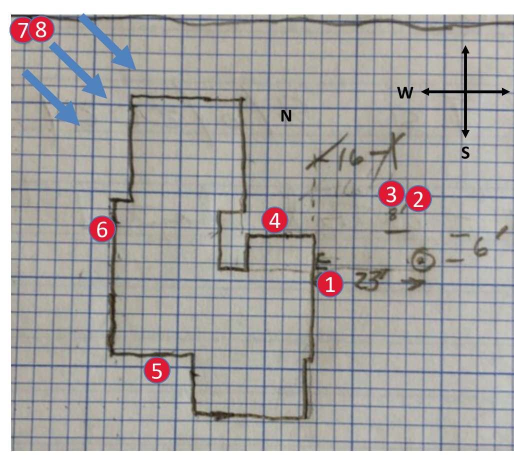


Tests to Confirm Best Approach

	Channel	# Obs	Avg	Std Dev
1	**P1 (East)**	**20**	**-5.58**	**0.52**
6	P2 (W)	20	-5.44	1.05
7	P3 (NW 2M)	20	-2.85	1.59
3	P4 (Dwyer)	20	-4.52	0.69
8	P5 (NW grass)	20	-4.19	1.03
4	P6 (N)	20	-4.7	0.81
2	P7 (Dwyer, T, Ground)	20	-5.55	0.87
	P8 (S)	20	-6.79	1.25
5	pbaro_Pa	20	7.69	2.21
	TBase_F	20	71.79	0.01

Wind out of Northwest at ~ 6.7 m/s

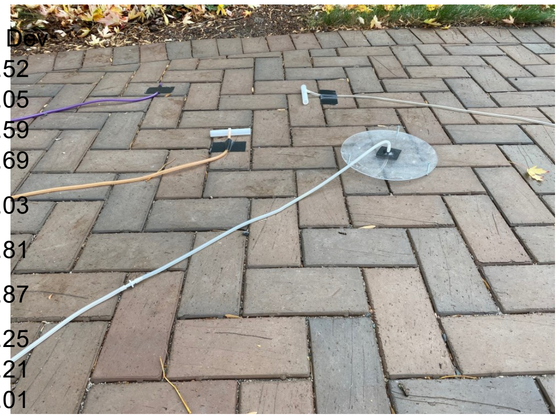


What's Next?

Barometric differences INSIDE the home

Channel	# Obs	Avg	Std Dev
P1 (East)	20	-5.58	0.52
P2 (W)	20	-5.44	1.05
P3 (NW 2M)	20	-2.85	1.59
P4 (Dwyer)	20	-4.52	0.69
P5 (NW grass)	20	-4.19	1.03
P6 (N)	20	-4.7	0.81
P7 (Dwyer, T, Ground)	20	-5.55	0.87
P8 (S)	20	-6.79	1.25
pbaro_Pa	20	7.69	2.21
TBase_F	20	71.79	0.01

Performance of different shapes



Tests to Confirm Best Approach

5

6

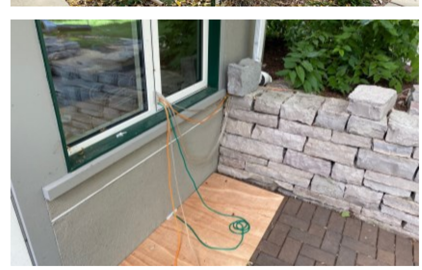
- Tested 7 different outdoor locations simultaneously
  - East side 23 feet away from bui
  - East side on stand

Tests to Confirm Best Approach

- Tested 7 different outdoor locations simultaneously
  - Northwest corner of property

Tests to Confirm Best Approach

- Tested 6 different outdoor locations simultaneously
  - Performance compared calculating standard deviation of the outdoor pressure over 30 second readings
  - To gather the data, used TEC TECLOG software collecting extended data at 1 sec averages



T·E·C

Significant Research Continues on this Topic

Quantification of uncertainty in zero-flow pressure approximation

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1170 Watermael Boitsfort, Belgium

ABSTRACT

Multiple authors stated that, when performing fan pressurization test, Ordinary Least Square (OLS) method should not be used as a regression technique anymore. However, alternative methods require first to quantify components of uncertainty in pressure and air flow rate measurements. This work aims at quantifying the uncertainty in zero-flow pressure approximation, which is mainly due to short-term fluctuation of wind speed and direction. This has been done by statistically analysing the uncertainty indicator of 40 zero-flow pressure tests performed on 30 different units on eight different sites in Brussels.

First, the analysis showed that this uncertainty could be reduced by increasing the period of measurement used to compute zero-flow pressure approximation. Second, it shows that the standard deviation of zero-flow pressure measurements was the variable with the most significant impact on the quality of the zero-flow pressure approximation. Third, it provides three different linear models to predict uncertainty as a function of different variables.

This study experienced some limitations due to the available sample of tested units. These limitations lead to important further work: the validation of the model on another sample of buildings and its adaptation if needed. Further work should also focus on integrating these results on the uncertainty in envelope pressure measurements and on the uncertainty in airtightness estimation of the building.

KEYWORDS

Airtightness measurement; Uncertainty; Zero-flow pressure; Fan pressurization test.

1 INTRODUCTION

To be reliable, a measured quantity should always be given with its uncertainty. When performing a fan pressurization test, the uncertainty is often given as a function of the scattering of the data around the linear model obtained with an Ordinary Least Square (OLS) method. However, multiple authors stated that the uncertainty estimated with OLS was not reliable in the case of airtightness measurements because the method neglects uncertainty in pressure measurements [1-3]. Therefore, other regression techniques should be used such as the Iterative Weighted Least Square (IWLS) [3, 4] or the Weighted Line of Organic Correlation (WLOC) [2]. These methods require quantifying uncertainty in pressure and air flow rate measurements.

One of the main sources of uncertainty is the fluctuation of reading in the pressure measurements due to variation in weather conditions [5]. ISO 9972:2015 requires the measurement of inside and outside temperature, and of wind speed (in Beaufort scale), but none of them are used in the calculation to deal with fluctuations in weather conditions [6]. In practice, pressure induced by weather conditions is handled in ISO 9972:2015 by measuring the zero-flow pressure (i.e., the pressure when there is no pressure induced by the fan). However, zero-flow pressure can be measured only when the fan is not working. Therefore, it

Airtightness of buildings – Considerations regarding place and nature of pressure taps

Christophe Delmotte

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Avenue Poincaré, 79
1060 Brussels, Belgium

ABSTRACT

This paper discusses two particular points of the buildings airtightness measurement method (ISO 9972) in relation with the pressure difference: (1) the nature of the pressure tap and (2) the place of the pressure tap outside.
The principle of the buildings airtightness measurement method is to measure the pressure difference induced by a given air flow rate generated by a fan. To that end, pressure measurements are made between inside and outside the building. However, with the increasing number of measurements and laboratories, more and more varied pressure taps such as pierced bottles or traffic cones are appearing. In addition, the place of the pressure tap outside largely varies; from very close to the building to very far away.
Although this may seem insignificant at first glance, the nature and the place of the pressure taps play a crucial role in the measurement uncertainty. This is mainly due to the effect of wind on the building and the dynamic pressure it generates.
This paper explains why it is necessary to use static pressure taps and place them away from the building and possible obstacles.

KEYWORDS

Airtightness of buildings, pressure tap, pressure difference, wind, zero-flow pressure

1 INTRODUCTION

In European countries, increasing importance has been given to airtightness of buildings since the first publication of the directive on the energy performance of buildings in 2002. In some countries there are even requirements or financial incentives linked with the airtightness level. It is therefore more and more important to pay attention to the quality of airtightness measurements.
Following the increase in the number of measurements and laboratories, discrepancies are beginning to appear in some aspects of the test. This is the case, for example, for pressure taps for which some use drilled bottles or traffic cones. The location of the pressure tap outside also varies greatly, from very close to the building to very far away; some even take the pressure from inside their car.
Although this may seem insignificant at first glance, the nature and the place of the pressure taps play a crucial role in the measurement uncertainty. This is mainly due to the effect of wind on the building and the dynamic pressure it generates.

2 PRESSURE DIFFERENCE INDUCED BY THE FAN

In given climatic conditions (wind and temperature) and in the absence of fan, pressure differences $\Delta p_{0,j}$ are naturally generated across the envelope of a building. The equilibrium internal pressure is such that the air flow that enters the building is equal to the flow that leaves. The sum of the air flows through the building envelope is therefore equal to zero (formally we

Influence of the external pressure tap position on the airtightness test result

Jiří Novák*[1]

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Thákurova 7
166 29 Prague, Czech Republic
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KEYWORDS

airtightness, blower door, measurement uncertainty, repeatability, wind

1 PURPUSE OF THE WORK

Due to the wind induced pressure, different results may be obtained if the inside-outside pressure difference is measured across different locations on the building envelope, i.e. if the external pressure tap of a differential pressure sensor measuring this pressure difference is placed in different positions. Therefore, the position of the external pressure tap may influence an airtightness test result as well. As the wind induced pressure is linked with the wind speed, it can be expected that the influence of the external pressure tap position on the airtightness test result would be amplified with increasing wind speed. The aim of this full-scale experiment is to quantify the variability of the airtightness test results obtained under repeatability conditions with different external pressure tap positions in function of the wind speed. The motivation is a better understanding of the real influence of the wind allowing a better estimation of the measurement uncertainty as well as possible improvement of the measurement technique.

2 METHOD

The airtightness of a single-family house was tested 9 times according to EN ISO 9972. During each test, the wind speed and the air flow rate through the measuring device fan were recorded simultaneously with 4 different inside-outside pressure differences.

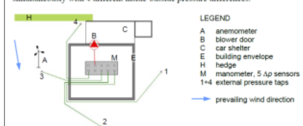


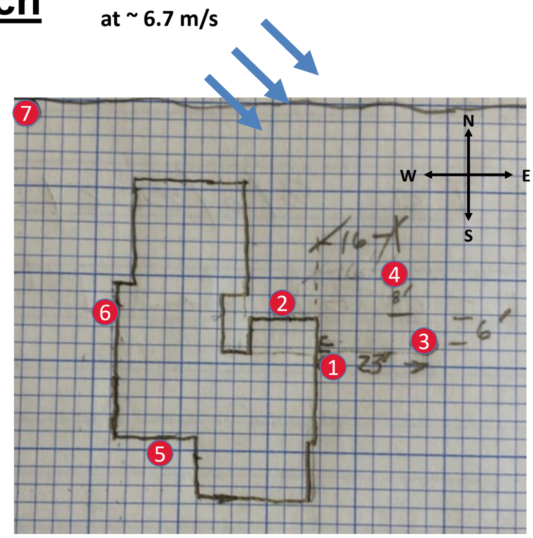
Figure 1: The experimental set-up, schematic plan view

Significant Research Continues on Methods to Minimize Impact of Wind

T·E·C

Tests to Confirm Best Approach

Wind out of Northwest at ~ 6.7 m/s

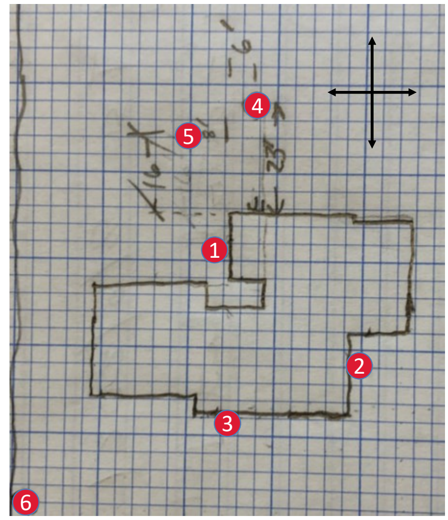


- Tested 7 different outdoor locations simultaneously
  - Performance compared calculating standard deviation of the outdoor pressure over the 30 second readings
  - To gather the data, used TEC TECLOG software collecting extended data at 1 sec averages

T·E·C

Tests to Confirm Best Approach

- Tested 6 different outdoor locations simultaneously
  - Performance compared calculating standard deviation of the outdoor pressure over the 30 second readings
  - To gather the data, used TEC TECLOG software collecting extended data at 1 sec averages



Tests to Confirm Best Approach

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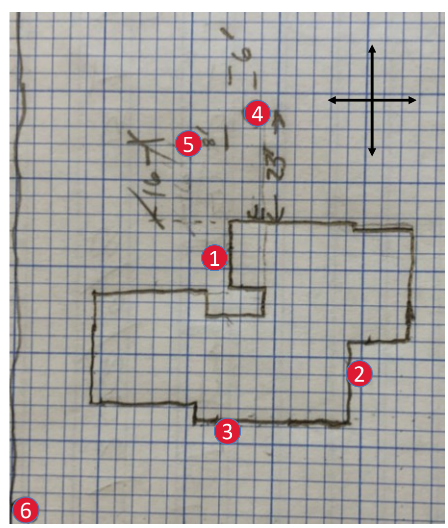

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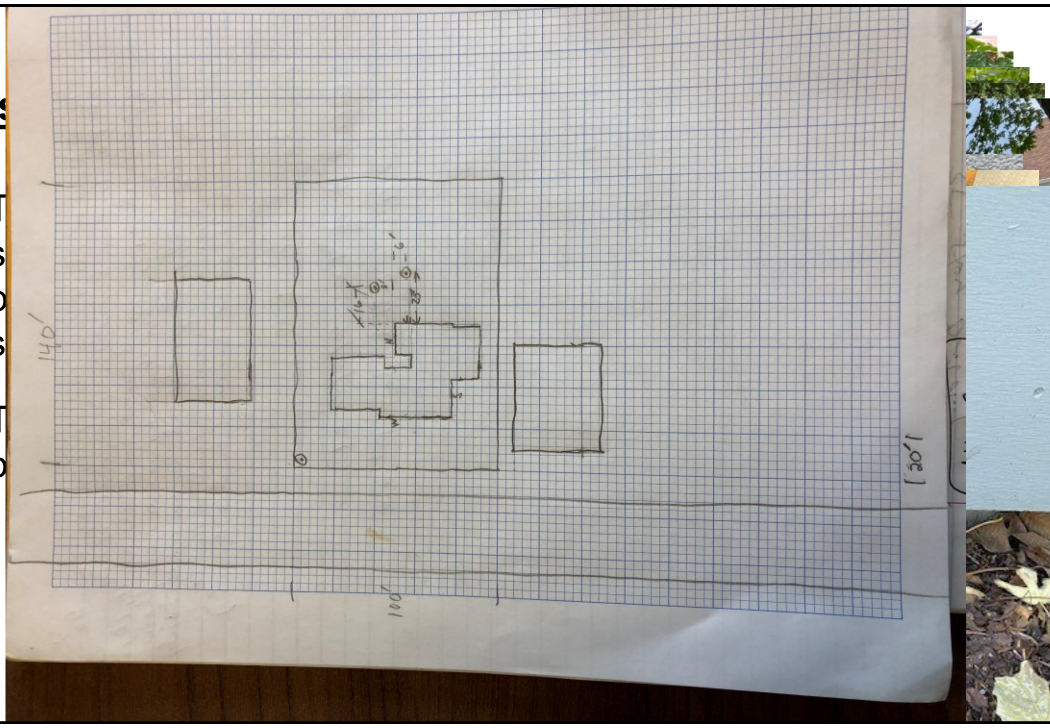

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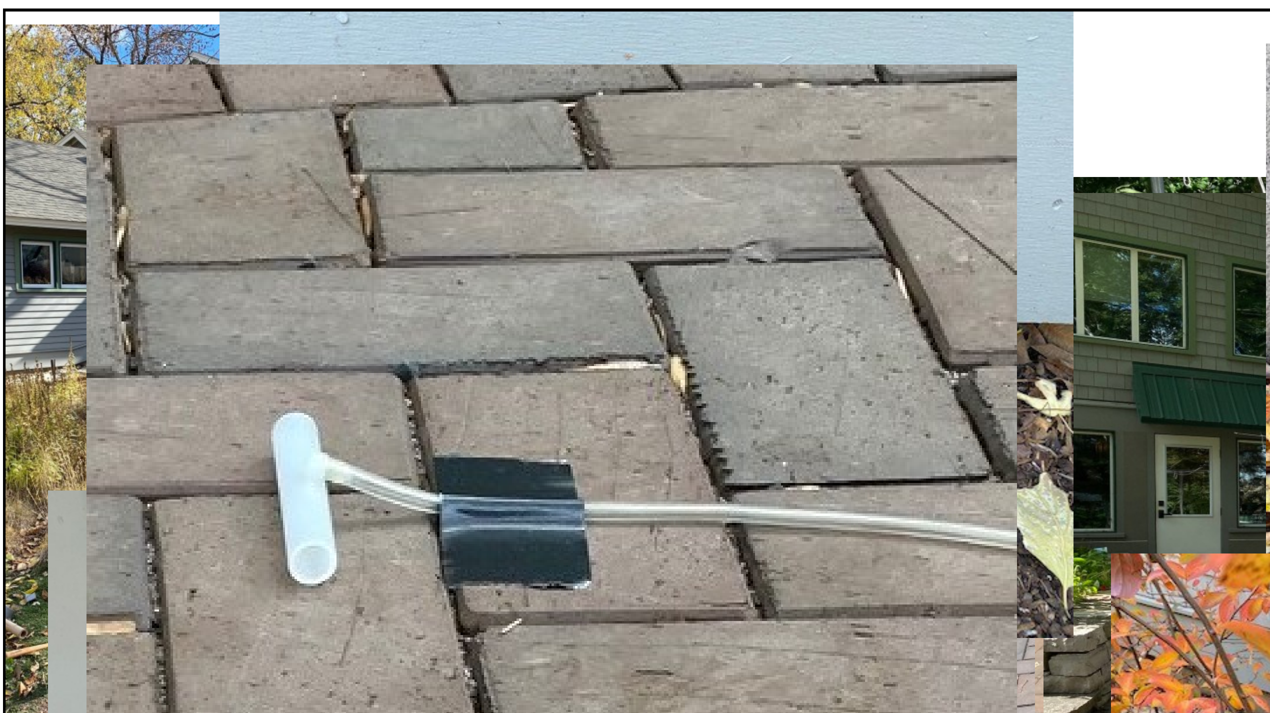

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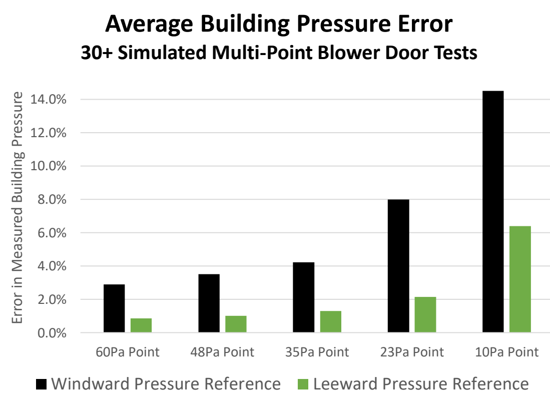
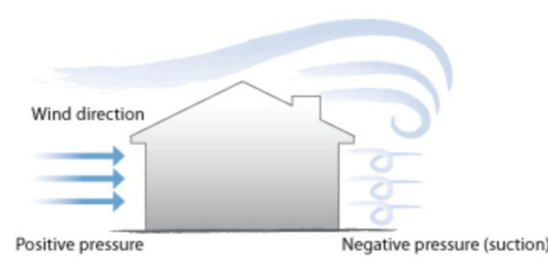
Best Location to Measure House to Outside Pressure



TEC testing in July 2020 show windward side of the building generally caused 3x the error of the leeward side



Best location is leeward side at ground level

Summary of Best Practices to Accommodate Wind

Wind Speed	Recommended P_{out} Location
< 5 mph	Outside > 5 feet from fan, time averaging = 10 sec
5-10 mph	Leeward side of the building, > 5 feet from the fan, time averaging = 10 sec
> 10 mph	Leeward side of the building, > 5 feet from the fan, time averaging = 30 to 60 sec

NOTES:

- It is important to ensure the exhaust from the blower door fan does not impact the outdoor pressure tap measurement. Ensure it is more than 5 feet from the exit of the fan and be aware of obstructions.
- Place end of tube at the joint between the wall and the ground as low as possible
- Make sure the end of the hose is protected from rain

Best Practices to Accommodate Wind

Minneapolis Blower Door Wind Tee is now included in the kit.

This simple tee, along with the TEC AutoTest app with built-in Wind Assistant makes it easier to comply with Best Practices.

AutoTest - Wind Assistant™

- Ensure the exhaust from the blower door fan does not impact the measurement by placing the tap more than 5 feet from the exit of the fan and be aware of obstructions.
- Place end of tube at the joint between the wall and the ground as low as possible
- Make sure the end of the hose is protected from rain
- For higher wind speeds, ensure outdoor tap is on the leeward side of the building and increase your time averaging during the period of record

Wind Speed	Recommended P_{out} Location
< 5 mph	Outside > 5 feet from fan, time averaging = 10 sec
5-10 mph	Leeward side, > 5 feet from the fan, time averaging = 10 sec
> 10 mph	Leeward side, > 5 feet from the fan, time averaging = 30+ sec

T·E·C

Agenda

- Best practices for minimizing the effects of wind
- TEC AutoTest with Wind Assistant™
- Review data from initial testing
- Where to get more information

AutoTest - Wind Assistant™

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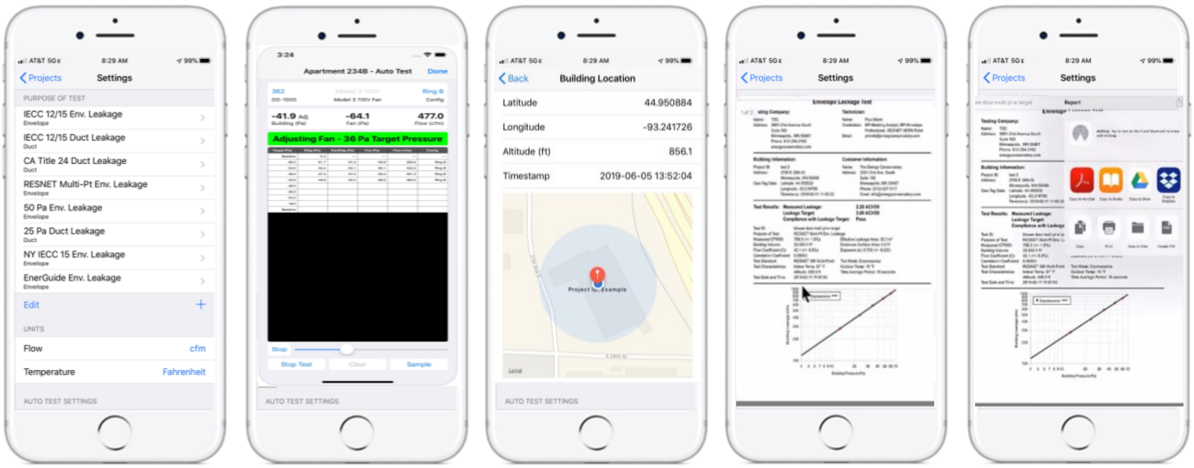
Automates Testing

TEC Auto Test App for IOS & Android



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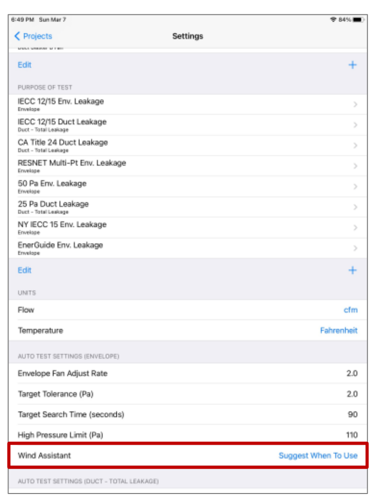
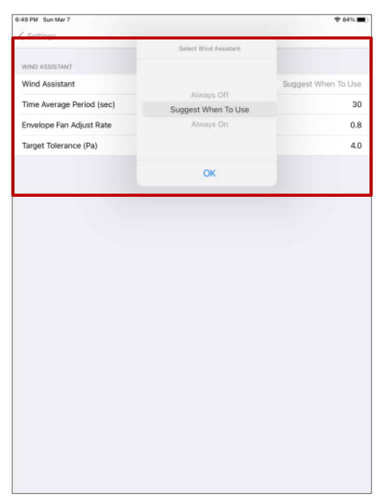
AutoTest - Wind Assistant™

Wind Assistant™

- Monitors data during a baseline and determines if adjustments should be made to data collection to reduce uncertainty in data
- Assistant which can be turned on or off





Wind Assistant Makes it Easier to Recognize Windy Conditions and Take the Right Actions

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Bill Test of Lake Home

AutoTest - Wind Assistant™

Calm Conditions

Envelope Leakage Test

Testing Company:
Name:
Address:

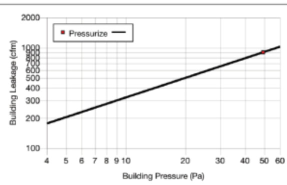
Technician:
Name:
Credentials:
Email:

Building Information:
Project ID: up north
Address: Comstock, WI
Geo-Tag Data: Latitude: 45.524764
Longitude: -92.202136
Timestamp: 2021-05-01 10:25:24

Customer Information:
Name:
Address: Comstock, WI

Measured Leakage: 911.1 CFM50

Test ID: calm
Purpose of Test: 50 Pa Env. Leakage
Measured ACH50: 2.17
Building Volume: 25,200.0 ft³
Coefficient (C): 71.7
Test Standard: RESNET 380 One-Point
Test Characteristics: Indoor Temp: 68 °F
Altitude: 1,266.0 ft
Test Date and Time: 2021-05-01 10:30:47
Effective Leakage Area: 50.1 in²
Enclosure Surface Area: 0.0 ft²
Exponent (n): 0.650 (assumed)
Test Mode: Pressurize
Outdoor Temp: 60 °F
Time Average Period: 10 seconds



Windy Conditions

Envelope Leakage Test

Testing Company:
Name:
Address:

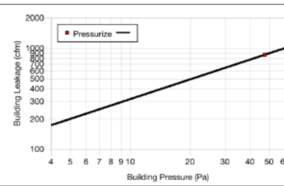
Technician:
Name:
Credentials:
Email:

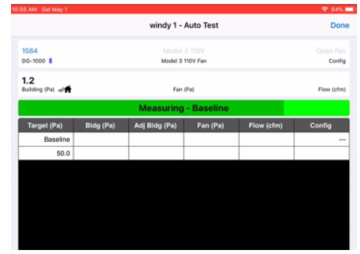
Building Information:
Project ID: lake
Address: Comstock, WI
Geo-Tag Data: Latitude: 45.524917
Longitude: -92.202431
Timestamp: 2021-05-01 10:36:16

Customer Information:
Name:
Address: Comstock, WI

Measured Leakage: 892.2 CFM50

Test ID: windy 1
Purpose of Test: 50 Pa Env. Leakage
Measured ACH50: 2.12
Building Volume: 25,200.0 ft³
Coefficient (C): 70.2
Test Standard: RESNET 380 One-Point
Test Characteristics: Indoor Temp: 68 °F
Altitude: 1,265.0 ft
Test Date and Time: 2021-05-01 10:56:25
Effective Leakage Area: 49.1 in²
Enclosure Surface Area: 0.0 ft²
Exponent (n): 0.650 (assumed)
Test Mode: Pressurize
Outdoor Temp: 65 °F
Time Average Period: 30 seconds





T·E·C

Summary

AutoTest - Wind Assistant™

- Wind Assistant was turned on "Suggest when to Use"
- Detected Wind and asked if I wanted to move to default adjustments for windy conditions
- Added ~ 20 seconds to each POR (period of record)
- Added a slower adjust rate to lock on to target building pressure

T·E·C

Agenda

- Best practices for minimizing the effects of wind
- TEC AutoTest with Wind Assistant™
- Review data from initial testing
- Where to get more information

AutoTest - Wind Assistant™

T·E·C

AutoTest - Wind Assistant™

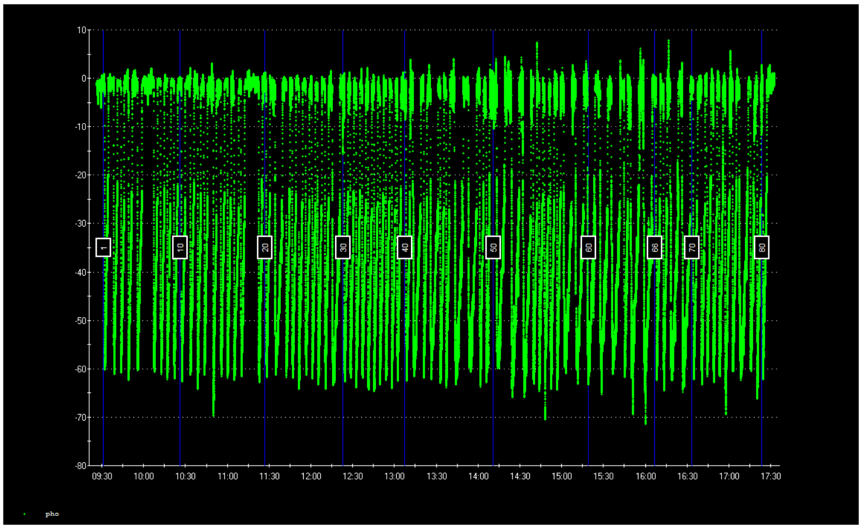
Collin and Gary Testing

- Collin and Gary performed multiple Blower Door tests
  - Performed over several days
  - Wind Assistant in “recommend” mode
- Goal was to confirm following
  - Only turns on in windy conditions (where extra test time is worth it)
  - Does not when it is not too windy
  - It improves data uncertainty when there is significant wind present
  - It does not deliver worse data uncertainty than with wind assistant off

T·E·C

AutoTest - Wind Assistant™

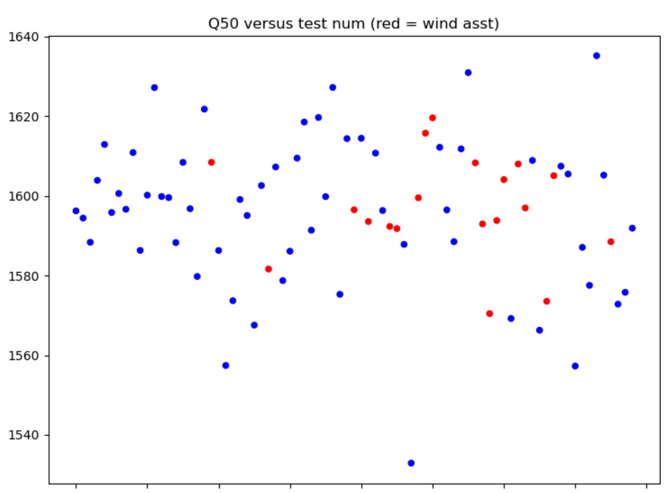
Collin and Gary Testing



T·E·C

AutoTest - Wind Assistant™

Collin and Gary Testing

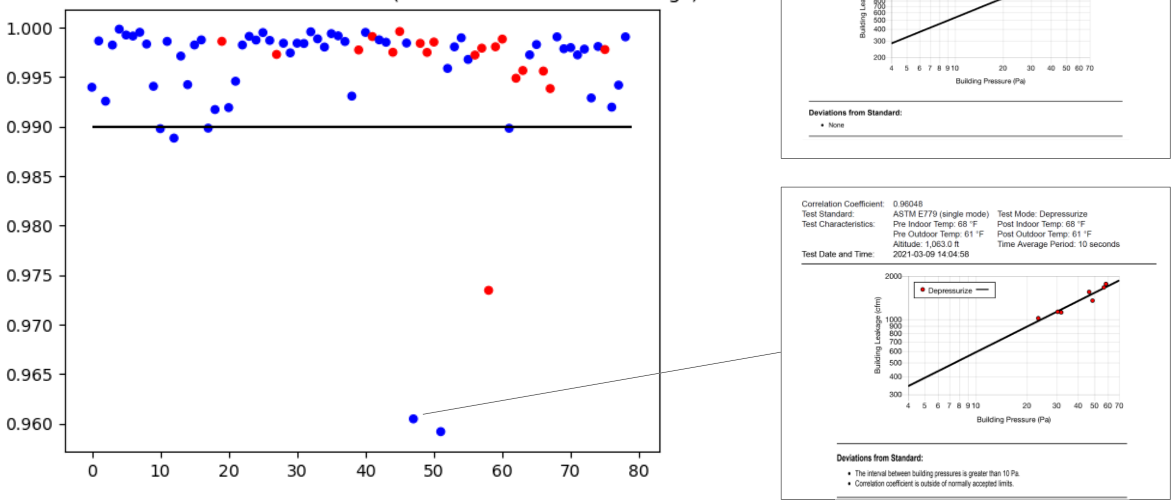


T·E·C

AutoTest - Wind Assistant™

Collin and Gary Testing

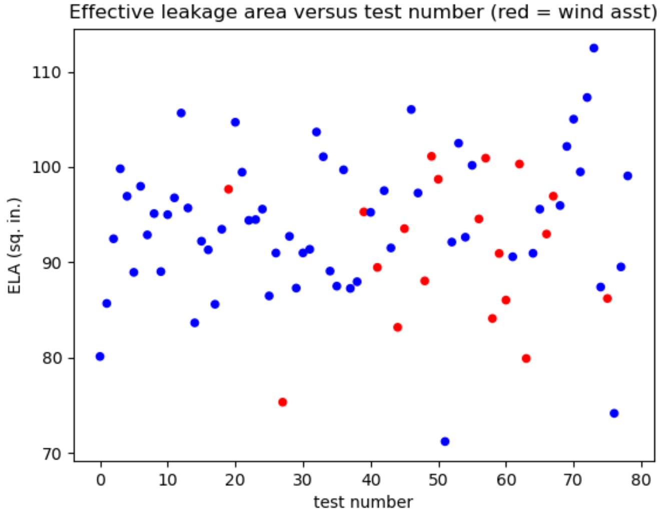
Correlation coefficient versus test # (red = wind assistant settings)



AutoTest - Wind Assistant™

Collin and Gary Testing

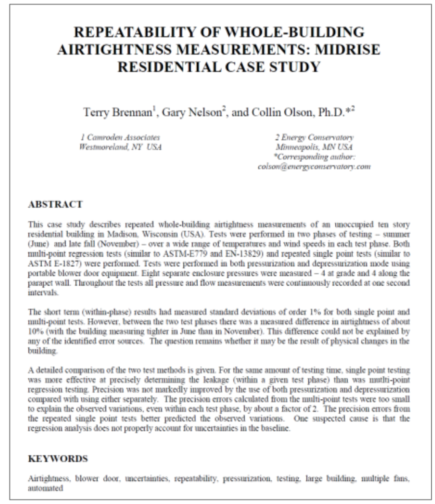
Effective leakage area versus test number (red = wind asst)



T·E·C

TEC has Contributed Other Research on this Topic

- Wind Effect on Residential Testing
- Wind Effect on Midrise Residential
- 4 side average pressure improves repeatability, but one pressure was often even better although difficult to determine ahead of time which side that would be.
- Repeated 1-point test at 50 or 75 Pa gave more repeatable results than multi point for the same amount of time.



REPEATABILITY OF WHOLE-BUILDING AIRTIGHTNESS MEASUREMENTS: MIDRISE RESIDENTIAL CASE STUDY

Terry Brennan[1], Gary Nelson[2], and Collin Olson, Ph.D.*[2]

1 Camroden Associates
Westmoreland, NY USA

2 Energy Conservatory
Minneapolis, MN USA
**Corresponding author:*
colson@energyconservatory.com

ABSTRACT

This case study describes repeated whole-building airtightness measurements of an unoccupied ten story residential building in Madison, Wisconsin (USA). Tests were performed in two phases of testing – summer (June) and late fall (November) – over a wide range of temperatures and wind speeds in each test phase. Both multi-point regression tests (similar to ASTM-E779 and EN-13829) and repeated single point tests (similar to ASTM E-1827) were performed. Tests were performed in both pressurization and depressurization mode using portable blower door equipment. Eight separate enclosure pressures were measured – 4 at grade and 4 along the parapet wall. Throughout the tests all pressure and flow measurements were continuously recorded at one second intervals.

The short term (within-phase) results had measured standard deviations of order 1% for both single point and multi-point tests. However, between the two test phases there was a measured difference in airtightness of about 10% (with the building measuring tighter in June than in November). This difference could not be explained by any of the identified error sources. The question remains whether it may be the result of physical changes in the building.

A detailed comparison of the two test methods is given. For the same amount of testing time, single point testing was more effective at precisely determining the leakage (within a given test phase) than was mutlti-point regression testing. Precision was not markedly improved by the use of both pressurization and depressurization compared with using either separately. The precision errors calculated from the multi-point tests were too small to explain the observed variations, even within each test phase, by about a factor of 2. The precision errors from the repeated single point tests better predicted the observed variations. One suspected cause is that the regression analysis does not properly account for uncertainties in the baseline.

KEYWORDS

Airtightness, blower door, uncertainties, repeatability, pressurization, testing, large building, multiple fans, automated

T·E·C

Agenda

- Best practices for minimizing the effects of wind
- TEC AutoTest with Wind Assistant™
- Review data from initial testing
- Where to get more information

AutoTest - Wind Assistant™

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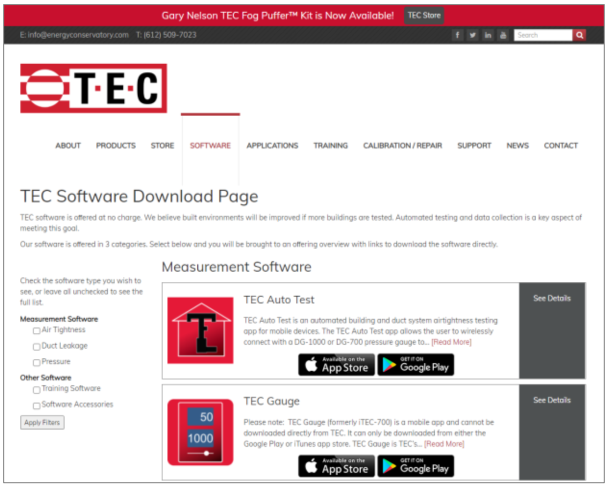
Where to get more information



AutoTest - Wind Assistant™

AutoTest if Free - Download from the TEC Website

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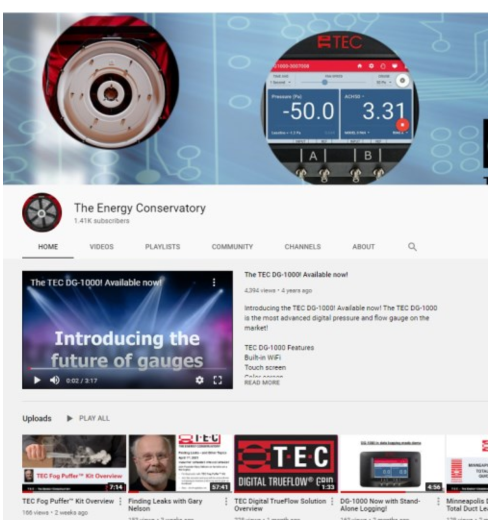
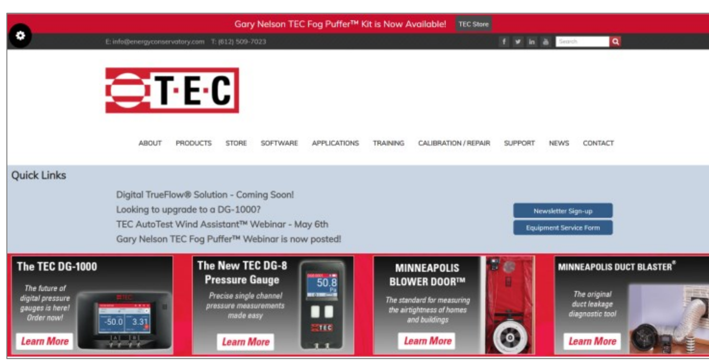
YouTube



Website: energyconservatory.com



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THE ENERGY CONSERVATORY

TEC Minneapolis Newsletter

April 22nd, 2021

All of us at The Energy Conservatory thank-you for your support and business. We continue to make progress on the mission set over 40 years ago by our founder Gary Nelson: to help the industry deliver improved built environments – more energy efficient, comfortable, durable, and healthier.

Many new items and products have been released in the past few months – with several more to come. Here is the latest news...

In This Issue

- NEW Digital TrueFlow® - simpler to use, broader capability & more cost-effective!
- TEC FOG PUFFER Kit™ developed by Gary Nelson is now available!
- Introducing AutoTest Wind Assistant™ - Join the Webinar with Collin Olson on May 6
- DG-8 Micromanometer is available - great for single channel pressure measurements
- DG-1000 free software update released – Logging, Tubing Assistant, Pitot-velocity
- Looking to Upgrade to a DG-1000?
- TEC training resource – including www.hvacairflow.com and the TEC Learning Portal
- TEC On-line Store is open and taking orders
- Upcoming Webinars and Links to Recent Webinars
- Allison Bailes and Gary Nelson - a Heat Pump can work in Minnesota!
- HVAC 2.0 - Opportunity for you & your Minneapolis BlowerDoor™?

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The NEW Digital TrueFlow® Starts Shipping in Early May

We are very excited to announce the Digital TrueFlow® solution will begin shipping in early May. A few years in the making, this new design and accompanying TrueFlow App delivers several new features which simplifies the use, broadens the measurement capability, and delivers it all at a significantly reduced price point. It is recognized as an effective and accurate method for measure total system air flow by many DOE and utility programs, as well as ANSI / RESNET / ACCA for Standard 310 grading. To learn more – check it out HERE!

NOTE: The Legacy TrueFlow is no longer available. We are announcing the new Digital TrueFlow product a month early because we have depleted our inventory of the legacy TrueFlow grid. A few of our distribution partners still have a few. In the meantime, please sign up to get on the waiting list for the new product – and let us know if you have questions by calling us at 612-827-1117.

TEC FOG PUFFER Kit™ is Now Available!

We are announcing the TEC Fog Puffer™ Kit developed by Gary is available for sale at the TEC store – at the very reasonable price of $59.

Gary has been refining this design for over 2 years - optimizing exactly how this Vapor-pen based product works.

Gary presented this product on April 1 and you can find the webinar here: https://youtu.be/I8tgu33xLfM

You can also watch his 7-minute product overview here: https://youtu.be/FNtv0SuuFvA

We will be taking feedback from users on both adjustments to make to the product and input on what we should call the product!

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The NEW DG-8 Digital Pressure Gauge

TEC Releases the DG-8 Micromanometer to Improve Accuracy in Key Building Pressure-Measurement Applications

DG-1000 Updates

The DG-1000 is the ONLY Pressure & Flow Gauge on the market able to run app assistants and provide options for both WiFi and Bluetooth connectivity.

NEW software update to the DG-1000 Gauge. This FREE software update adds stand-alone data logging, another update to the on-board tubing assistant app to include guidance on duct leakage to outside test set-up, and a pitot velocity mode.

New DG-1000 software (1.7.0.26) is released, and includes:

- Stand-alone Logging: Leave a DG-1000 to log data for extended periods (set up logging and extract data via TECGauge PC – available here: https://energyconservatory.com/downloads/tec-gauge-pc/)
- Tubing Assistant with Duct Leakage to Outside
- Pitot Velocity Mode

There is no cost for this update. Just connect the gauge to the internet, press the Update button on the Home screen of the DG-1000 and you will see 1.7.0.26 available to download and install. Once installed, you will be prompted to restart the DG-1000 for the new features to be activated.

You can find more information on setting up logging mode here: https://youtu.be/igqmx3gepps

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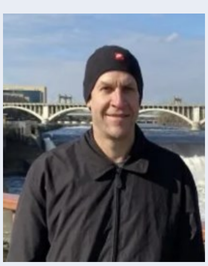
THE ENERGY CONSERVATORY



Questions for Collin?

Can also send questions to:
Bill Graber
bgraber@energyconservatory.com
PH: 612-254-2161

AutoTest - Wind Assistant™

T E C - THE ENERGY CONSERVATORY

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AIVC – TightVent Europe - INIVE
Webinar 'Impact of wind on airtightness test results'
8th November 2021

In-situ investigation of the impact of dynamic wind on fan pressurization method

Dimitrios Kraniotis

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Oslo Metropolitan University - OsloMet
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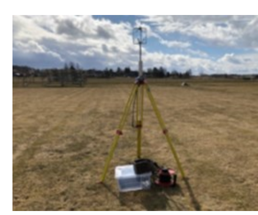
OSLO METROPOLITAN UNIVERSITY
STORBYUNIVERSITETET

1

Experimental site – Ås, 30 km south of Oslo

The file of the meteorological station BIOKLIM of the Norwegian University of Life Sciences (NMBU)



3d ultrasonic anemometer

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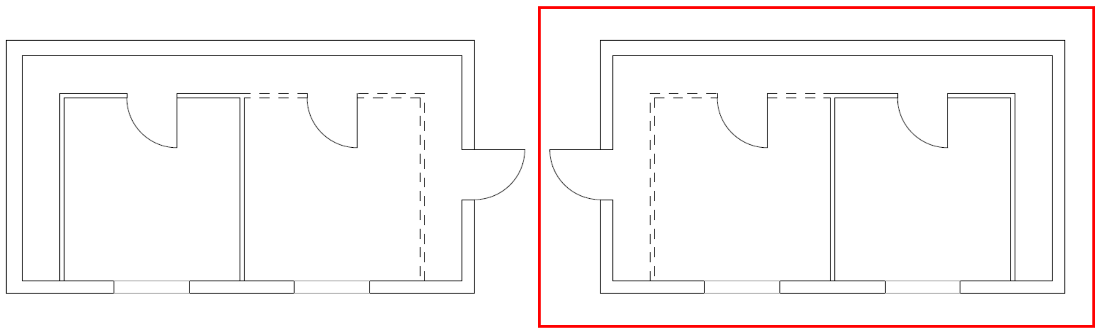
2

Insulated test house in cross-laminated timber (CLT)



	Internal Dimensions	External Dimensions
Length [m]	7 m	7.4 m
Width [m]	3.6 m	4.05 m
Height [m]	2.26 m	2.65 m
Elevation [AMSL [1]] [m]	90 m	

Internal Volume [m^3]	56.952 [m^3]
Net Floor Area [m^2]	25.2 [m^2]
Envelope Area [m^2]	60.685 [m^2]

3

3

In-situ measurements – Overview of temperature

- 10 selected days (variation in 3d wind speed and direction)
- Both pressurization and depressurization; 8+8 tests during a day
- In total: 158 tests

	Indoor Temperature [°C]	Outdoor Temperature [°C]	Temperature Difference [mK]
Day 1	21	4.8	35.6
Day 2	21	6.5	32.0
Day 3	21	6.6	31.7
Day 4	21	10.0	24.2
Day 5	21	5.0	35.3
Day 6	21	13.0	17.6
Day 7	21	9.7	24.9
Day 8	21	5.9	33.2
Day 9	21	16.5	9.8
Day 10	21	19.7	2.9

< 250 mK

likely that a satisfactory zero flow pressure difference can be obtained.

4

4

In-situ measurements – Overview of wind conditions

ISO 9972: 'A wind speed near the ground that exceeds 3 m/s or a meteorological wind speed above 6 m/s is unlikely to satisfy the zero-flow pressure difference requirement.'

Day #	Wind Condition: Wind Direction	Mean Wind Speed Magnitude at 2.2m $[\frac{m}{s}]$	Meteorological Wind Speed at 10m $[\frac{m}{s}]$	Wind Condition: Wind Direction	Mean Wind Magnitude at 2.2m $[\frac{m}{s}]$	Meteorological Wind Speed at 10m $[\frac{m}{s}]$
1A	SSE	7.01	9.13	SSW	7.56	9.08
1B	SSW	7.55	9.56	SSW	7.02	8.72
2	SSE	4.03	4.68	SSE	4.78	5.96
3	NNW	4.33	6.17	NNE	4.31	6.86
4	WWN	4.82	3.22	WWN	5.29	5.65
5	WWS	7.15	8.45	WWS	7.55	8.09
6	WWS	3.55	2.89	WWN	3.67	4.46
7	NW	2.32	2.58	WWN	2.34	2.71
8	SW	2.92	4.12	WWS	1.63	3.34
9	SSW	5.90	7.47	SSW	6.07	5.80
10	WWN	2.24	2.84	WWN	1.72	2.25

pressurization depressurization

5

ISO 997 ical wind

speed ab irement.'

One would expect that Days 7, 8 and 10 would satisfy the zero-flow pressure difference requirement

WHILE

The Days 1-6 and Day 9 would not satisfy it

Day #	Wind	leteorological Wind peed at 10m
1A	SSE	08
1B	SSW	72
2	SSE	96
3	NNW	86
4	WWN	65
5	WWS	09
6	WWS	46
7	NW	71
8	SW	34
9	SSW	80
10	WWN	25

One would expect that Days 2, 4, 6, 7, 8 and 10 would satisfy the zero-flow pressure difference requirement

WHILE

The Days 1, 3, 5 and Day 9 would not satisfy it

6

ISO 9972:2015 – Criteria control

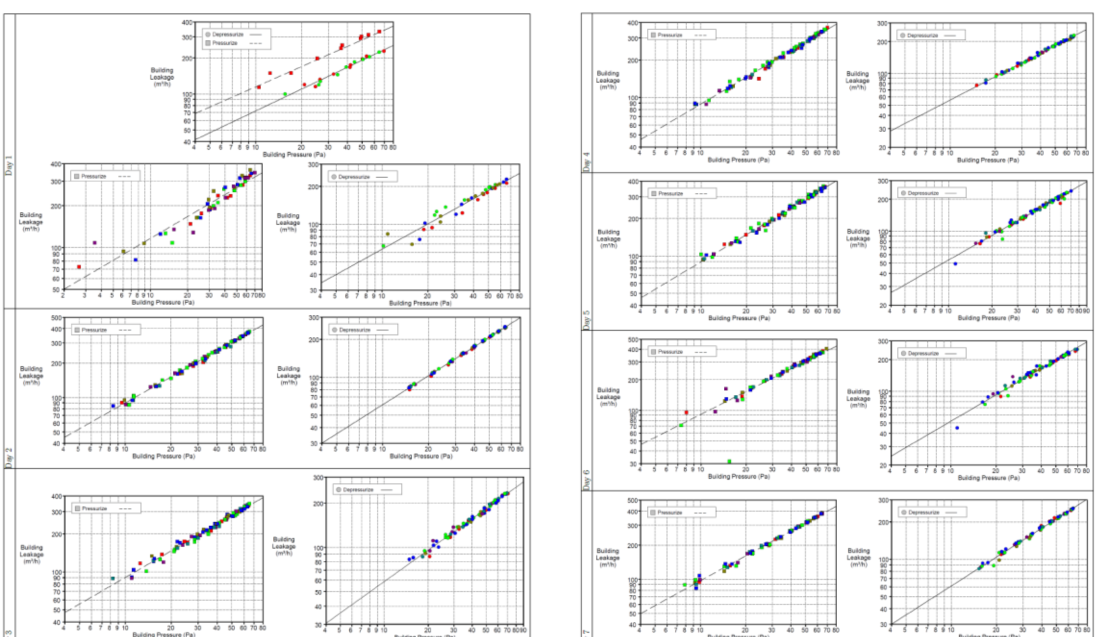
- air flow exponent (n): $0.5 \leq n \leq 1$
- coefficient of determination (r^2): $0.98 \leq r^2 \leq 1$
- zero-flow pressure difference (baseline pressure value):

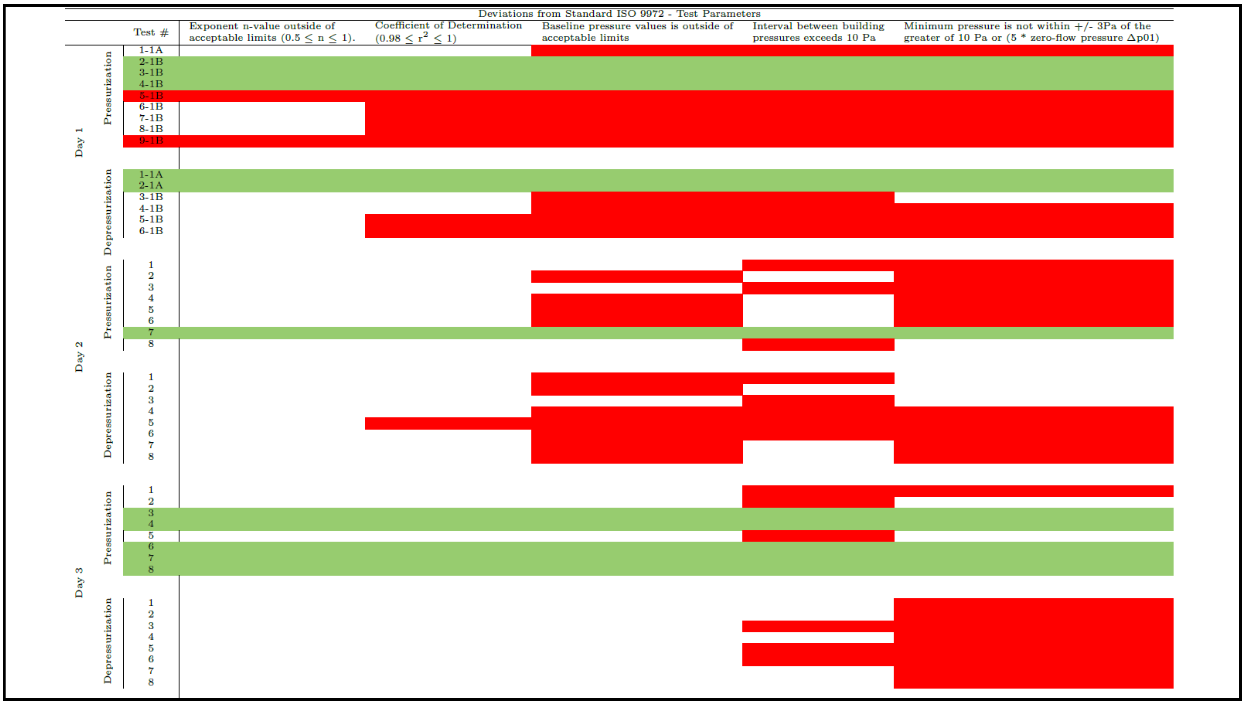
$$\left\{ \begin{array}{l} |\Delta p01+| \text{ and } |\Delta p01-| \\ |\Delta p02+| \text{ and } |\Delta p02-| \end{array} \right\} \leq 5Pa$$

- pressure difference sequence (ΔP): $\Delta P \leq 10Pa$
- lowest target pressure difference (ΔP):

$$\Delta P = \left\{ \begin{array}{ll} 10\ 3\,\%Pa, & \text{if } [10\ 3\,\% \geq 5 * \Delta p01] \\ 5 * \Delta p01, & \text{if } [5 * \Delta p01 \geq 10\ 3\,\%] \end{array} \right\}$$

Building leakage rate results (sample: Days 1-7)




Deviations from Standard ISO 9972 - Test Parameters
Test #
Exponent n-value outside of acceptable limits (0.5 ≤ n ≤ 1).
Coefficient of Determination (0.98 ≤ r² ≤ 1)
Baseline pressure values is outside of acceptable limits
Interval between building pressures exceeds 10 Pa
Minimum pressure is not within +/- 3Pa of the greater of 10 Pa or (5 * zero-flow pressure Δp01)
Day 1
Pressurization
1-1A
2-1B
3-1B
4-1B
5-1B
6-1B
7-1B
8-1B
9-1B
Depressurization
1-1A
2-1A
3-1B
4-1B
5-1B
6-1B
Day 2
Pressurization
1
2
3
4
5
6
7
8
Depressurization
1
2
3
4
5
6
7
8
Day 3
Pressurization
1
2
3
4
5
6
7
8
Depressurization
1
2
3
4
5
6
7
8

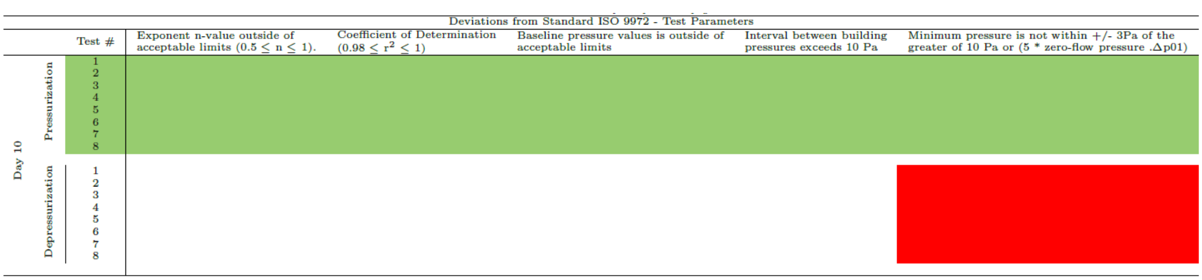
10


Deviations from Standard ISO 9972 - Test Parameters
Test #
Exponent n-value outside of acceptable limits (0.5 ≤ n ≤ 1).
Coefficient of Determination (0.98 ≤ r² ≤ 1)
Baseline pressure values is outside of acceptable limits
Interval between building pressures exceeds 10 Pa
Minimum pressure is not within +/- 3Pa of the greater of 10 Pa or (5 * zero-flow pressure .Δp01)
Day 4
Pressurization
1
2
3
4
5
6
7
8
Depressurization
1
2
3
4
5
6
7
8
Day 5
Pressurization
1
2
3
4
5
6
7
Depressurization
1
2
3
4
5
6
7
8
Day 6
Pressurization
1
2
3
4
5
6
7
8
Depressurization
1
2
3
4
5
6
7
8

11

12

ISO 9972 criteria control



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Criteria control - Discussion

One would expect that Days 7, 8 and 10 would satisfy the zero-flow pressure difference requirement WHILE The Days 1-6 and Day 9 would not satisfy it	One would expect that Days 2, 4, 6, 7, 8 and 10 would satisfy the zero-flow pressure difference requirement WHILE The Days 1, 3, 5 and Day 9 would not satisfy it

- The wind-based criterion in ISO 9972:2015 generally predicts the likelihood, **HOWEVER fails to predict the non-likelihood** of zero-flow pressure difference requirement;
  - The days 7, 8 and 10 have fulfilled the requirement both in the pressurization and depressurization tests.
  - The days 3, 4 and 6 **also** fulfil the requirement both in the pressurization and depressurization tests.
  - The vast majority of tests during the day 5 also fulfil the requirement (only 1 out of 8 fails in pressurization and 2 out of 8 in depressurization)
  - The days 1, 2 and 9 show the worst performance.

Criteria control – The role of turbulence intensity (?)

- On the day 5 - pressurization: the one test that fails to fulfil the requirement has the highest turbulence intensity among all tests, i.e. 25.5%, while the other tests have between 15.5 and 19.5% (approximately).
- On the day 5 - depressurization: the two test that fail to fulfil the requirement have the highest turbulence intensity, i.e. 21%, while the other tests have between 17.5 and 19.5% (approximately).

Summary of results – Steady state analysis | Pressurization

	Test Results at 50 Pascals:			Building Leakage Curve:			Wind Condition:			
Day #	Air Leakage Rate: q_{50} $[\frac{m^3}{h}]$	Leakage Areas:ELA_{50} $[m^2]$	Air Flow Coefficient C_{env}	Air Leakage Coefficient C_L	Air Flow Exponent n	Determination Coefficient: $[r^2]$	Wind Class	Wind Direction	Mean Wind Speed Magnitude at 2.2m $[\frac{m}{s}]$	Meteorological Wind Speed at 10m $[\frac{m}{s}]$
1A	283	0.0086	31.6	31.5	0.561	0.93828	Fresh breeze	SSE	7.01	9.13
1B	269	0.0082	34.9	34.9	0.522	0.89903	Fresh breeze	SSW	7.55	9.56
2	279	0.0085	18	18	0.701	0.98515	Gentle breeze	SSE	4.03	4.68
3	278	0.0085	17.1	17.1	0.713	0.99151	Moderate breeze	NNW	4.33	6.17
4	289	0.0088	16.9	16.9	0.726	0.98968	Gentle breeze	WWN	4.82	3.22
5	304	0.0093	16.6	16.6	0.744	0.82193	Fresh breeze	WWS	7.15	8.45
6	314	0.0096	18.2	18.2	0.728	0.99471	Gentle breeze	WWS	3.55	2.89
7	313	0.0095	19.3	19.3	0.712	0.98242	Light breeze	NW	2.32	2.58
8	311	0.0095	17.4	17.3	0.738	0.99511	Gentle breeze	SW	2.92	4.12
9	313	0.0095	16.4	16.4	0.754	0.97962	Moderate breeze	SSW	5.90	7.47
10	302	0.0092	15.9	15.9	0.753	0.99566	Light breeze	WWN	2.24	2.84

Pressurization: Coefficient of determination & mean wind speed

			Wind Speed$[\frac{m}{s}]$		Wind Direction$[\theta_w]$	
Test Day	R^2	Mean Speed	Probability density function Normal distribution	Probability density function Weibull distribution	Mean	Exposure Zone
Day 10	0.99566	2.24	0.4499	0.4289	296.4169	[WWN]
Day 8	0.99511	2.92	0.5256	0.4549	227.5659	[SW]
Day 6	0.99471	3.55	0.4235	0.3928	252.7078	[WWS]
Day 3	0.99151	4.33	0.2636	0.2506	353.7472	[NNW]
Day 4	0.98968	4.82	0.3427	0.3150	279.9403	[WWN]
Day 2	0.98515	4.03	0.3015	0.2867	162.7255	[SSE]
Day 7	0.98242	2.32	0.3276	0.3250	302.4302	[NW]
Day 9	0.97962	5.9	0.3129	0.2914	208.4336	[SSW]
Day 1A	0.93828	7.01	0.2301	0.2199	178.2021	[SSE]
Day 1B	0.89903	7.55	0.1919	0.1781	186.1113	[SSW]
Day 5	0.82193	7.15	0.1669	0.1486	254.3990	[WWS]

Day 7: High turbulence intensity!

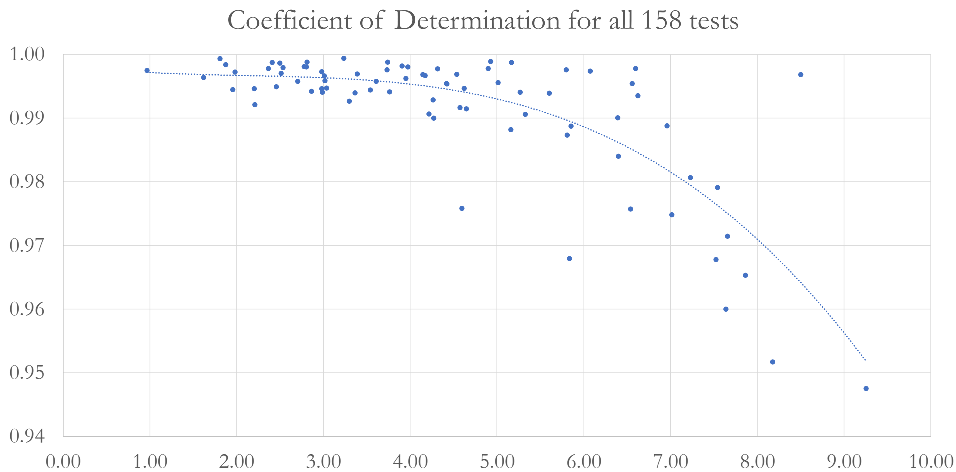
Summary of results – Steady state analysis | Depressurization

Day	Test Results at 50 Pascals: Air Leakage Rate: q_{50}	Leakage Areas:ELA_{50}	Building Leakage Curve: Air Flow Coefficient	Air Leakage Coefficient	Air Flow Exponent	Determination Coefficient:	Wind Condition: Wind Class	Wind Direction	Mean Wind Magnitude at 2.2m	Meteorological Wind Speed at 10m
#	$[\frac{m^3}{h}]$	$[m^2]$	C_{env}	C_L	n	$[r^2]$			$[\frac{m}{s}]$	$[\frac{m}{s}]$
1A	191	0.0058	17.5	17.9	0.606	0.97508	Fresh breeze	SSW	7.56	9.08
1B	186	0.0057	13.4	13.6	0.667	0.93826	Fresh breeze	SSW	7.02	8.72
2	184	0.0056	11.3	11.4	0.711	0.98592	Gentle breeze	SSE	4.78	5.96
3	183	0.0056	10.1	10.2	0.738	0.99557	Moderate breeze	NNE	4.31	6.86
4	186	0.0057	8.9	8.9	0.775	0.97915	Gentle breeze	WWN	5.29	5.65
5	198	0.0060	7.6	7.7	0.831	0.97466	Fresh breeze	WWS	7.55	8.09
6	212	0.0065	10.2	10.3	0.774	0.99282	Gentle breeze	WWN	3.67	4.46
7	225	0.0069	12	12.1	0.746	0.99563	Light breeze	WWN	2.34	2.71
8	204	0.0062	10.4	10.5	0.758	0.99817	Gentle breeze	WWS	1.63	3.34
9	209	0.0064	12.7	12.7	0.715	0.96174	Moderate breeze	SSW	6.07	5.80
10	208	0.0063	10.4	10.4	0.766	0.99871	Light breeze	WWN	1.72	2.25

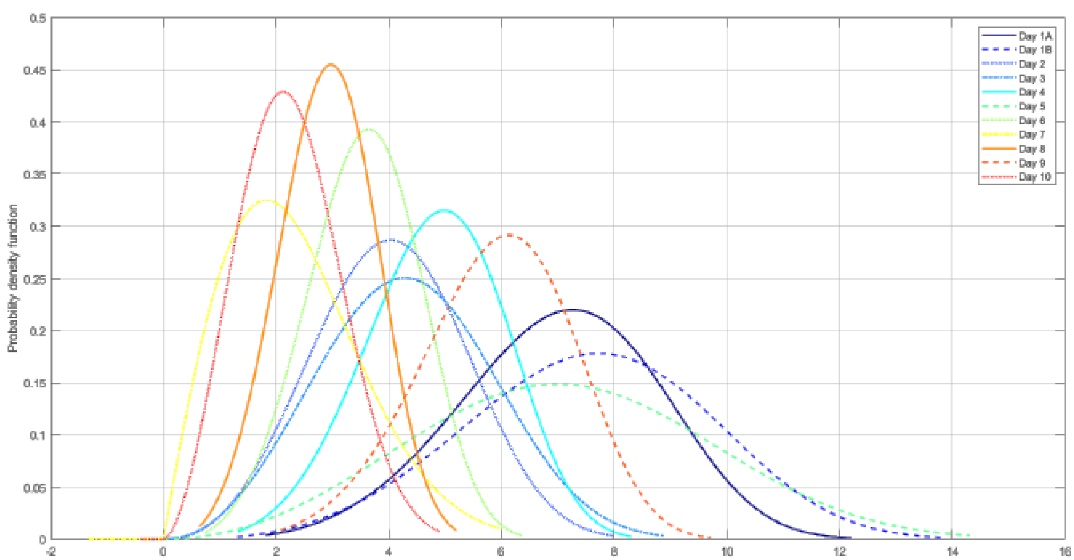
Depressurization: Coefficient of determination & mean wind speed

Test Day	R^2	Mean Speed	Wind Speed$[\frac{m}{s}]$: Probability density function Normal distribution	Probability density function Weibull distribution	Wind Direction$[\theta_w]$: Mean	Exposure Zone
Day 10	0.99871	1.7218	0.5457	0.5222	277.4304	[WWN]
Day 8	0.99817	1.6338	0.4303	0.4428	247.0509	[WWS]
Day 7	0.99563	2.3416	0.3607	0.3501	282.1677	[WWN]
Day 3	0.99557	4.3091	0.2588	0.2434	11.6032	[NNE]
Day 6	0.99282	3.6732	0.3698	0.3460	278.5971	[WWN]
Day 2	0.98592	4.7778	0.3137	0.2907	176.9836	[SSE]
Day 4	0.97915	5.2948	0.2537	0.2312	280.3751	[WWN]
Day 1A	0.97508	7.5580	0.1927	0.1802	188.3780	[SSW]
Day 5	0.97466	7.5540	0.1855	0.1689	252.6940	[WWS]
Day 9	0.96174	6.0691	0.2567	0.2425	211.7289	[SW]
Day 1B	0.93826	7.0195	0.2068	0.1896	185.3449	[SSW]

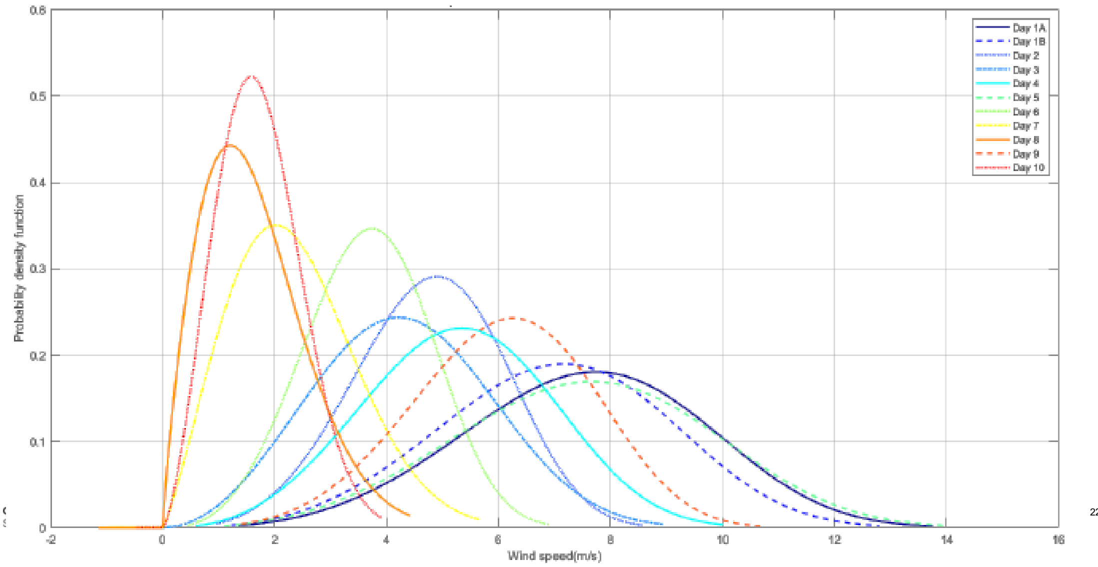
Coefficient of determination & mean wind speed



Probability density function of wind speed - Pressurization



Probability density function of wind speed - Depressurization



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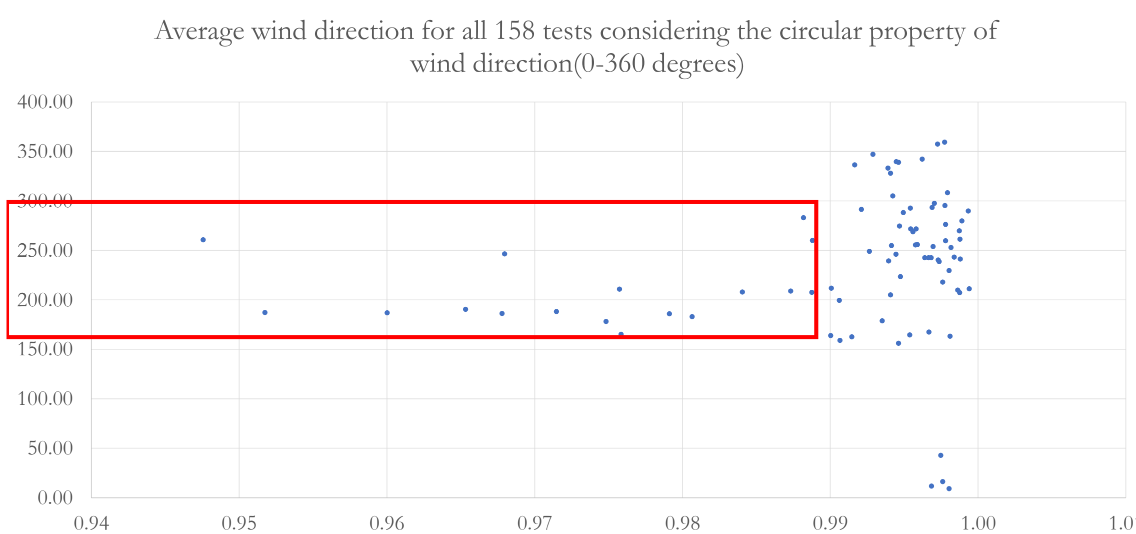
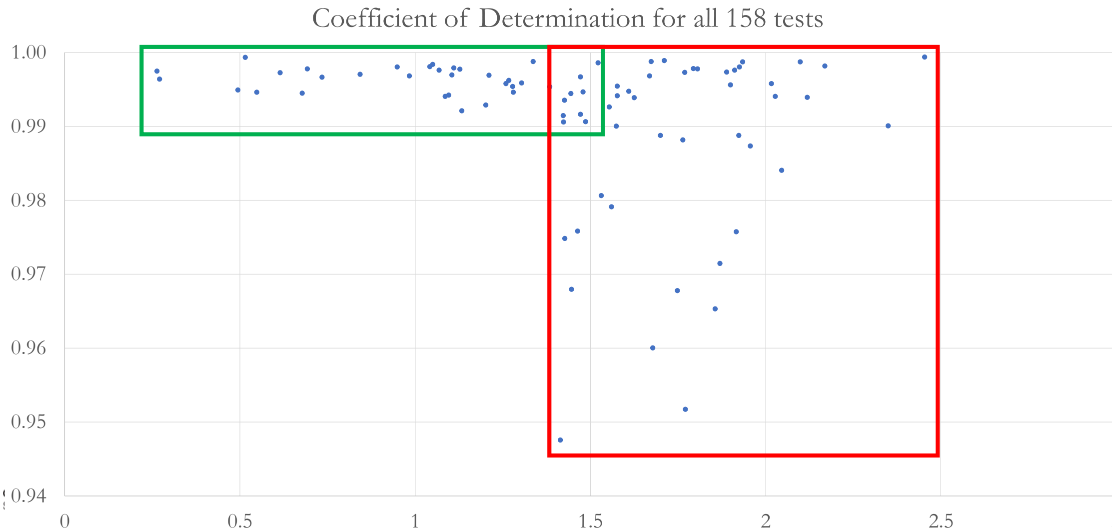
Wind direction and coefficient of determination



Probability density function of wind direction and coefficient of determination



Synoptic points

- Pressurization and depressurization: different performance with respect to the fulfilment of the criteria as per ISO 9972; Pressurization fulfils 'easier' the criteria compared to depressurization
- Pressure difference sequence and lowest target pressure difference show the highest failure potential, after the zero-flow pressure difference criterion
- Over 25% of the tests would have been rejected by the ISO, however they fulfil the zero-flow requirement.
- Wind fluctuations and turbulence intensity increase the likelihood for failure of the zero-flow requirement as well as the uncertainty of the test(s), even in favourable (according to ISO 9972) wind conditions
- Wind direction against relatively big leakages increases the uncertainty of the test(s)
- The variation in wind direction is important: when wind direction changes a lot (and therefore the pressure distribution around the building), the test becomes more reliable.


Thank you for your attention!
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