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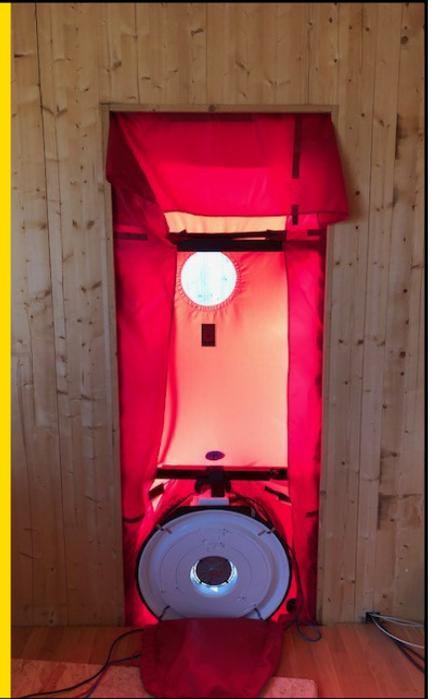**Webinar 'Impact of wind on airtightness test results'**
8th November 2021

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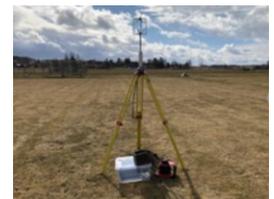
Dimitrios Kraniotis

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Oslo Metropolitan University - OsloMet
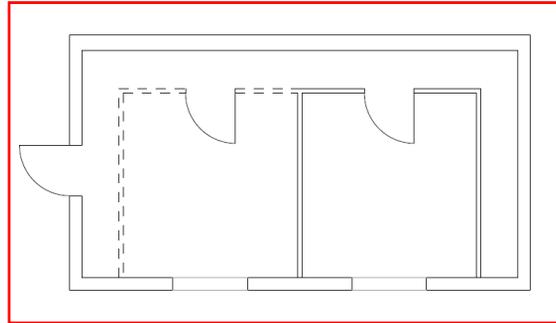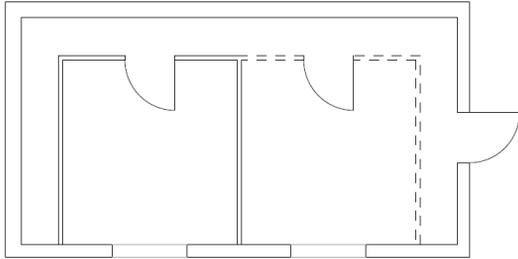dimkra@oslomet.no

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Experimental site – Ås, 30 km south of Oslo

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

Module B
Point A
Point B
Point C

3d ultrasonic anemometer

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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]

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.

Slide 5

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 Direction	Wind Condition: Mean Wind Speed Magnitude at 2.2m $[\frac{m}{s}]$	Wind Condition: Meteorological Wind Speed at 10m $[\frac{m}{s}]$	Wind Direction	Wind Condition: Mean Wind Magnitude at 2.2m $[\frac{m}{s}]$	Wind Condition: 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

Slide 6

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					Meteorological Wind Speed 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
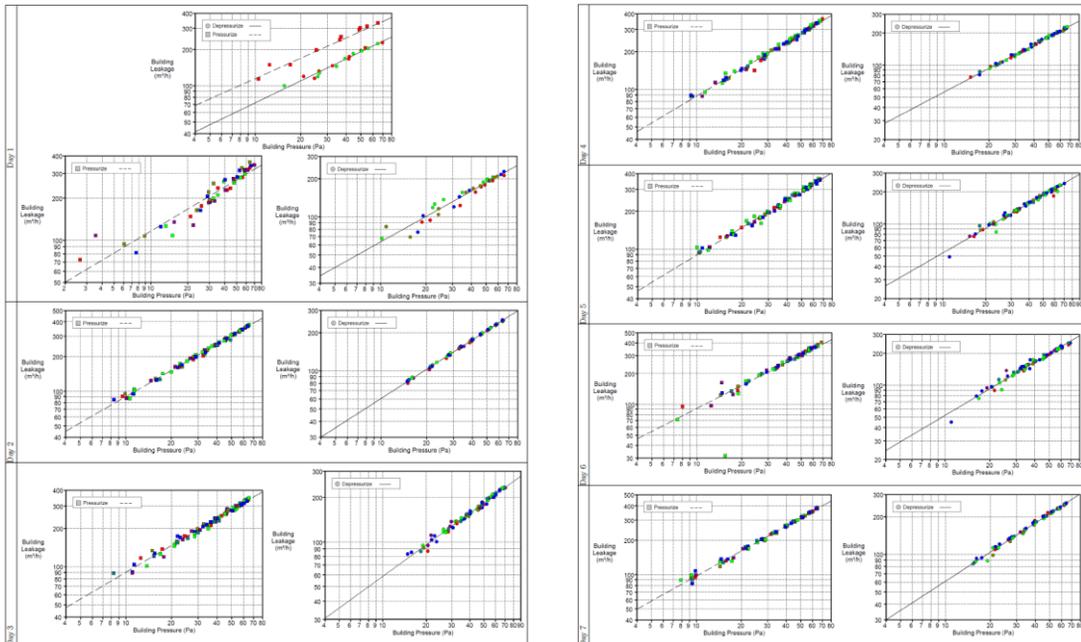
ISO 9972:2015 – Criteria control

- air flow exponent (n): $0.5 \leq n \leq 1$

- coefficient of determination (r²): $0.98 \leq r^2 \leq 1$

- 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):

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

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

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	Test #	Exponent n-value outside of acceptable limits ($0.5 \leq n \leq 1$).	Coefficient of Determination ($0.98 \leq r^2 \leq 1$)	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 $\Delta p01$)
Day 1 — Pressurization	1-1A					
	2-1B					
	3-1B					
	4-1B					
	5-1B					
	6-1B					
	7-1B					
	8-1B					
	9-1B					
Day 1 — Depressurization	1-1A					
	2-1A					
	3-1B					
	4-1B					
	5-1B					
	6-1B					
Day 2 — Pressurization	1					
	2					
	3					
	4					
	5					
	6					
	7					
	8					
Day 2 — Depressurization	1					
	2					
	3					
	4					
	5					
	6					
	7					
	8					
Day 3 — Pressurization	1					
	2					
	3					
	4					
	5					
	6					
	7					
	8					
Day 3 — Depressurization	1					
	2					
	3					
	4					
	5					
	6					
	7					
	8					

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	Test #	Exponent n-value outside of acceptable limits ($0.5 \leq n \leq 1$).	Coefficient of Determination ($0.98 \leq r^2 \leq 1$)	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 $.\Delta p01$)
Day 4 — Pressurization	1					
	2					
	3					
	4					
	5					
	6					
	7					
	8					
Day 4 — Depressurization	1					
	2					
	3					
	4					
	5					
	6					
	7					
	8					
Day 5 — Pressurization	1					
	2					
	3					
	4					
	5					
	6					
	7					
Day 5 — Depressurization	1					
	2					
	3					
	4					
	5					
	6					
	7					
	8					
Day 6 — Pressurization	1					
	2					
	3					
	4					
	5					
	6					
	7					
	8					
Day 6 — Depressurization	1					
	2					
	3					
	4					
	5					
	6					
	7					
	8					

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	Test #	Exponent n-value outside of acceptable limits ($0.5 \leq n \leq 1$).	Coefficient of Determination ($0.98 \leq r^2 \leq 1$)	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 .$\Delta p01$)

Day 7 — Pressurization: 1, 2, 3, 4, 5, 6, 7, 8
Day 7 — Depressurization: 1, 2, 3, 4, 5, 6, 7, 8
Day 8 — Pressurization: 1, 2, 3, 4, 5, 6, 7, 8
Day 8 — Depressurization: 1, 2, 3, 4, 5, 6, 7, 8
Day 9 — Pressurization: 1, 2, 3, 4, 5, 6, 7, 8
Day 9 — Depressurization: 1, 2, 3, 4, 5, 6, 7, 8

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ISO 9972 criteria control

	Test #	Exponent n-value outside of acceptable limits ($0.5 \leq n \leq 1$).	Coefficient of Determination ($0.98 \leq r^2 \leq 1$)	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 .$\Delta p01$)

Day 10 — Pressurization: 1, 2, 3, 4, 5, 6, 7, 8
Day 10 — Depressurization: 1, 2, 3, 4, 5, 6, 7, 8

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⚙️OSLOMET Criteria control - Discussion

<table>
<tr>
<td>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</td>
<td>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</td>
</tr>
</table>

- 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.

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⚙️OSLOMET 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).

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Summary of results – Steady state analysis | Pressurization

	Test Results at 50 Pascals:			Building Leakage Curve:				Wind Condition:			
Day	Air Leakage Rate: q_{50}	Leakage Areas:ELA_{50}	Air Flow Coefficient	Air Leakage Coefficient	Air Flow Exponent	Determination Coefficient:	Wind Class	Wind Direction	Mean Wind Speed 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	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

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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!

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Summary of results – Steady state analysis | Depressurization

	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 Magnitude at 2.2m $[\frac{m}{s}]$	Meteorological Wind Speed at 10m $[\frac{m}{s}]$	
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	

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Depressurization: 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	0.99871	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]

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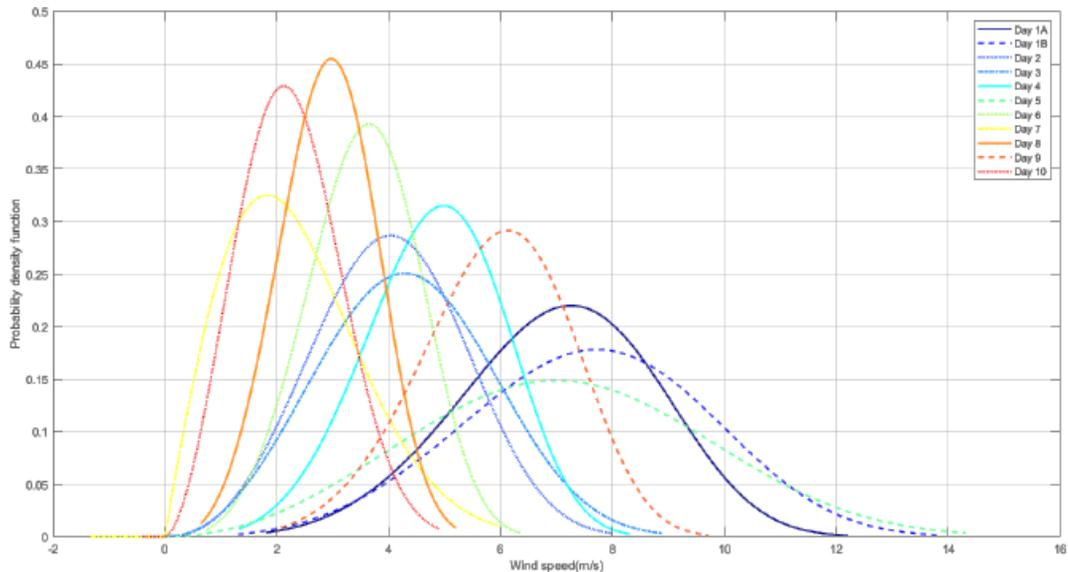
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Coefficient of determination & mean wind speed

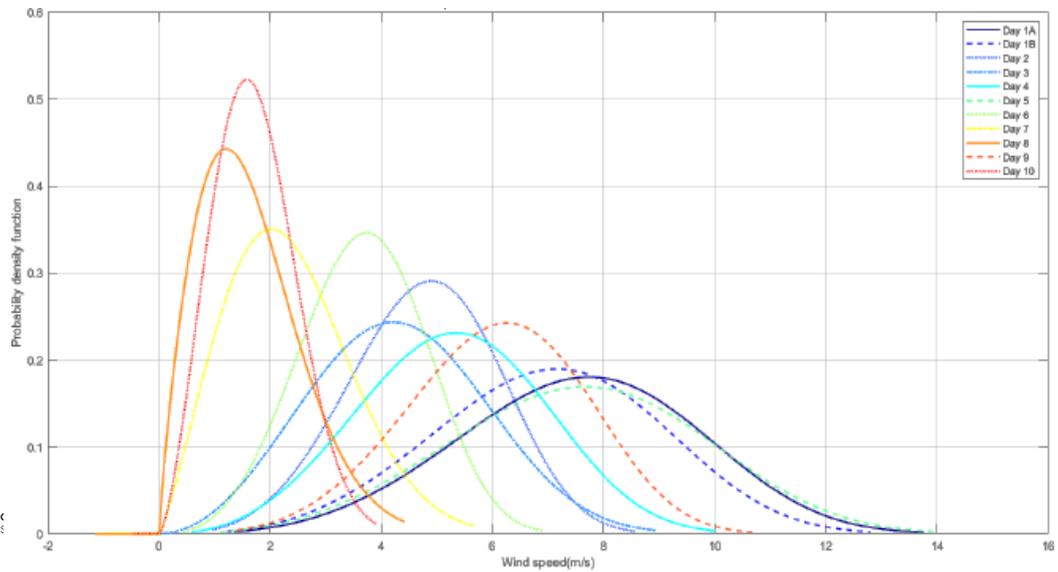Coefficient of Determination for all 158 tests
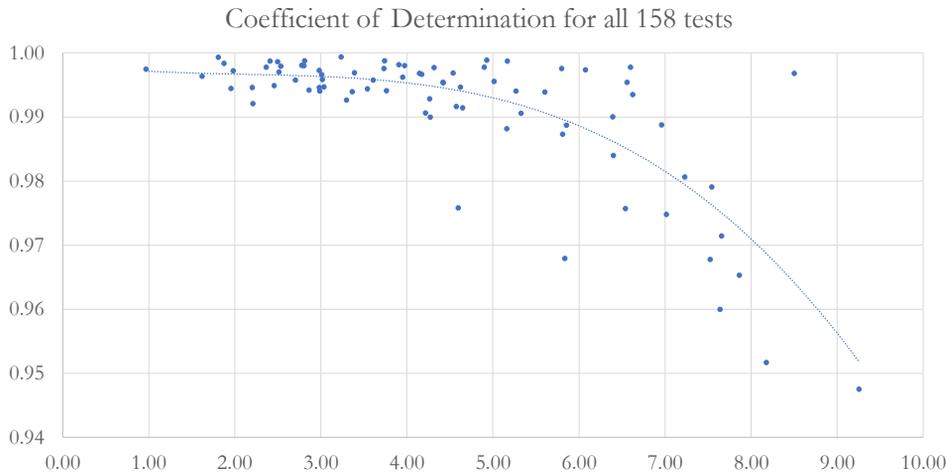
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Probability density function of wind speed - Pressurization

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Probability density function of wind speed - Depressurization

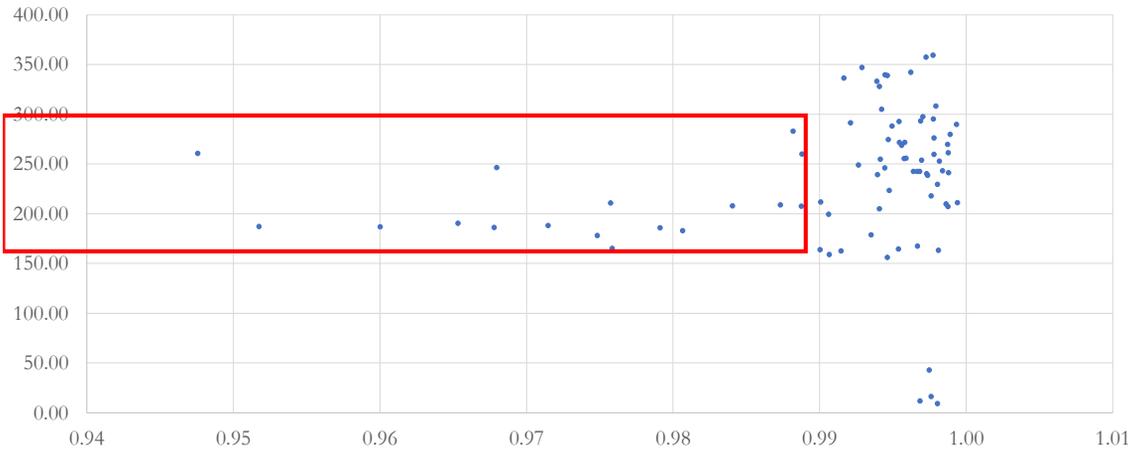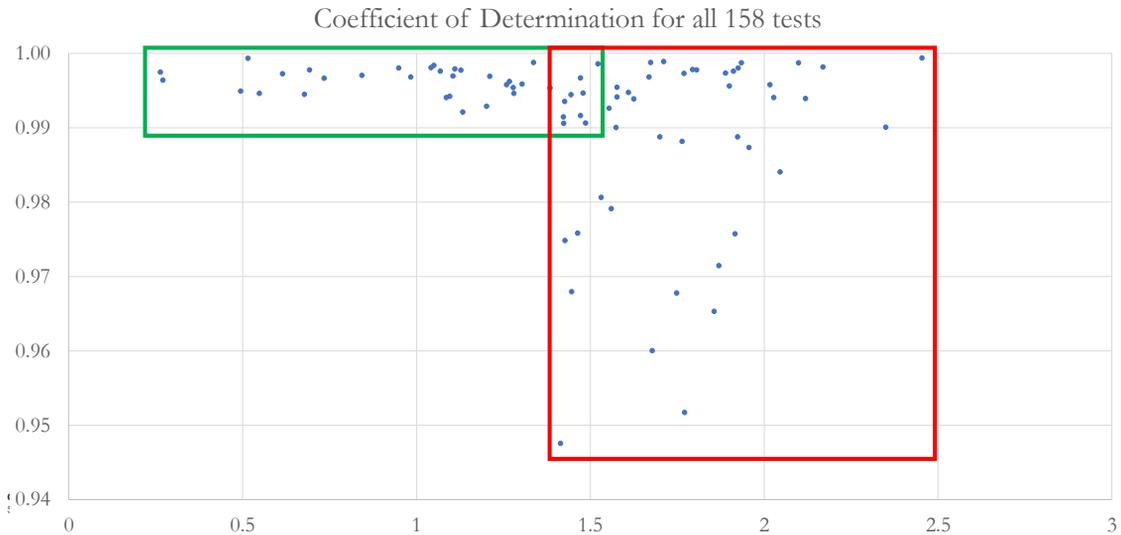

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Wind direction and coefficient of determination

Average wind direction for all 158 tests considering the circular property of wind direction(0-360 degrees)

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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.

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Thank you for your attention!