VIP 41: Impact of wind on building airtightness test

VALÉRIE LEPRINCE – INIVE

NOVEMBER 8TH – AIVC & TIGHTVENT WEBINAR

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
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.
Content

Impact of wind on building airtightness tests

Part 1: The physic

Part 2: Literature review

Part 3: How to limit the impact?

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, \( \Delta P_{p+} \),
- the average of the negative values of zero-flow pressure difference, \( \Delta P_{p-} \), and
- the average of all values of zero-flow pressure difference, \( \Delta P_{p} \).

Repeat this process at the end of the test (to obtain \( \Delta P_{p+}, \Delta P_{p-}, \) and \( \Delta P_{p} \)).

If the absolute value of \( \Delta P_{p+}, \Delta P_{p-}, \Delta P_{p} \), or \( \Delta P_{p} \), 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.
Pressure measurement

Theoretical
Wind

The external pressure is “absolute”

In practice

Wind

The external pressure gauge is behind or in front of an obstacle (the building or else)

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.

The calculation assumes:

\[ \Delta p_0 = p_i - p_{ext} \]

In practice we measure:

\[ \Delta p_0 = p_i - p_{ext} + \frac{1}{2} \rho C_p g_{auge} U^2 \]

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.
Wind fluctuations

Indoor pressure varies of more than 20 Pa within a few minutes \( \rightarrow \) large induced uncertainty

3rd issue

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

<table>
<thead>
<tr>
<th>Natural pressure difference (zero-flow pressure)</th>
<th>No wind</th>
<th>Wind</th>
</tr>
</thead>
<tbody>
<tr>
<td>( p_i = p_{\text{ext}} ) ( \Delta p_0 = 0 )</td>
<td><img src="Diagram.png" alt="Diagram" /></td>
<td><img src="Diagram.png" alt="Diagram" /></td>
</tr>
<tr>
<td>Equilibrium pressure: ( \Delta p_0 = p_i - p_{\text{ext}} = \frac{C_{\text{up}}}{n} p_{\text{up}} + \frac{C_{\text{down}}}{n} p_{\text{down}} )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Equilibrium pressure: \( \Delta p_0 = p_i - p_{\text{ext}} = \frac{1}{n} p_{\text{up}} + \frac{1}{n} p_{\text{down}} \)
... as the problem is not linear (n≠1)

Model error

If the whole building is pressurized (respect. depressurized) averaging the results of a pressurized and a depressurized test decreases the error.
To sum up: 4 main wind issues

1. Wind variation
2. Pressure measurement location
3. Wind fluctuations
4. 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 10 m/s
  - 4 Pa: main uncertainty at 4 m/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?
- A better characterisation of unsteady winds
- A better knowledge of leakages behaviour

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
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

Minimizing the wind impact on airtightness tests results
Main recommendations for minimising wind impact

<table>
<thead>
<tr>
<th>Improve zero-flow pressure measurement</th>
</tr>
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<tbody>
<tr>
<td>• Increase the duration and frequency of the measurements: 30 to 60 s and 1 data /s (&gt; 10 points/data)</td>
</tr>
<tr>
<td>• Monitor the wind during the entire test to detect variations</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Choose carefully the location of pressure taps</th>
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<tr>
<td>• Let gauges at the same location during the whole test</td>
</tr>
<tr>
<td>• Use T-pieces and put the pipe some distance away</td>
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</table>

<table>
<thead>
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<th>Use a weighed method for the regression</th>
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<td>• Average the results of pressurization and depressurization tests</td>
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<table>
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<th>Adapt the pressure difference sequence</th>
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<td>• Average the results of pressurization and depressurization tests</td>
</tr>
<tr>
<td>• Single-point test to estimate a flow rate at 50 Pa or at 4 Pa with wind &gt; 5 m/s (multipressure-point when &lt; 5 m/s)</td>
</tr>
<tr>
<td>• 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.</td>
</tr>
</tbody>
</table>
Improving Air Tightness Measurements in Windy Conditions

With Gary Nelson

Introduction

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

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
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.

Where and How Should Outdoor Pressure be Measured?

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 m³
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

Indoor barometric pressure (Paroscientific barometer)
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
9. **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

<table>
<thead>
<tr>
<th>Channel</th>
<th>Avg (Pa)</th>
<th>Std Dev (Pa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>East Side, tee</td>
<td>-5.58</td>
<td>0.52</td>
</tr>
<tr>
<td>North Side, tee</td>
<td>-4.7</td>
<td>0.81</td>
</tr>
<tr>
<td>South Side, tee</td>
<td>-6.79</td>
<td>1.25</td>
</tr>
<tr>
<td>West Side, tee</td>
<td>-5.44</td>
<td>1.05</td>
</tr>
<tr>
<td>5.5 m East, Dwyer 2m up</td>
<td>-4.52</td>
<td>0.69</td>
</tr>
<tr>
<td>5.5 m East, ground w/tee</td>
<td>-5.55</td>
<td>0.87</td>
</tr>
<tr>
<td>NW Corner, 2m up w/tee</td>
<td>-2.85</td>
<td>1.59</td>
</tr>
<tr>
<td>NW Corner, ground w/tee</td>
<td>-4.19</td>
<td>1.03</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Wind Speed</th>
<th>Outdoor Pressure Tap Location</th>
<th>Measurement Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 2.2 m/s</td>
<td>More than 2 m from fan</td>
<td>10+ seconds</td>
</tr>
<tr>
<td>2.2 – 4.5 m/s</td>
<td>Leeward side, more than 2 m from fan</td>
<td>10+ seconds</td>
</tr>
<tr>
<td>&gt; 4.5 m/s</td>
<td>Leeward side, more than 2 m from fan</td>
<td>30+ seconds</td>
</tr>
</tbody>
</table>

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

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

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
**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
Nat. Gebäudedruckdifferenzen / nat. building Pressure

34. Floor
112 m above ground

22. Floor
73 m above ground

12. Floor
41 m above ground

Ground Floor
0 m above ground

+70 Pa

-10 Pa

Improving Air Tightness Measurements in Windy Conditions

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?
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
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
   - East side 5.5 m away from building
   - East side on stand
   - Northwest corner of property, up 2 m
   - Northwest corner of property, ground

Testing Outdoor Pressure Locations

Tested 8 locations at the same time

- East side, ground level with tee
- North side, ground level with tee
- South side, ground level with tee
- West side, ground level with tee
- East side 5.5 m away from building
- East side on stand
- Northwest corner of property, up 2M
- Northwest corner of property, ground
Testing Outdoor Pressure Locations

Tested 8 locations at the same time

- East side, ground level with tee
- North side, ground level with tee
- South side, ground level with tee
- West side, ground level with tee
- East side 5.5 m away from building
- East side on stand
- 7 Northwest corner of property, up 2M
- 8 Northwest corner of property, ground
### Building Pressures in Very Tall Buildings

**Conclusion:** Measure outdoor pressure at ground level

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

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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
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

<table>
<thead>
<tr>
<th>Channel</th>
<th>Avg</th>
<th>Std Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 P1 East Side</td>
<td>-5.58</td>
<td>0.52</td>
</tr>
<tr>
<td>2 P6 North Side</td>
<td>-4.7</td>
<td>0.81</td>
</tr>
<tr>
<td>3 P8 South Side</td>
<td>-6.79</td>
<td>1.25</td>
</tr>
<tr>
<td>4 P2 West Side</td>
<td>-5.44</td>
<td>1.05</td>
</tr>
<tr>
<td>5 P7 (5.5M East, Ground)</td>
<td>-5.55</td>
<td>0.87</td>
</tr>
<tr>
<td>6 P4 (5.5M East, Dwyer)</td>
<td>-4.52</td>
<td>0.69</td>
</tr>
<tr>
<td>7 P3 (NW Corner, 2M Up)</td>
<td>-2.85</td>
<td>1.59</td>
</tr>
<tr>
<td>8 P5 (NW Corner, Ground)</td>
<td>-4.19</td>
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</tr>
</tbody>
</table>
## Testing to Confirm Best Approach

### Data Summary

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<thead>
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<td>P7 (5.5M East, Ground)</td>
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Wind out of Northwest at ~ 6.7 m/s

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## Tests to Confirm Best Approach

<table>
<thead>
<tr>
<th>Channel</th>
<th># Obs</th>
<th>Avg</th>
<th>Std Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1 (East)</td>
<td>20</td>
<td>-5.58</td>
<td>0.52</td>
</tr>
<tr>
<td>P2 (W)</td>
<td>20</td>
<td>-5.44</td>
<td>1.05</td>
</tr>
<tr>
<td>P3 (NW 2M)</td>
<td>20</td>
<td>-2.85</td>
<td>1.59</td>
</tr>
<tr>
<td>P4 (Dwyer)</td>
<td>20</td>
<td>-4.52</td>
<td>0.69</td>
</tr>
<tr>
<td>P5 (NW grass)</td>
<td>20</td>
<td>-4.19</td>
<td>1.03</td>
</tr>
<tr>
<td>P6 (N)</td>
<td>20</td>
<td>-4.7</td>
<td>0.81</td>
</tr>
<tr>
<td>P7 (Dwyer, T, Ground)</td>
<td>20</td>
<td>-5.55</td>
<td>0.87</td>
</tr>
<tr>
<td>P8 (S)</td>
<td>20</td>
<td>-6.79</td>
<td>1.25</td>
</tr>
<tr>
<td>pbaro_Pa</td>
<td>20</td>
<td>7.69</td>
<td>2.21</td>
</tr>
<tr>
<td>TBase_F</td>
<td>20</td>
<td>71.79</td>
<td>0.01</td>
</tr>
</tbody>
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Wind out of Northwest at ~ 6.7 m/s
What’s Next?

Barometric differences INSIDE the home

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Performance of different shapes

Tests to Confirm Best Approach

- Tested 7 different outdoor locations simultaneously
  - East side 23 feet away from building
  - 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
Significant Research Continues on this Topic

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

Christophe Dumortier
Belgium Building Research Institute
Poitiers, France

ABSTRACT

The paper presents the particular points of the building: airtightness measurement (D50 & D150) and pressure readings at different positions of the building.

The points of the building: the area of the façade, roof, windows, and doors are measured by placing pressure taps on the façade, roof, windows, and doors, respectively. The measurements are performed at different points of the building. The pressure taps are connected to an electronic meter, which records the air pressure at the different points of the building. The results of the measurements are presented in the form of graphs and tables. The graphs and tables show the air pressure at different points of the building. The results indicate that the air pressure at different points of the building is not the same. The air pressure at the top of the building is higher than the air pressure at the bottom of the building.

KEYWORDS

Airtightness measurement, U-value, Zero-flow pressure, Fug, pressure loss

1 INTRODUCTION

In Belgium, airtightness measurements have been given to the airtightness of buildings since the first performances of the building. The energy performance of buildings in 2012 for new houses and buildings is given to the airtightness of the building. The airtightness of the building is given to the airtightness of the windows, doors, and walls. The airtightness of the building is given to the airtightness of the building in two conditions: the first condition is when the building is in airtight condition, and the second condition is when the building is in non-airtight condition. The airtightness of the building is given to the airtightness of the windows, doors, and walls in two conditions: the first condition is when the building is in airtight condition, and the second condition is when the building is in non-airtight condition. In the first condition, the airtightness of the windows, doors, and walls is given to the airtightness of the windows, doors, and walls in two conditions: the first condition is when the building is in airtight condition, and the second condition is when the building is in non-airtight condition.

Tests to Confirm Best Approach

- 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
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

• Tested x approaches simultaneously to see which performed best in exactly the same conditions
• Test informed by previous AIVC papers
• Good data will be informed by monitoring the standard deviation of the outdoor pressure reading
**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.

**Summary of Best Practices to Accommodate Wind**

<table>
<thead>
<tr>
<th>Wind Speed</th>
<th>Recommended $P_{out}$ Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 5 mph</td>
<td>Outside &gt; 5 feet from fan, time averaging = 10 sec</td>
</tr>
<tr>
<td>5-10 mph</td>
<td>Leeward side of the building, &gt; 5 feet from the fan, time averaging = 10 sec</td>
</tr>
<tr>
<td>&gt; 10 mph</td>
<td>Leeward side of the building, &gt; 5 feet from the fan, time averaging = 30 to 60 sec</td>
</tr>
</tbody>
</table>

**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.

- 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

<table>
<thead>
<tr>
<th>Wind Speed</th>
<th>Recommended ( P_{\text{out}} ) Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 5 mph</td>
<td>Outside &gt; 5 feet from fan, time averaging = 10 sec</td>
</tr>
<tr>
<td>5-10 mph</td>
<td>Leeward side, &gt; 5 feet from the fan, time averaging = 10 sec</td>
</tr>
<tr>
<td>&gt; 10 mph</td>
<td>Leeward side, &gt; 5 feet from the fan, time averaging = 30+ sec</td>
</tr>
</tbody>
</table>

Agenda

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

TEC Auto Test App for iOS & Android

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
Bill Test of Lake Home

Calm Conditions

Windy Conditions

Summary

- 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
**Agenda**

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

**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
Collin and Gary Testing

[Graph of data]

Collin and Gary Testing

[Graph of data]
Collin and Gary Testing

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

Collin and Gary Testing

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

Agenda

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

AutoTest if Free - Download from the TEC Website

YouTube

Website: energyconservatory.com
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 out 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!
  - HUAC 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 130 grading. To learn more – check it out [here](https://example.com/)

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 412-887-1117.

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**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://youtube/bHlkT7b8kTU](https://youtube/bHlkT7b8kTU)

You can also watch his 7-minute product overview here: [https://youtube/bTnQG5ucz2A](https://youtube/bTnQG5ucz2A)

We will be taking feedback from users on both adjustments to make to the product and input on what we should call the product!
TEC Releases the DG-8 Micromanometer to Improve Accuracy in Key Building Pressure-Measurement Applications

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 pilot 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 TEC gauge PC – available here: https://energyconservatory.com/download/tec-gauge-pc/)
- Tubing Assistant with Duct Leakage to Outdoors
- Pilot 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://www.youtube.com/watch?v=nvE5o5pp

Questions for Collin?

Can also send questions to:
Bill Graber
bgraber@energyconservatory.com
PH: 612-254-2161
In-situ investigation of the impact of dynamic wind on fan pressurization method

Dimitrios Kraniotis
Dep. of Civil Engineering & Energy Technology
Oslo Metropolitan University - OsloMet
dimkra@oslomet.no

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

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
Insulated test house in cross-laminated timber (CLT)

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

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

< 250 mK likely that a satisfactory zero flow pressure difference can be obtained.
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.’

<table>
<thead>
<tr>
<th>Day</th>
<th>Wind Direction</th>
<th>Mean Wind Speed at 2.2m</th>
<th>Meteorological Wind Speed at 10m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>SSE</td>
<td>7.61</td>
<td>9.13</td>
</tr>
<tr>
<td>1B</td>
<td>SSE</td>
<td>7.56</td>
<td>9.66</td>
</tr>
<tr>
<td>2</td>
<td>SSE</td>
<td>4.63</td>
<td>6.08</td>
</tr>
<tr>
<td>3</td>
<td>NNW</td>
<td>4.33</td>
<td>6.17</td>
</tr>
<tr>
<td>4</td>
<td>WNW</td>
<td>4.82</td>
<td>3.22</td>
</tr>
<tr>
<td>5</td>
<td>WWS</td>
<td>7.15</td>
<td>8.45</td>
</tr>
<tr>
<td>6</td>
<td>WWS</td>
<td>3.55</td>
<td>2.89</td>
</tr>
<tr>
<td>7</td>
<td>NW</td>
<td>2.32</td>
<td>2.58</td>
</tr>
<tr>
<td>8</td>
<td>SW</td>
<td>2.62</td>
<td>4.12</td>
</tr>
<tr>
<td>9</td>
<td>SSW</td>
<td>5.69</td>
<td>7.47</td>
</tr>
<tr>
<td>10</td>
<td>WNW</td>
<td>2.24</td>
<td>2.84</td>
</tr>
</tbody>
</table>

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
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):
  \[
  \left\{ \frac{|\Delta p01+| + |\Delta p01-|}{|\Delta p02+| + |\Delta p02-|} \right\} \leq 5Pa
  \]
- pressure difference sequence \( (\Delta P) \): \( \Delta P \leq 10Pa \)
- lowest target pressure difference \( (\Delta P) \):
  \[
  \Delta P = \begin{cases} 
  10.3\%Pa, & \text{if } [10.3\% \geq 5 \times \Delta p01] \\
  5 \times \Delta p01, & \text{if } [5 \times \Delta p01 \geq 10.3\%] 
  \end{cases}
  \]

Building leakage rate results (sample: Days 1-7)
### Deviation from Standard ISO 9972 - Test Parameters

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Exposed a-value outside of acceptable limits (0.5 ≤ a ≤ 1)</th>
<th>Coefficient of Determination (0.99 ≤ r² ≤ 1)</th>
<th>Baseline pressure value is outside of acceptable limits</th>
<th>Interval between building pressurization change and 90 Pa</th>
<th>Minimum pressure is not within 10 Pa or (5 * max airflow pressure ΔpH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 1</td>
<td></td>
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<td>Day 4</td>
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<td>Day 5</td>
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<td>Day 6</td>
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</tr>
<tr>
<td>Test #</td>
<td>Exponent n-value outside of acceptable limits ($0.5 \leq n \leq 1$)</td>
<td>Coefficient of Determination ($0.96 \leq r^2 \leq 1$)</td>
<td>Baseline pressure value is outside of acceptable limits</td>
<td>Interval between building pressure exceeds 10 Pa</td>
<td>Minimum pressure is not within $\pm 3$ Pa of the greater of 10 Pa or $3 \times$ net-flow (measure $\Delta P_{01}$)</td>
</tr>
<tr>
<td>--------</td>
<td>-------------------------------------------------</td>
<td>-------------------------------------------------</td>
<td>-------------------------------------------------</td>
<td>------------------------------------------------</td>
<td>-------------------------------------------------</td>
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<tr>
<td>Day 1</td>
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<td>Day 2</td>
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<td>Day 9</td>
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<td>Day 10</td>
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</tbody>
</table>

ISO 9972 criteria control
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

<table>
<thead>
<tr>
<th>Test Results at 50 Pausahaan</th>
<th>Building Leakage Curve</th>
<th>Wind Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day</td>
<td>Air Rate</td>
<td>Leakage Area</td>
</tr>
<tr>
<td>#</td>
<td>[m^3/s]</td>
<td>[m^2]</td>
</tr>
<tr>
<td>1A</td>
<td>283</td>
<td>0.0086</td>
</tr>
<tr>
<td>1B</td>
<td>289</td>
<td>0.0082</td>
</tr>
<tr>
<td>2</td>
<td>279A</td>
<td>0.0085</td>
</tr>
<tr>
<td>3</td>
<td>278</td>
<td>0.0085</td>
</tr>
<tr>
<td>4</td>
<td>269</td>
<td>0.0088</td>
</tr>
<tr>
<td>5</td>
<td>301</td>
<td>0.0093</td>
</tr>
<tr>
<td>6</td>
<td>314</td>
<td>0.0096</td>
</tr>
<tr>
<td>7</td>
<td>313</td>
<td>0.0095</td>
</tr>
<tr>
<td>8</td>
<td>311</td>
<td>0.0095</td>
</tr>
<tr>
<td>9</td>
<td>313</td>
<td>0.0095</td>
</tr>
<tr>
<td>10</td>
<td>302</td>
<td>0.0092</td>
</tr>
</tbody>
</table>

Pressurization: Coefficient of determination & mean wind speed

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal distribution</td>
<td>Weibull distribution</td>
<td>Day 10</td>
<td>0.99566</td>
<td>2.24</td>
</tr>
<tr>
<td>Day 8</td>
<td>0.99511</td>
<td>2.92</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 6</td>
<td>0.99471</td>
<td>3.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 3</td>
<td>0.99151</td>
<td>4.33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 4</td>
<td>0.98968</td>
<td>4.82</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 2</td>
<td>0.98515</td>
<td>4.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Day 7</strong></td>
<td><strong>0.98242</strong></td>
<td><strong>2.32</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 9</td>
<td>0.97962</td>
<td>5.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 1A</td>
<td>0.93828</td>
<td>7.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 1B</td>
<td>0.89903</td>
<td>7.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 5</td>
<td>0.82193</td>
<td>7.15</td>
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</tbody>
</table>

Day 7: High turbulence intensity!
Summary of results – Steady state analysis | Depressurization

<table>
<thead>
<tr>
<th>Test Results at 50 Pa/sec:</th>
<th>Building Leakage Curve:</th>
<th>Wind Condition:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day</td>
<td>Air Rate $Q_a$</td>
<td>Leakage Area $E_{LA_{sd}}$</td>
</tr>
<tr>
<td>#</td>
<td>$[\text{m}^3/\text{s}]$</td>
<td>$[\text{m}^2]$</td>
</tr>
<tr>
<td>1A</td>
<td>191</td>
<td>0.0058</td>
</tr>
<tr>
<td>1B</td>
<td>186</td>
<td>0.0057</td>
</tr>
<tr>
<td>2</td>
<td>184</td>
<td>0.0056</td>
</tr>
<tr>
<td>3</td>
<td>183</td>
<td>0.0056</td>
</tr>
<tr>
<td>4</td>
<td>186</td>
<td>0.0057</td>
</tr>
<tr>
<td>5</td>
<td>192</td>
<td>0.0060</td>
</tr>
<tr>
<td>6</td>
<td>212</td>
<td>0.0065</td>
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<tr>
<td>7</td>
<td>225</td>
<td>0.0069</td>
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<td>8</td>
<td>294</td>
<td>0.0062</td>
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<tr>
<td>9</td>
<td>299</td>
<td>0.0064</td>
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<tr>
<td>10</td>
<td>288</td>
<td>0.0063</td>
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</tbody>
</table>

Depressurization: Coefficient of determination & mean wind speed

<table>
<thead>
<tr>
<th>Test Day</th>
<th>$R^2$</th>
<th>Mean Speed</th>
<th>Probability density function</th>
<th>Probability density function</th>
<th>Mean</th>
<th>Exposure Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 10</td>
<td>0.99871</td>
<td>1.7218</td>
<td>Normal distribution</td>
<td>Weibull distribution</td>
<td>0.5457</td>
<td>0.5222</td>
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<td>Day 8</td>
<td>0.99817</td>
<td>1.6338</td>
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<td></td>
<td>0.4303</td>
<td>0.4428</td>
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<td>Day 7</td>
<td>0.99563</td>
<td>2.3416</td>
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<td></td>
<td>0.3607</td>
<td>0.3501</td>
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<td>Day 3</td>
<td>0.99557</td>
<td>4.3091</td>
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<td></td>
<td>0.2588</td>
<td>0.2434</td>
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<tr>
<td>Day 6</td>
<td>0.99282</td>
<td>3.6732</td>
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<td>0.3698</td>
<td>0.3460</td>
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<tr>
<td>Day 2</td>
<td>0.98592</td>
<td>4.7778</td>
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<td>0.3137</td>
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<tr>
<td>Day 4</td>
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<td>Day 1A</td>
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<td>Day 5</td>
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<td>Day 1B</td>
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<td>7.0195</td>
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<td></td>
<td>0.2068</td>
<td>0.1896</td>
</tr>
</tbody>
</table>
Coefficient of determination & mean wind speed

Probability density function of wind speed - Pressurization
Probability density function of wind speed - Depressurization

Wind direction and coefficient of determination

Average wind direction for all 158 tests considering the circular property of wind direction (0-360 degrees)
Probability density function of wind direction and coefficient of determination

Coefficient of Determination for all 158 tests

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!