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AIRTIGHTNESS TESTS FOR HIGH-RISE BUILDINGS

AIVC/TightVent Webinar – 26 January 2024

AIVC TightVent Europe BUILDING AND DUCTWORK AIRTIGHTNESS PLATFORM EBC Energy in Buildings and Communities Programme

webinar
2024.01.26

Airtightness tests for high-rise buildings




Agenda (CET)

- 10:00 | Welcome & Introduction, Valérie Leprince (Cerema, France)
- 10:05 | | Challenges and Experiences of Airtightness Tests in Tall Buildings, Stefanie Rolfsmeier (BlowerDoor, Germany)
- 10:35 | ISO 9972 and constraints on zero flow pressure difference: a comprehensive study on the influence of stack effect, Benedikt Kölsch (Cerema, France)
- 10:55 | Questions and answers
- 11:00 |Practical recommendations for airtightness tests in high-rise buildings, Nolwenn Hurel and Valérie Leprince (Cerema, France)
- 11:20 | Questions and answers
- 11:30 | End of webinar

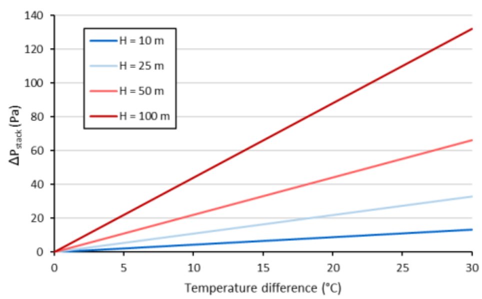
WHAT IS THE ISSUE WITH HIGH-RISE BUILDINGS?

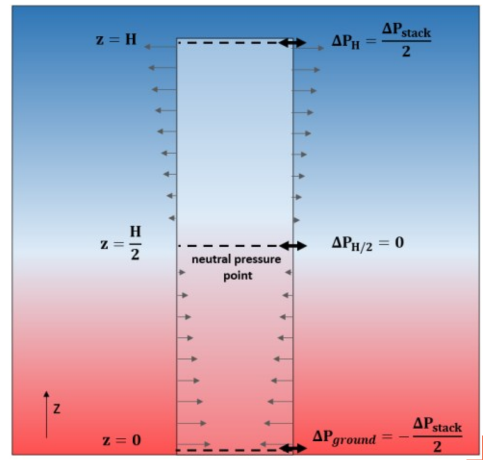
1/ Stack effect

Proportional to:

- The **temperature difference** between inside and outside
- The building's **height**

$$\Delta P_{stack} \approx 0.044 \times H \times (T_{int} - T_{ext})$$

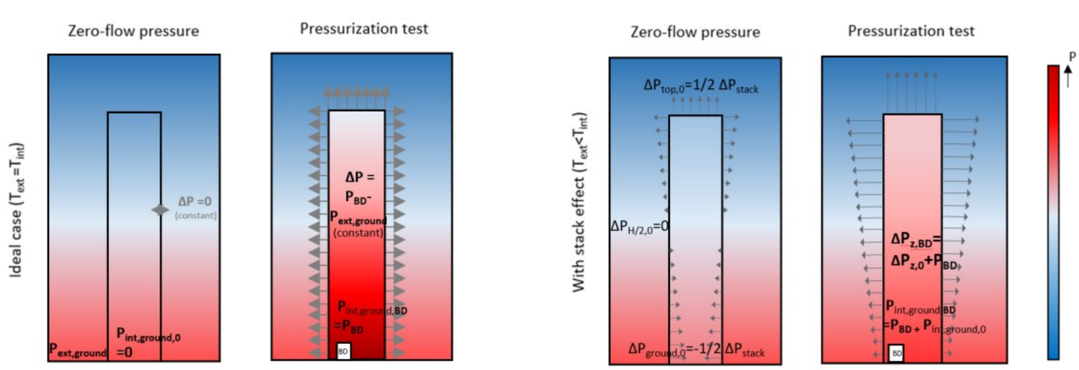




WHAT IS THE ISSUE WITH HIGH-RISE BUILDINGS?

1/ Stack effect

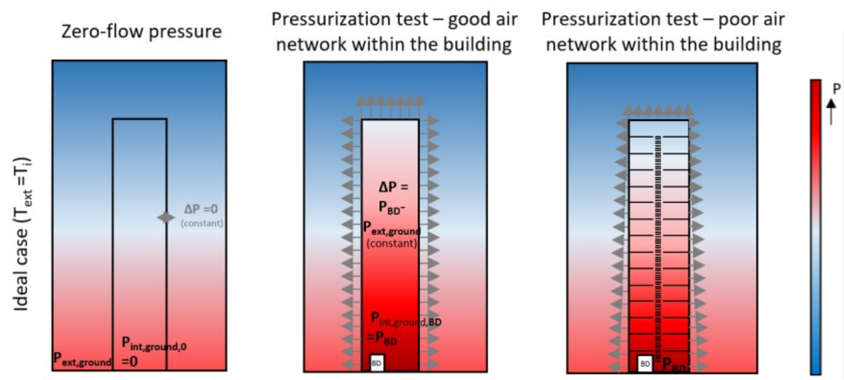
Induces significant **ΔP variations along the building's height**



WHAT IS THE ISSUE WITH HIGH-RISE BUILDINGS?

2/ Pressure loss through stairwell and circulation

Also induces significant **ΔP variations along the building's height**



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WEBINAR PROGRAMME

- 10:00 | Welcome & Introduction
  Valérie Leprince (Cerema, France)

- 10:05 | Challenges and experiences of airtightness tests in tall buildings
  Stefanie Rolfsmeier (BlowerDoor, Germany)
- 10:20 | Questions and answers

- 10:30 | ISO 9972 and constraints on zero flow pressure difference: a comprehensive study on the influence of stack effect
  Benedikt Kölsch (Cerema, France)
- 10:45 | Questions and answers

- 10:55 | Practical recommendations for airtightness tests in high-rise buildings
  Valérie Leprince and Nolwenn Hurel (Cerema, France)
- 11:10 | Questions and answers
- 11:30 | End of webinar

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Airtightness Tests in Tall Buildings

Challenges & Experiences

Presenter: Stefanie Rolfsmeier

TrIIIple Tower Vienna

Project Leader

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

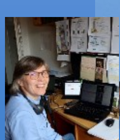
Partner

- *Johannes Neubig, Thomas Gayer, MA39, Stadt Wien*
- *Gary Nelson, Collin Olson, The Energy Conservatory*
- *Stefanie Rolfsmeier, BlowerDoor GmbH*

125 m – 115 m – 108 m

93 m

47 m



Lange Anna
Helgoland (Germany)

Triiiple Tower 3, 2, 1
Vienna (Austria)

Statue of Liberty
New York (USA)

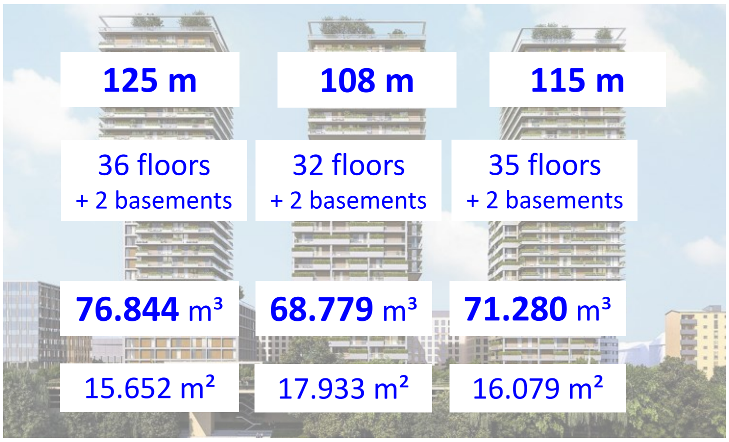
Agenda

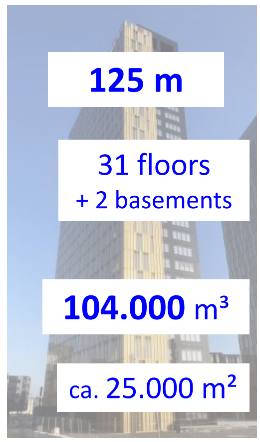
- Test Objects and Requirments
- Challenges, Needs, Worries
- Setup of test equipment
- Lessons learned and results
- Summary

Test Objects and Requirements

Test Objects

	Triiiple Tower 3	Triiiple Tower 2	Triiiple Tower 1	Building 4
h →	125 m	108 m	115 m	125 m
Floors →	36 floors + 2 basements	32 floors + 2 basements	35 floors + 2 basements	31 floors + 2 basements
V →	76.844 m^3	68.779 m^3	71.280 m^3	104.000 m^3
A_E →	15.652 m^2	17.933 m^2	16.079 m^2	ca. 25.000 m^2





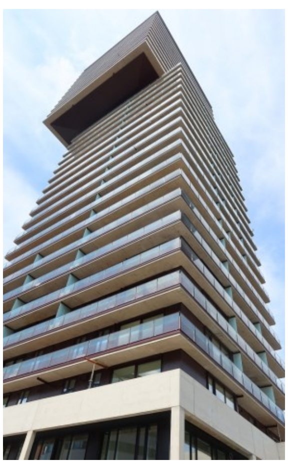
Requirements for building airtightness

Tower 3 | Tower 2 | Tower 1 | Building 4

Challenges

mzt Dr. Ronald Mischek ZT GmbH | Stadt Wien Prüf-, Inspektions- und Zertifizierungsstelle | BlowerDoor GmbH MessSysteme für Luftdichtheit | T·E·C THE ENERGY CONSERVATORY

Is it possible to measure high rise buildings?



Our Motivation:

Reduce leakages in building envelope

Learn more about how to test tall buildings

ISO 9972 is not developed for testing tall buildings, i. e.:

- "5 Pa" limit for the natural pressure difference
- lowest test point of multipoint test
- To achieve a uniform "induced" building pressure in the entire building generated by the test equipment

Share results and **experiences** to **develop** a **test procedure** that gives us **repeatable** and **reliable test results**

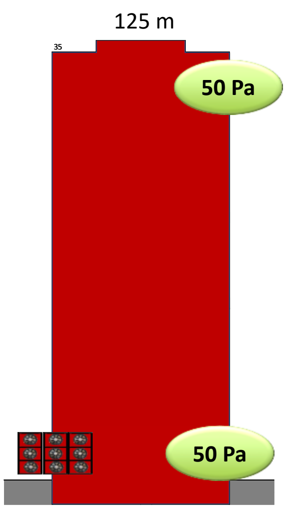
Where is the best place to install the measuring fans?

Best location(s) to install the measuring fans?

Exchange with:

Gary Nelson, Collin Olson
and Sören Peper, Wolfgang Hasper from PHI, colleagues from Vienna Universität

Is it possible to create a uniform induced pressure difference?



Single Zone Building

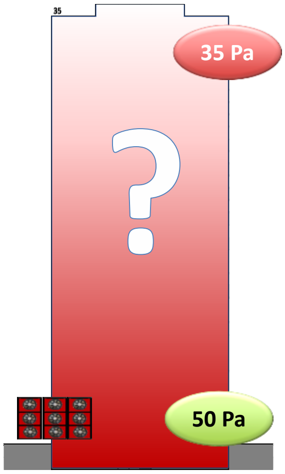
Is it possible to create a uniform induced pressure difference

("induced" only by measuring fans)
in the whole building?

Exchange with:

Gary Nelson, Collin Olson
and Sören Peper, Wolfgang Hasper from PHI, colleagues from Vienna Universität

What do we do if the induced building pressure is uneven?



How can we detect an uneven pressure distribution?

What are the reasons for a "pressure drop"?

What can we do, if we see this kind of "pressure drop"?

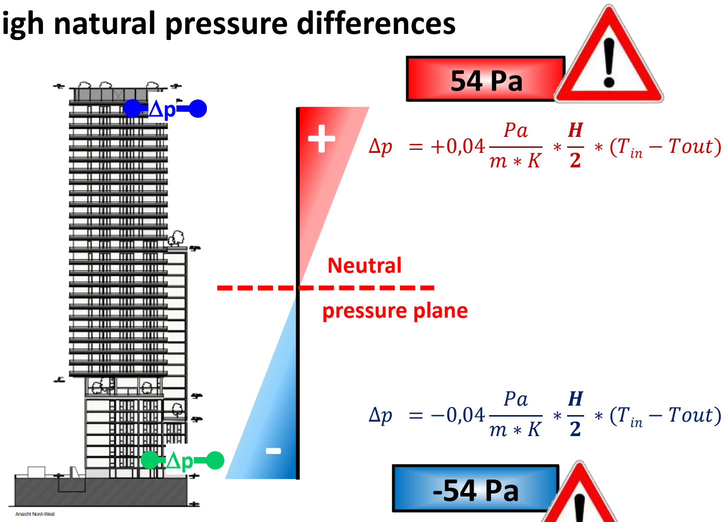
Exchange with:

Gary Nelson, Collin Olson
and Sören Peper, Wolfgang Hasper from PHI, colleagues from Vienna Universität

WORRY: Thermal lift can cause high natural pressure differences

ESTIMATION of ***natural building pressure*** some weeks **BEFORE** **the test.**
(Tower 3, Test in Feb. 2021)

- H = building height **125 m**
- T_{in} = inside temperature **20°C**
- T_{out} = outside temperature **-1.5°C**



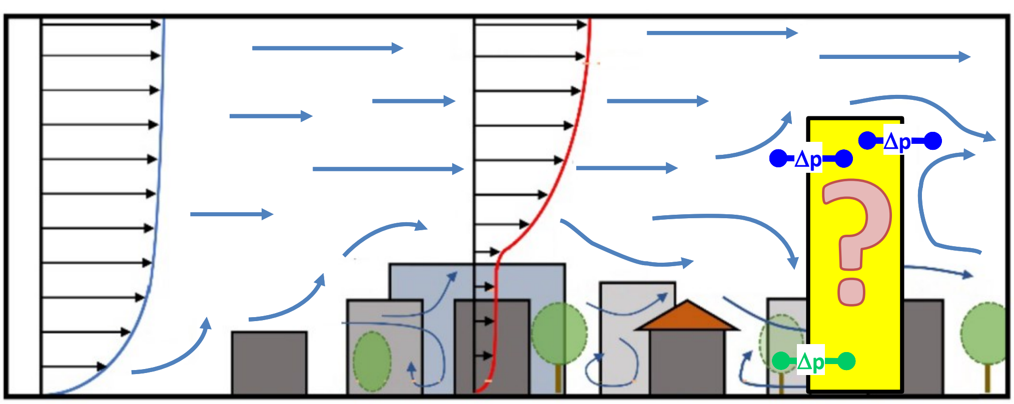
$$\Delta p = +0{,}04 \frac{Pa}{m * K} * \frac{\boldsymbol{H}}{\boldsymbol{2}} * (T_{in} - Tout)$$

$$\Delta p = -0{,}04 \frac{Pa}{m * K} * \frac{\boldsymbol{H}}{\boldsymbol{2}} * (T_{in} - Tout)$$

Source: Airtightness measurement of high-rise buildings, PHI

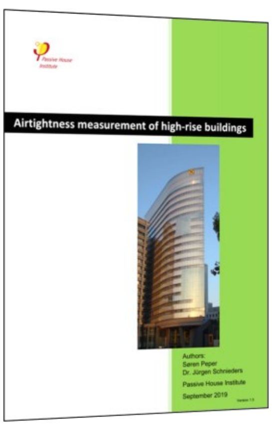
WORRY: Wind can lead to high nat. pressure differences with strong fluctuations

Wind

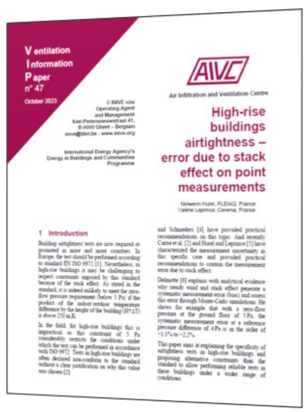


Source: Professur für Bauphysik – ETH Zürich: Wind bei Hochhäusern

Airtightness measurement of high-rise buildings

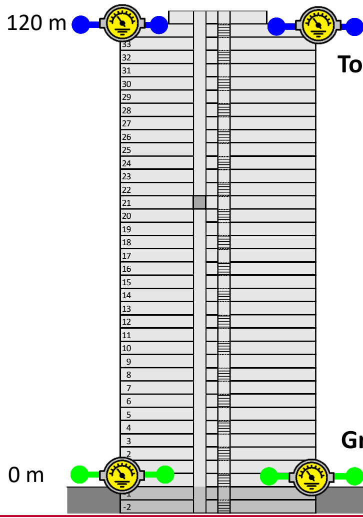


Airtightness Measurement of High-Rise Buildings Guidelines
from Søren Peper, Dr. Jürgen Schnieders
Passivhaus Institut, September 2019



High-rise buildings airtightness – error due to stack effect on point measurements
from Nolwenn Hurel, Valérie Leprince
AIVC VIP 47, 2023

Measure Pressure differences between inside and outside at Building Envelope

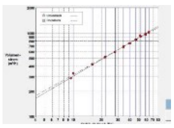


1 - 4 pressure differences between inside / ouside

(Building Sides: North, East, South, West)

What it is used for:

- See natural building pressure at the top of the building
- Ensure for each test point of the multipoint test:
  - building **pressure diff. negative** during **depressurization test**
  - **positive** during the **pressurization test**



What is it used for:

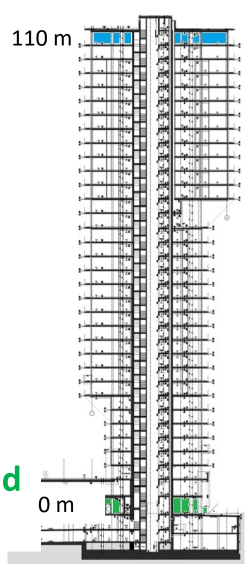
- Calculate the leakage graph (using the average pressure from all sides of building - if tested)
- See natural building pressure at the bottom of the building
- Ensure for each test point of the multipoint test:
  - building **pressure** diff. **negative** during **depressurization** test
  - **positive** during the **pressurization** test

1 - 4 envelope pressure diff. between inside / outside

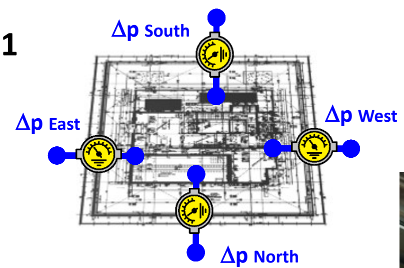
(Building Sides: North, East, South, West)

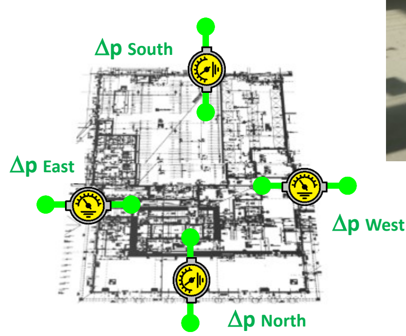
Example Triiiple Tower 1

33. Floor



Ground Floor





Fan Locations (Example: Triiipel Tower 3)

34. Floor

if needed

22. Floor

if needed

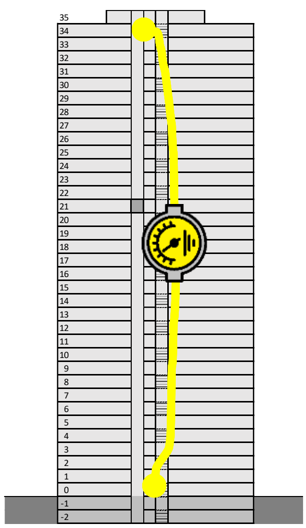
12. Floor

if needed

Ground Floor

Base Camp
main measuring station

Pressure Difference between two Points inside of Building "pressure drop"



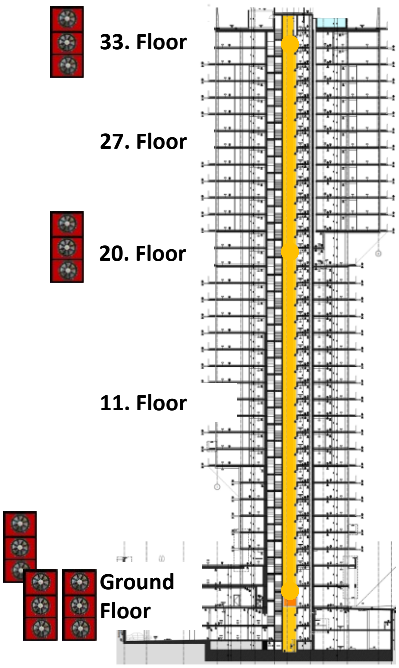
Internal

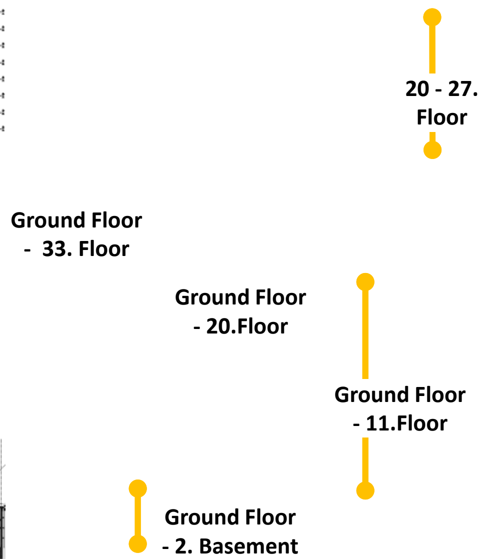
Check if there is a pressure drop of induced pressure

Target / Wish:

Ensure that pressure drop within the building is less than ≤ **10 %** of the induced building pressure (created only by the fans)

Triiiple Tower 1: Internal Pressure Differences





mzt Stadt Wien Prüf-, Inspektions- und Zertifizierungsstelle BlowerDoor GmbH MessSysteme für Luftdichtheit TEC THE ENERGY CONSERVATORY

Industrial climbers

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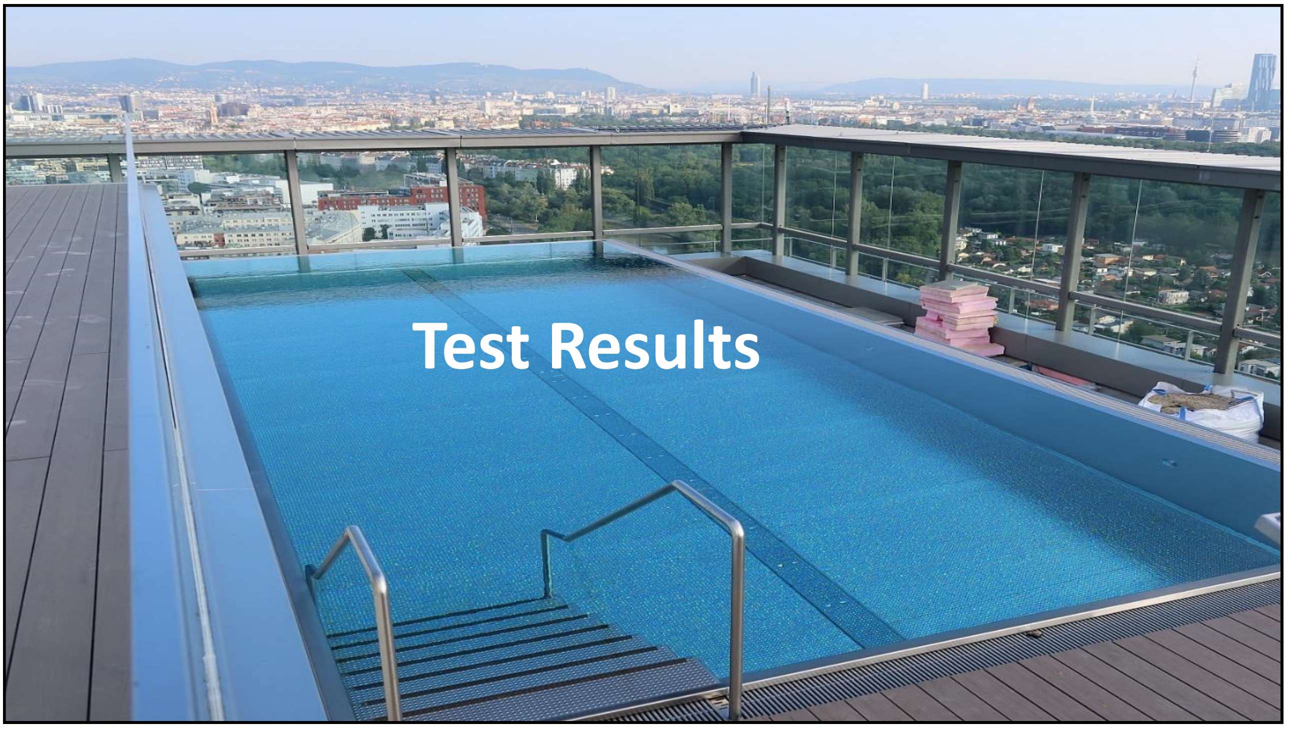
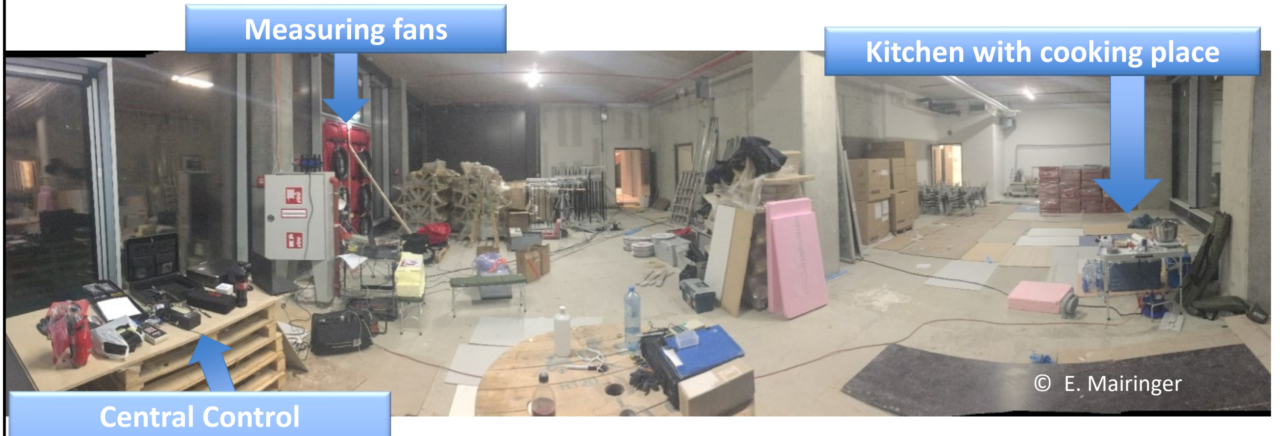


Test Results

	Triiiple Tower 3	Triiiple Tower 2	Triiiple Tower 2	Building 4
n_{50} →	**0.8** h^{-1}	**1.1** h^{-1}	**1.0** h^{-1}	**0.2** h^{-1}
q_{E50} →	**3.8** m³/hm²	**4.2** m³/hm²	**4.3** m³/hm²	**0.9** m³/hm²
q_{50} Depress. →	52700 m³/h	75970 m³/h	69937 m³/h	22700 m³/h
q_{50} Press. →	66800 m³/h	75760 m³/h	69222 m³/h	23000 m³/h

Base Camp (Ground Floor)



Number and Position of fans, depending on Quality of the Air Barrier

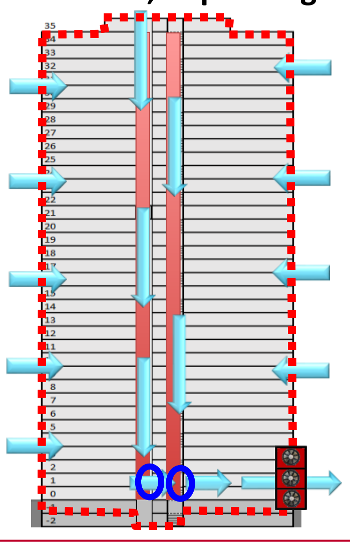
„leaky“ building envelope

Fans needed on higher floors

„Tight“ building envelope

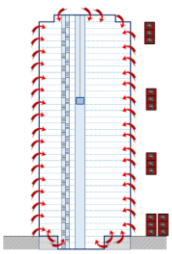
Fans required only on ground floor

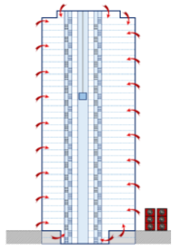
Position of fans, depending on Vertical / Horizontal AirFlow Paths / Openings



- **Single Zone building**
  → wish to test the entire building
- **vertical airflow paths**
  → **stairwells**
  → **lift shaft**
  (Challenge: Fall protection at the doors / Responsibility)
- **Horizontal airflow paths and openings**
  → openings / doors to the vertical paths
  → openings / doors from the vertical paths to fans

"Narrow" Stairwells and "Open" Stairwells





Poor distribution of the airflow due to:
„narrow"or „too few" stairwells / liftshaft and too small doors between fans and vertical flow pathes

Fans needed on higher floors

Good distribution of the air flow due to:
"large and wide" or "several" stairwells / elevator shafts"

Fans required only on ground floor

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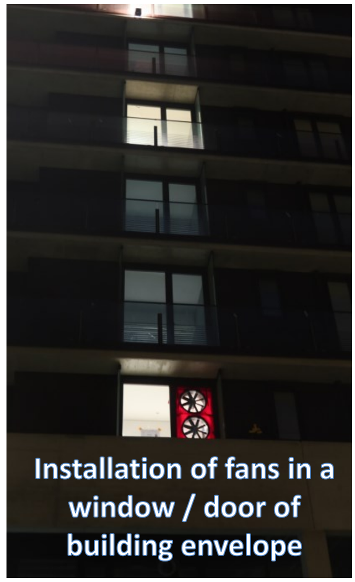
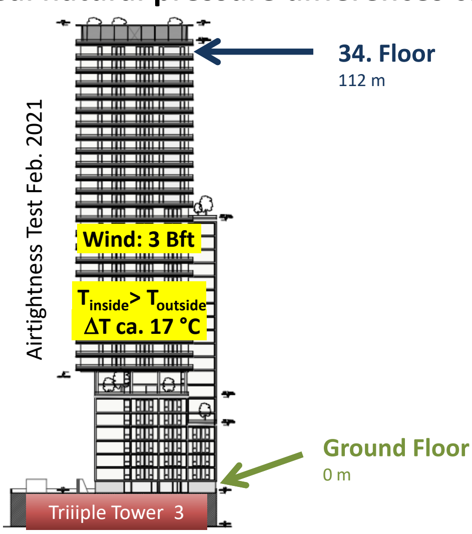
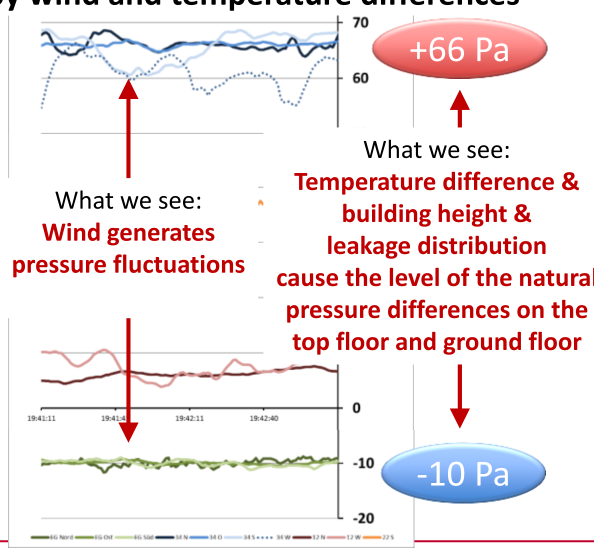
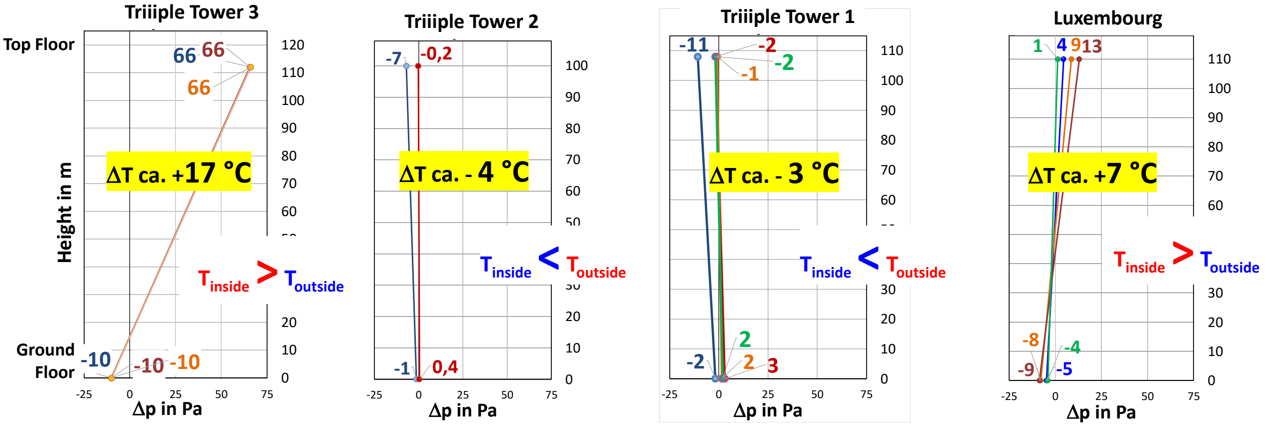


Real natural pressure differences caused by wind and temperature differences



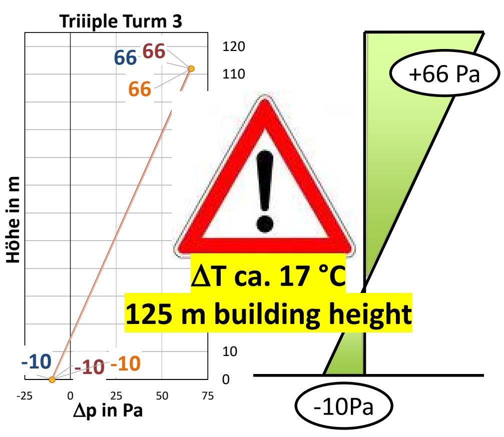


Impact of difference in Temperature and Building Height – Nat. Δp MEASURED



What we see: **The smaller the temperature differences between inside and outside, the lower the baseline pressure on the ground floor and top floor**

Impact of Natural Pressure differences on Lowest Test point of Multipoint Test



Baseline pressure on ground floor and top floor form the lowest test point of multipoint test

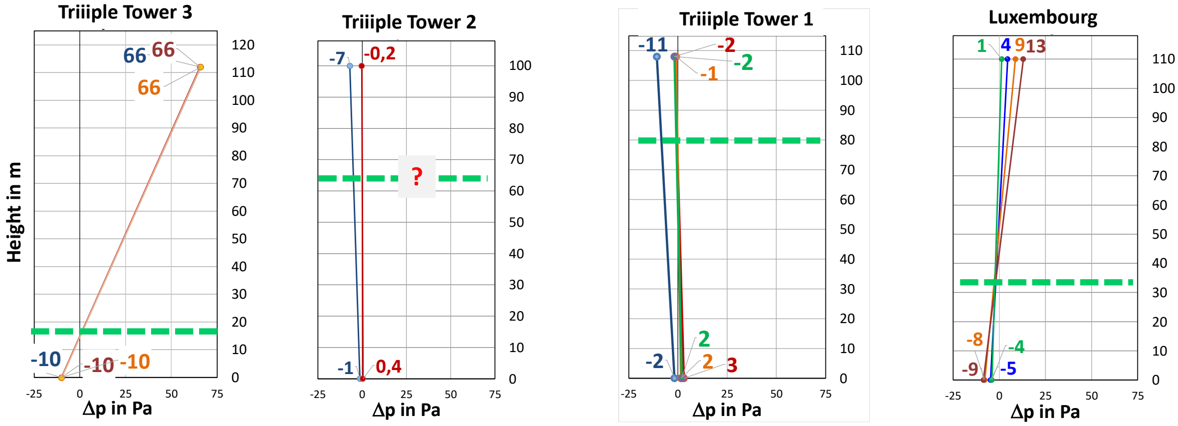
- Depressurization test: Air must leak into the building also on the top floor –building pressure must be negative over entire height
  → Lowest test point here: **-76 Pa + Buffer**
- Pepressurization test: Air must leak out of the building also on the ground floor → positive building pressure over entire height:
  → Lowest test point here: -0 Pa + Buffer

Recommendation:

building height x temperature difference ≤ ca. 1250 mK

Example for a 100 m high building:
temperature difference of between inside and outside 12.5 °C This
→can cause -25 Pa (ground floor) and + 25 Pa (top floor)

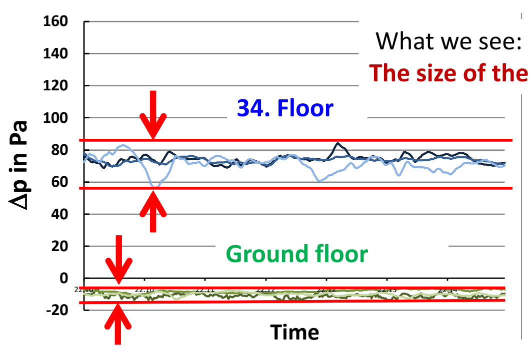
Effect of leakage distribution over the height of the building



Neutral pressure plane is NOT located in the middle of the building

Wind-induced pressure fluctuations (Triiiple Tower 3, wind force 3 Bft)

Natural Building pressure differences



What we see:
The size of the pressure fluctuations increases on higher floors

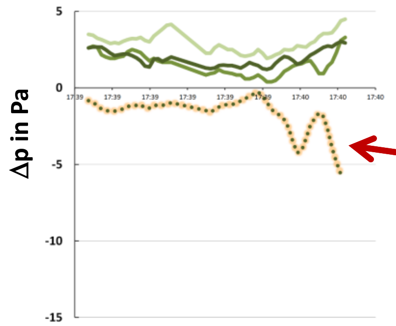
Recommendation:

- **Install the fans on the ground floor level**
  → Measuring Fans see smaller pressure fluctuations
- **Only test at Wind force ≤ 3 Beaufort**
- **At windy conditions increase measuring time per test point (e.g. 60 s -120 s)**

Impact of the wind direction (Triiiple Tower 1)

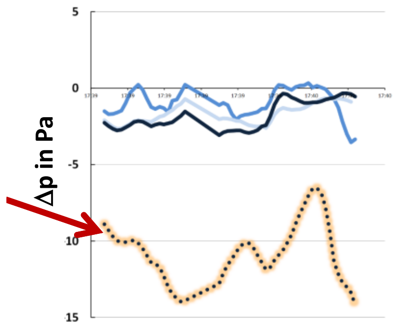
Natural building pressure differences on the four sides of the building (North, East, South, West)

Ground Floor



What we see:
fluctuations and pressures are highest windward side of building

33. Floor



Recommendation: **If possible, install the test equipment NOT on windward side of building**

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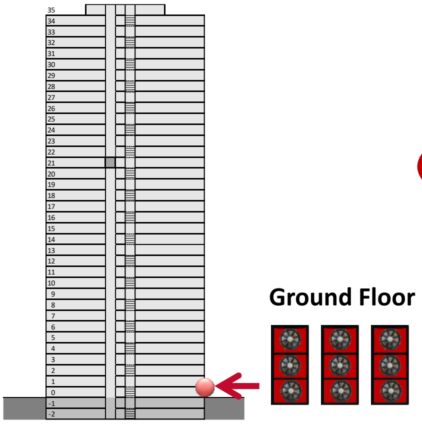
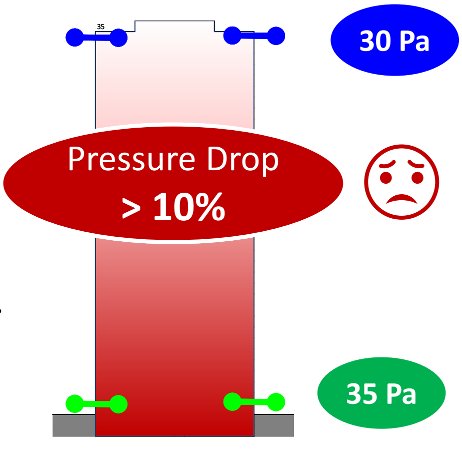
Situation: Pressure Drop (between two points inside the building) > 10 %

Setup Fans



Induced Pressure Difference



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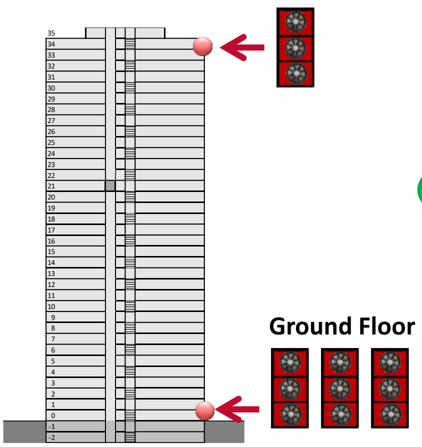
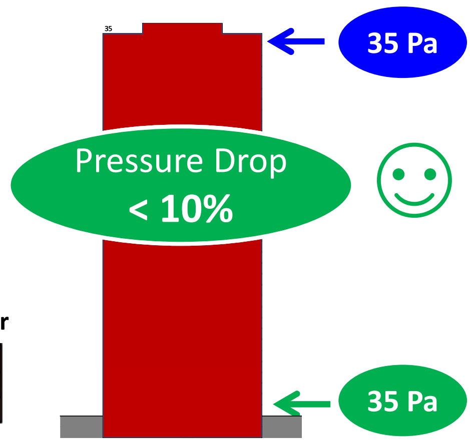
Solution: Activate fans on upper floors

Setup Fans



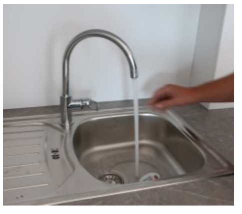
Induced Pressure Difference



- Manpower - Womanpower - and More -

Time needed to measure one Building

- Several online meetings to plan the test setup
- Several construction site visits and pretests of individual rooms
- Three days to carry out one test (and the nights...)
  - First day setup of test equipment and building preparation
  - Second day rest of setup, 50 Pa Leakage detection, Multipoint tests
  - Third day take down of test equipment



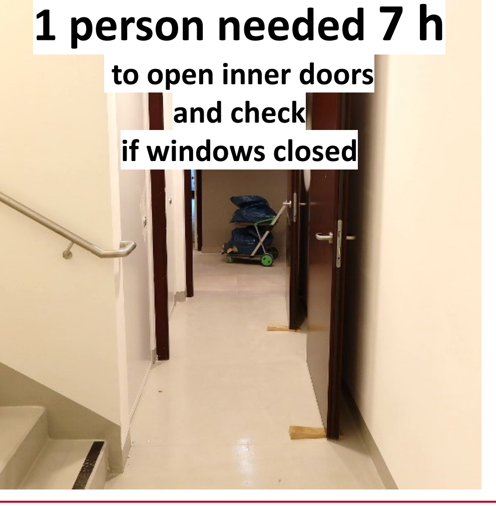
Building preparation

Triiiple Tower 3

1200

timber wedges to fix self-closing doors open

Triiiple Tower 1



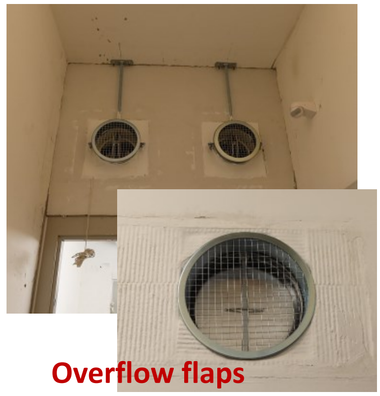
Challenge to check all Openings and Leaks in the Building Envelope

Humidity-controlled supply air elements

28 – 40 m³/h per element & r. H. in 280 to 670 apartments

Fire protection devices top floor

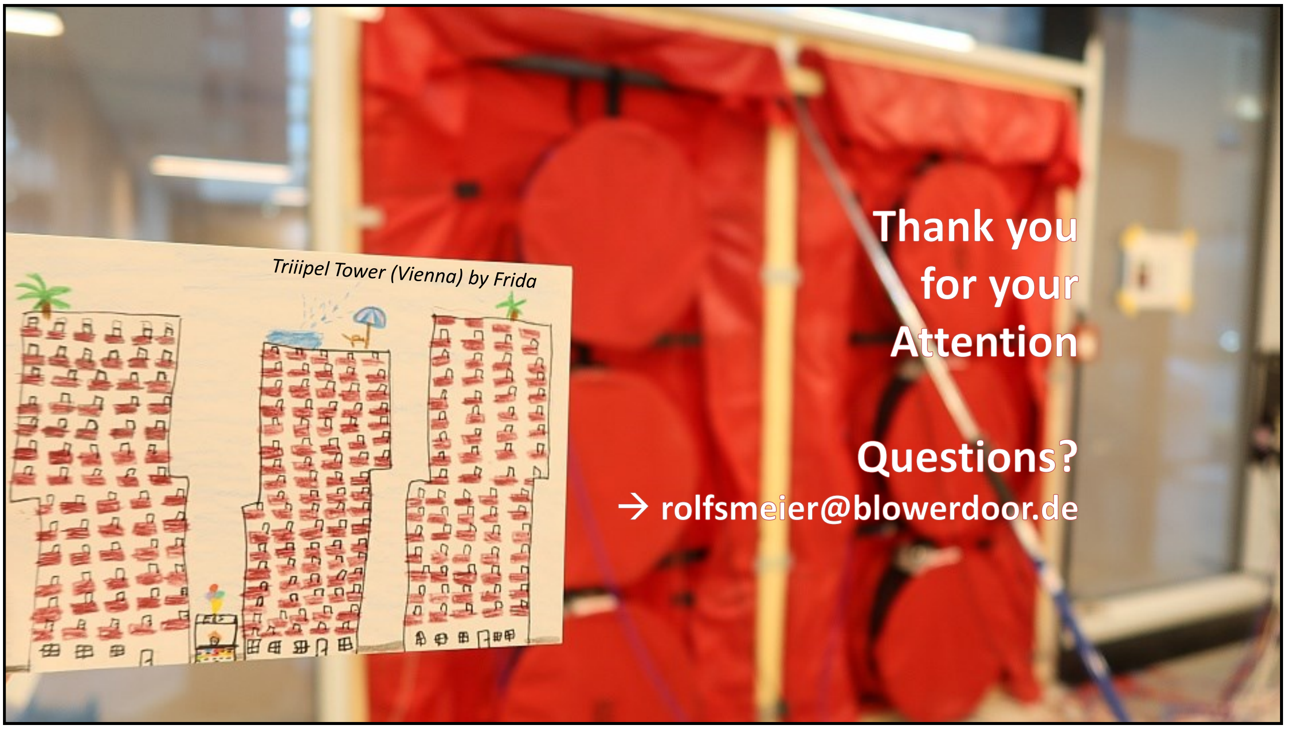
Fire dampers in basements



Overflow flaps (stairwell airlocks)

Summary

- Airtightness tests of high-rise buildings around 100 m high are possible (*"Guidling PHI → good basis)*
- Buildings with good airtightness and large airflow paths easier to test
- Additional test points for building pressure differences at top floor level and ground floor level
  - to ensure negative pressure throughout the building during depressurization test
  - to ensure positive pressure throughout the building during pressurization test
  - in windy conditions test points on all 4 sides of the building
- Check pressure drop ≤ 10 % of induced building pressure (if larger add fans in zone with pressure drop)
- Wind ≤ 3 BFT (*for windy weather increase sample interval per target pressure e. g. 60 sec.*)
- Product of difference in temperature and building height ≤ 1250 mK
  → 125 m tall buildings: ΔT between inside and outside max. 8-10 K
- Take average q_{50} of depressurization and pressurization test
  to compensate the uneven pressure distribution due to impact of wind and thermal lift


Triiipel Tower (Vienna) by Frida
Thank you
for your
Attention
Questions?
→ rolfsmeier@blowerdoor.de

ISO 9972 AND CONSTRAINTS ON ZERO-FLOW PRESSURE DIFFERENCE

A comprehensive study on the influence of stack effects

AIVC Webinar – Airtightness tests for high-rise buildings – 26.01.2024

Benedikt Kölsch

ISO 9972: FAN PRESURIZATION METHOD

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN ISO 9972

September 2015

ICS: 91.120.10

Supersedes EN 13829:2000

English Version

Thermal performance of buildings — Determination of air permeability of buildings — Fan presurization method
(ISO 9972:2015)

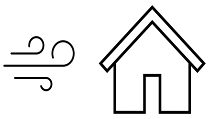
Performance thermique des bâtiments — Détermination de la perméabilité à l'air des bâtiments — Méthode de pressurisation par ventilateur
(ISO 9972:2015)

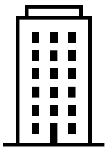
Wärmetechnisches Verhalten von Gebäuden — Bestimmung der Luftdurchlässigkeit von Gebäuden — Differenzdruckverfahren
(ISO 9972:2015)

ISO CONSTRAINTS

Zero-Flow Pressure Differences

- Δp_0 = Pressure difference between inside and outside when a building is not artificially pressurized
- ISO 9972 defines constraints to limit the influence of wind + temperatures
- Constraints for valid measurements:
    1. **$|\Delta p_0| < 5$ Pa**
    2. **Lowest Δp_{st} = 10 Pa** or **5 x $|\Delta p_0|$**





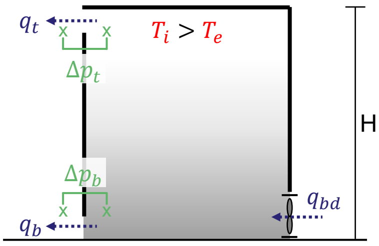
ISO CONSTRAINTS EXCLUDE MANY BUILDINGS FROM BEING TESTED!

Understanding airflow errors and effectiveness of ISO constraints:

- What is the **error of the measured airflow** induced by Δp_0?
- Which **parameters influence Δp_0** in detail?
- Does **pressure tap position** have an influence on Δp_0 ?
- Are there **alternative constraints** that could be applied when the ones in ISO 9972 are impossible to reach (e.g., for high-rise buildings)?

?

STACK EFFECT MODEL



Stack

UNDERSTANDING ZERO-FLOW PRESSURE

Stack measurement position of Δp_0

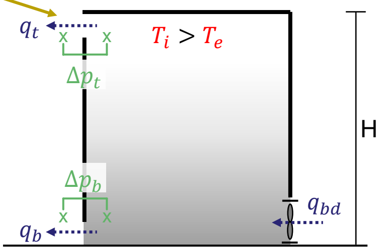
$$\Delta p_{0,s} = -\frac{p_s}{1 + 1/z_s^{1/n}}$$

$$p_s \approx \frac{\rho_0}{T_0} g\, \Delta T\, H$$

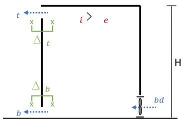
$$z_s = \frac{C_t}{C_b}$$

- Always **negative**
- Depends on:
  - Temperature difference
  - Building height
  - Pressure exponent
  - Leakage distribution

$$\Delta p_t = \Delta p_b + p_s$$



ISO 9972 AIRFLOW ERROR



Calculation procedure and assumptions in ISO 9972:

Correction of the measured pressure station with Δp_0:

$$q_{est} = C_{est}(\Delta p_{st} - \Delta p_0)^n$$

Contrary to the assumption in ISO 9972:

$$C_{est}(\Delta p_{st} - \Delta p_0)^n = C_b\,\Delta p_b^n + C_t(\Delta p_b - p_s)$$

$$C_{est} \neq C_{real} = C_b + C_t$$

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Airflow error:

$$\frac{\delta q}{q} = \frac{C_{est} - C_{real}}{C_{real}} = \frac{C_{est}(\Delta p_{st} - \Delta p_0)^n}{C_{real}(\Delta p_{st} - \Delta p_0)^n} - 1 = \frac{C_b\,\Delta p_b^n + C_t(\Delta p_b - p_s)}{C_{real}(\Delta p_{st} - \Delta p_0)^n} - 1$$

UNDERSTANDING ZERO-FLOW PRESSURE

Stack measurement position of Δp_0

$$\Delta p_{0,s} = -\frac{p_s}{1 + 1/z_s^{1/n}}$$

$$p_s \approx \frac{\rho_0}{T_0} g\,\Delta T\,H$$

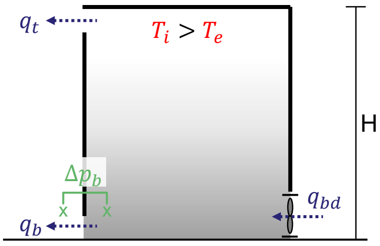
$$z_s = \frac{C_t}{C_b}$$

Airflow error:

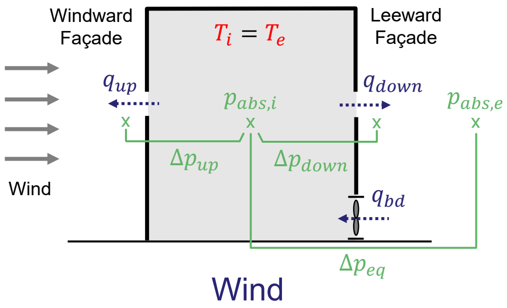
$$\left.\frac{\delta q}{q}\right|_s = \frac{C_b\,\Delta p_b^n + C_t(\Delta p_b - p_s)}{C_{real}(\Delta p_{st} - \Delta p_0)^n} - 1$$

$$x_s = \frac{p_s}{\Delta p_{st}}$$

$$\left.\frac{\delta q}{q}\right|_s = \frac{1 + z_s(1 + x_s)^n}{(1 + z_s)\left(1 + \frac{x_s}{1 + 1/z_s^{1/n}}\right)^n} - 1 \qquad (\Delta p_b = \Delta p_{st})$$

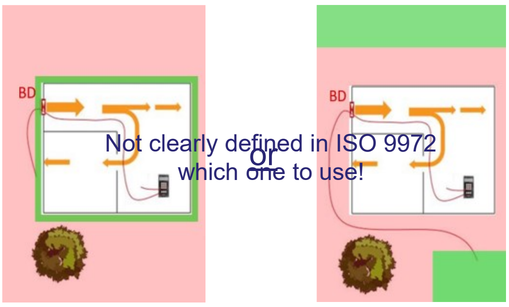


WIND MODEL – PRESSURE TAP POSITIONS



Next to the building

Further away from the building



Pressure difference across envelope

Equilibrium internal pressure

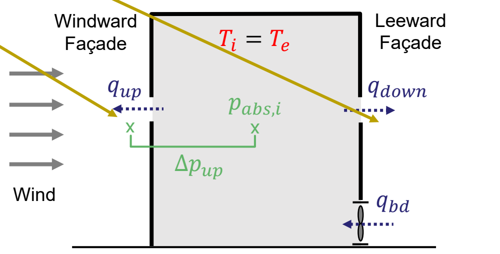
UNDERSTANDING ZERO-FLOW PRESSURE

Upwind measurement position of Δp_0

$$\Delta p_{0,up} = -\frac{p_{up} - p_{down}}{1 + 1/z_w^{1/n}} \qquad z_w = \frac{C_{down}}{C_{up}}$$

- Always **negative**
- Depends on:
  - Upwind pressure
  - Downwind pressure
  - Pressure exponent
  - Leakage distribution

$$q = C\,\Delta p^n$$



$$p_{up} = C_{p,up}\frac{\rho_0}{2}u^2 \qquad p_{down} = C_{p,down}\frac{\rho_0}{2}u^2$$

UNDERSTANDING ZERO-FLOW PRESSURE

Upwind measurement position of Δp_0

$$\Delta p_{0,up} = -\frac{p_{up} - p_{down}}{1 + 1/z_w^{1/n}}$$

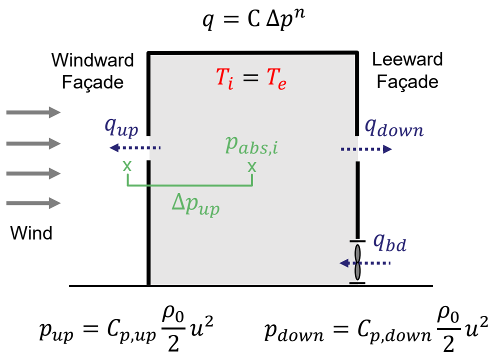
$$z_w = \frac{C_{down}}{C_{up}}$$

$$x_w = \frac{p_{up} - p_{down}}{\Delta p_{st}}$$

Airflow error:

$$\frac{\delta q}{q}_{w,up} = \frac{C_{est,w,up} - C_{real,w}}{C_{real,w}}$$

$$= \frac{1 + z_w(1 + x_w)^n}{(1 + z_w)\left(1 + \frac{x_w}{1 + 1/z_w^{1/n}}\right)^n} - 1$$



UNDERSTANDING ZERO-FLOW PRESSURE

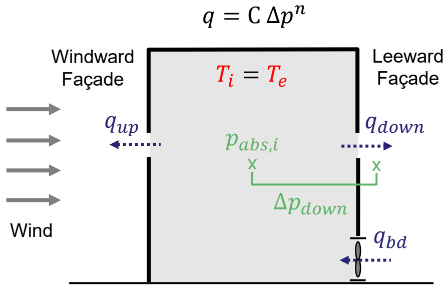
Downwind measurement position of Δp_0

$$\Delta p_{0,down} = \frac{p_{up} - p_{down}}{1 + z_w^{1/n}} \qquad \Delta p_{0,up} = -\frac{p_{up} - p_{down}}{1 + 1/z_w^{1/n}}$$

- Always **positive**

Airflow error:

$$\frac{\delta q}{q}_{w,down} = \frac{z_w + (1 - x_w)^n}{(1 + z_w)\left(1 - \frac{x_w}{1 + z_w^{1/n}}\right)^n} - 1$$

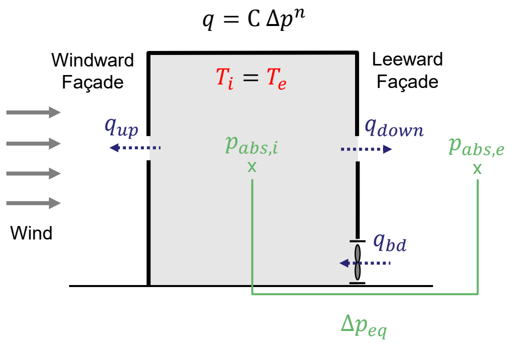


UNDERSTANDING ZERO-FLOW PRESSURE

Equilibrium measurement position of Δp_0

$$\Delta p_{0,w,eq} = \frac{p_{up} + z_w^{1/n} p_{down}}{1 + z_w^{1/n}} \qquad z_w = \frac{C_{down}}{C_{up}}$$

- Can be **positive** or **negative** depending on the **leakage distribution!**



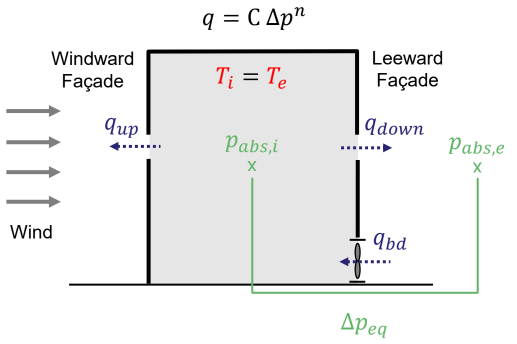
UNDERSTANDING ZERO-FLOW PRESSURE

Equilibrium measurement position of Δp_0

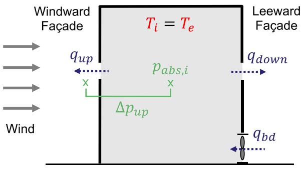
$$\Delta p_{0,w,eq} = \frac{p_{up} + z_w^{1/n} p_{down}}{1 + z_w^{1/n}}$$

Airflow error:

$$\frac{\delta q}{q}_{w,eq} = \frac{\left(1 - x_{w,up}\right)^n + z_w\left(1 - x_{w,down}\right)^n}{\left(1 + z_w\right)\left(1 - \frac{x_{w,up} + z_w^{1/n} x_{w,down}}{1 + z_w^{1/n}}\right)^n} - 1$$



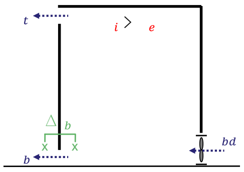
UNDERSTANDING ZERO-FLOW PRESSURE



Wind

$$\frac{\delta q}{q} = \frac{1 + z(1+x)^n}{(1+z)\left(1 + \frac{x}{1+1/z^{1/n}}\right)^n} - 1$$

$$\Delta p_{zf} = -\frac{p_{force}}{1+1/z^{1/n}}$$



Stack

$$p_{force,w,up} = p_{up} - p_{down}$$

$$x_w = \frac{p_{force,w}}{\Delta p_{st}}$$

$$z_w = \frac{C_{down}}{C_{up}}$$

$$p_{force,s} = p_s \approx \frac{\rho_0}{T_0} g\, \Delta T\, H$$

$$x_s = \frac{p_{force,s}}{\Delta p_{st}}$$

$$z_s = \frac{C_t}{C_b}$$

SIMULATION OF VARIOUS BUILDING SCENARIOS

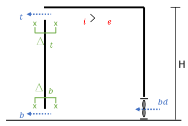
Range of parameters

Input variable	Min. value	Max. value	Distribution characteristics
$\boldsymbol{n}$	0.5	0.9	Linear distribution in steps of 0.1
$\Delta \boldsymbol{p}_{st,pres/depres}$	± 10 Pa	± 100 Pa	Linear distribution in steps of 10 Pa
$\boldsymbol{u}$	0 m/s	10 m/s	Linear distribution in steps of 0.1 m/s
$\boldsymbol{z}$	1/99	99	Logarithmic distribution with 100 values
$\boldsymbol{\Delta T}$	1 K	20 K	Linear distribution in steps of 1 K (always $T_i > T_e$)
$\boldsymbol{H}$	4 m	100 m	Linear distribution in steps of 1 m
$\boldsymbol{C}_{p,down}$	–	–	$[-0.3, -0.5, -0.7]$
$\boldsymbol{C}_{p,up}$	–	–	$[0.05, 0.25, 0.5]$

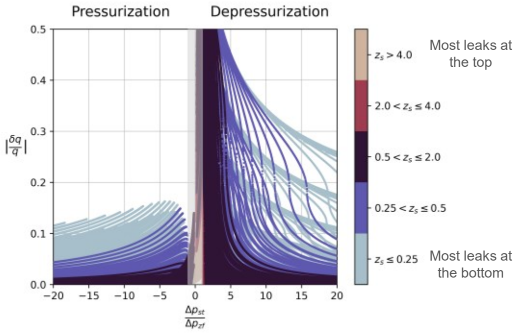
3 million wind and 7 million stack pressure scenarios!

KEY FINDINGS

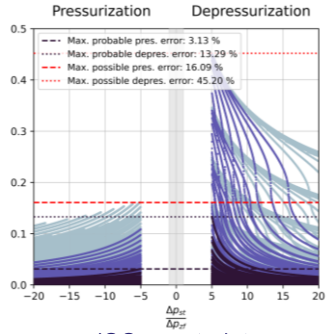
$$z_w = \frac{C_t}{C_b}$$



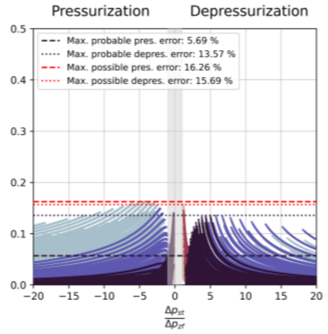
Stack measurement position of Δp_0



Full dataset



ISO constraints



Alternative

→ Fully pres/depres building with a margin of 10 Pa!

$|\Delta p_0| < 5$ Pa

$|\Delta p_{st,low}| > 5 \times |\Delta p_0|$

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ISO 9972 & Zero-flow pressure

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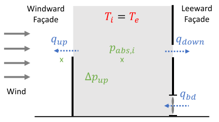
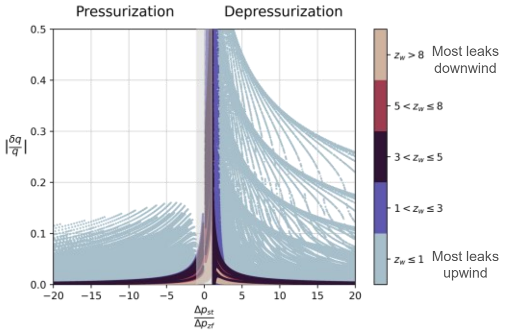
KEY FINDINGS

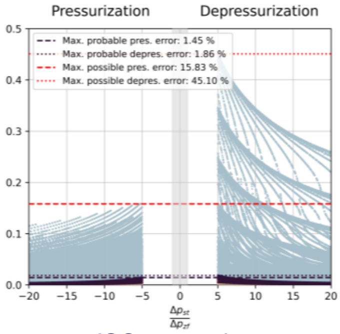
$$z_w = \frac{C_{down}}{C_{up}}$$



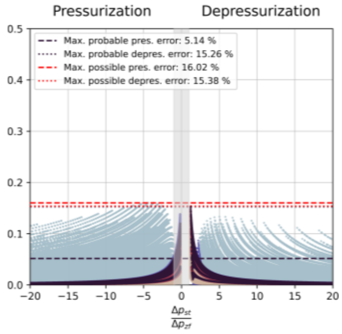
Upwind measurement position of Δp_0



Full dataset



ISO constraints



Alternative

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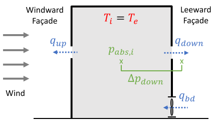
ISO 9972 & Zero-flow pressure

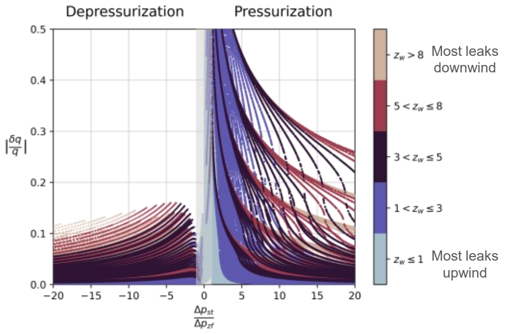
18

KEY FINDINGS

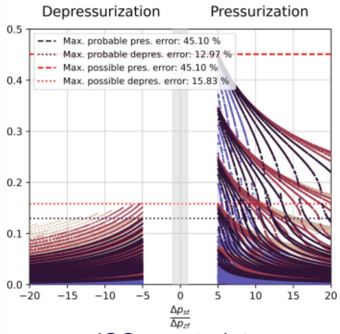
$$z_w = \frac{C_{down}}{C_{up}}$$



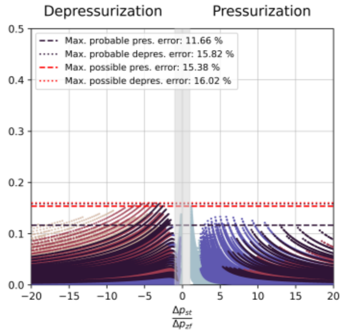
Downwind measurement position of Δp_0



Full dataset



ISO constraints

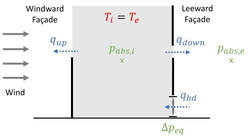


Alternative

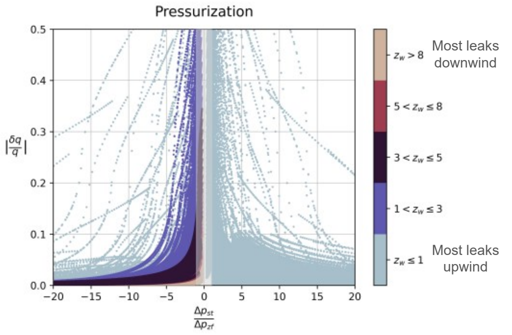
→ Fully pres/depres building with a margin of 10 Pa!

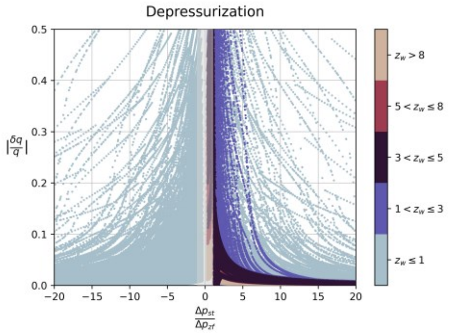
KEY FINDINGS

$$z_w = \frac{C_{down}}{C_{up}}$$



Equilibrium measurement position of Δp_0





KEY FINDINGS

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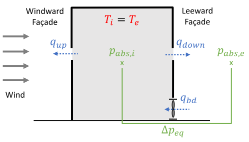
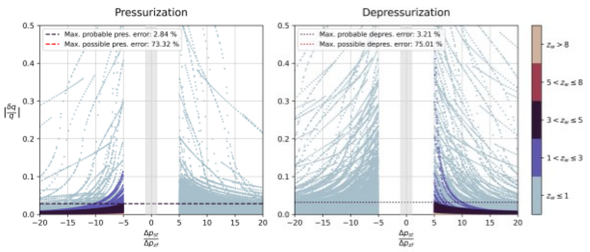
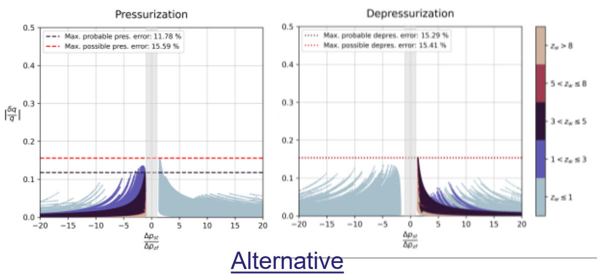


Equilibrium measurement position of Δp_0



ISO constraints



Alternative

→ Fully pres/depres building with a margin of 10 Pa!

SUMMARY AND CONCLUSION

- ISO 9972 constraints reduce significant flow errors
- High-rise buildings or buildings in windy locations are often impossible to test

SUMMARY AND CONCLUSION

<u>Alternative</u>: Pressurizing or depressurizing the entire building with a margin of 10 Pa would → same range of error!

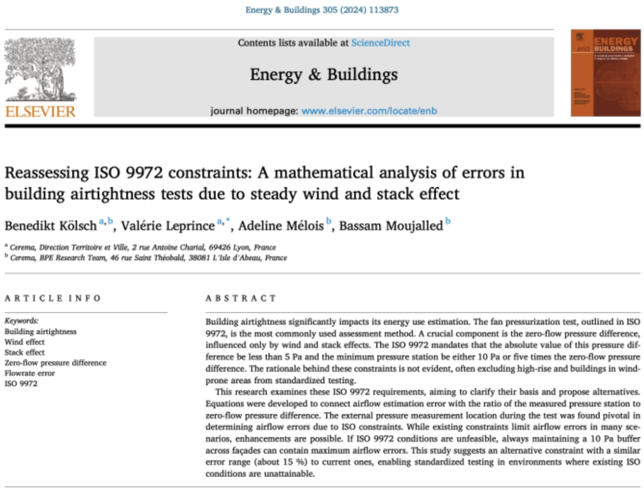
Max. <u>probable</u> error:

	Pressurization				Depressurization			
	Downwind	Upwind	Equilibirum	Stack	Downwind	Upwind	Equilibirum	Stack
ISO constraint	45%	1%	3%	3%	13%	2%	3%	13%
New constraint	12%	5%	12%	6%	16%	15%	15%	14%

Max. <u>possible</u> error:

	Pressurization				Depressurization			
	Downwind	Upwind	Equilibirum	Stack	Downwind	Upwind	Equilibirum	Stack
ISO constraint	45%	16%	73%	16%	16%	45%	75%	45%
New constraint	15%	16%	16%	16%	16%	15%	15%	16%

PUBLICATION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Reassessing ISO 9972 constraints: A mathematical analysis of errors in building airtightness tests due to steady wind and stack effect

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Stack effect
Zero-flow pressure difference
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ISO 9972

ABSTRACT

Building airtightness significantly impacts its energy use estimation. The fan pressurization test, outlined in ISO 9972, is the most commonly used assessment method. A crucial component is the zero-flow pressure difference, influenced only by wind and stack effects. The ISO 9972 mandates that the absolute value of this pressure difference be less than 5 Pa and the minimum pressure station be either 10 Pa or five times the zero-flow pressure difference. The rationale behind these constraints is not evident, often excluding high-rise and buildings in wind-prone areas from standardized testing.

This research examines these ISO 9972 requirements, aiming to clarify their basis and propose alternatives. Equations were developed to connect airflow estimation error with the ratio of the measured pressure station to zero-flow pressure difference. The external pressure measurement location during the test was found pivotal in determining airflow errors due to ISO constraints. While existing constraints limit airflow errors in many scenarios, enhancements are possible. If ISO 9972 conditions are unfeasible, always maintaining a 10 Pa buffer across façades can contain maximum airflow errors. This study suggests an alternative constraint with a similar error range (about 15 %) to current ones, enabling standardized testing in environments where existing ISO conditions are unattainable.

QUESTIONS?

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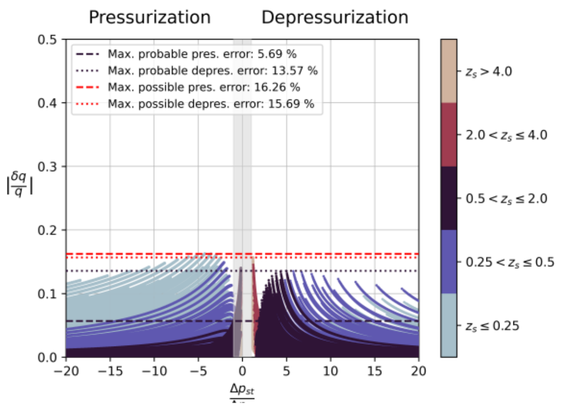

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PRACTICAL RECOMMENDATIONS FOR AIRTIGHTNESS TESTS IN HIGH-RISE BUILDINGS

AIVC/TightVent Webinar – 26 January 2024

Valérie Leprince & Nolwenn Hurel, Cerema

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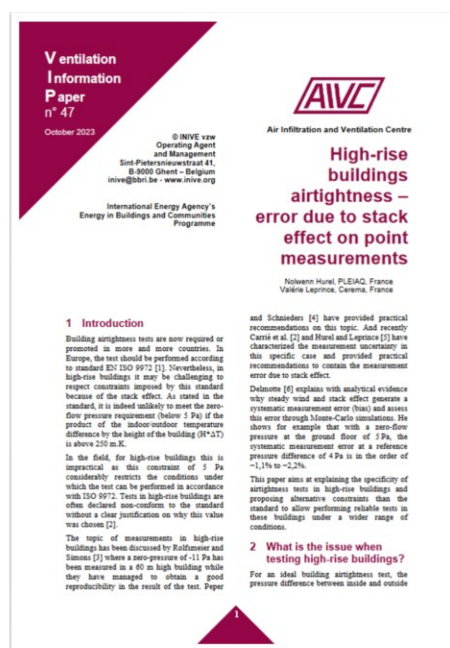
AIVC PUBLICATION

VIP 47: **High-rise buildings airtightness – error due to stack effect on point measurements**
(Hurel & Leprince, 2023)

- **New criteria** for high-rise buildings
- **Analysis of the error** due to stack effect
- **New test methodology**
- **Practical recommendations**

Focus of this presentation



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International Energy Agency's
Energy in Buildings and Communities
Programme

AIVC
Air Infiltration and Ventilation Centre

High-rise buildings airtightness – error due to stack effect on point measurements

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1 Introduction

Building airtightness tests are now required or promoted in more and more countries. In Europe, the test should be performed according to standard EN ISO 9972 [1]. Nevertheless, in high-rise buildings it may be challenging to respect constraints imposed by this standard because of the stack effect. As stated in the standard, it is indeed unlikely to meet the zero-flow pressure requirement (below 5 Pa) if the product of the indoor/outdoor temperature difference by the height of the building (H*ΔT) is above 250 m.K.

In the field, for high-rise buildings this is impractical as this constraint of 5 Pa considerably restricts the conditions under which the test can be performed in accordance with ISO 9972. Tests in high-rise buildings are often declared non-conform to the standard without a clear justification on why this value was chosen [2].

The topic of measurements in high-rise buildings has been discussed by Rolfsmeier and Simons [3] where a zero-pressure of -11 Pa has been measured in a 60 m high building while they have managed to obtain a good reproducibility in the result of the test. Peper and Schnieders [4] have provided practical recommendations on this topic. And recently Carrié et al. [2] and Hurel and Leprince [5] have characterized the measurement uncertainty in this specific case and provided practical recommendations to contain the measurement error due to stack effect.

Delmotte [6] explains with analytical evidence why steady wind and stack effect generate a systematic measurement error (bias) and assess this error through Monte-Carlo simulations. He shows for example that with a zero-flow pressure at the ground floor of 5 Pa, the systematic measurement error at a reference pressure difference of 4 Pa is in the order of −1,1% to −2,2%.

This paper aims at explaining the specificity of airtightness tests in high-rise buildings and proposing alternative constraints than the standard to allow performing reliable tests in these buildings under a wider range of conditions.

2 What is the issue when testing high-rise buildings?

For an ideal building airtightness test, the pressure difference between inside and outside

1

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2

New criteria

Error due to stack effect

Test methodology & practical advices

CONFLICTS WITH STANDARD ISO 9972

Some criteria are difficult to meet:

- **Zero-flow pressure measurements:** $|\Delta P_{0,ground}| < 5$ Pa
  - 50 m high building, $|\Delta P_{0,ground}| < 5$ Pa → $\Delta T < 4.5°C$
- **Lowest pressure station** $> 5 \times |\Delta P_{0,ground}|$
  - 50 m high building, $\Delta T = 15°C$ → $|\Delta P_{s,ground}| > 82$ Pa
- **Single zone:** "*The entire building or part of the building to be tested shall respond to pressurization as a single zone*"
  → Challenging as for any large building


FINAL DRAFT
INTERNATIONAL STANDARD
ISO/FDIS 9972
Thermal performance of buildings — Determination of air permeability of buildings — Fan pressurization method

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NEW CRITERIA SUGGESTED

Standard ISO 9972

- **Zero-flow pressure measurements:**
  $|\Delta P_{0,ground}| < 5$ Pa

- **Lowest pressure station**
  $|\Delta P_{s,ground}| > 5 \times |\Delta P_{0,ground}|$

New criteria suggested (high-rise)

- **Zero-flow pressure measurements:**
  standard deviation < 5 Pa

- **Averaging pressurization & depressurization tests**

- **Entire building pressurized/depressurized**
  with a margin of 10 Pa (ideally)

- **Limit on the stack effect:** $H \times \Delta T < 2000$ m.K
  (Ideally < 1250 m.K for multiple points < 100 Pa)

- New criteria
- **Error due to stack effect**
- Test methodology & practical advices

ERROR DUE TO STACK EFFECT

Maximum error: on the **1st pressure** measurement station

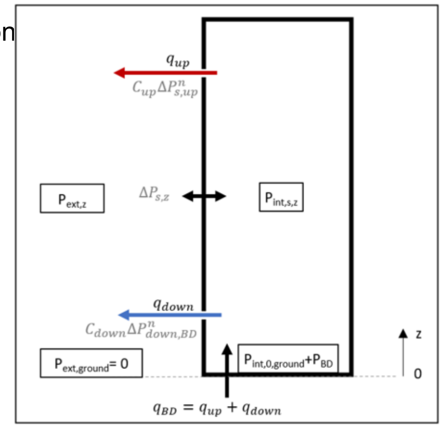
Parameter study:

- ISO criteria
- New criteria

Stack effect (H x ΔT)
Min: 50 m.K
Max: 2000 m.K
Step: 50 m.K

Leakage distrib. (C_{up}/C_t)
Min: 0
Max: 1
Step: 0,01

- Pressurization
- Depressurization
- Average



ERROR DUE TO STACK EFFECT

Main results:

Standard ISO 9972

- H*ΔT > 1000 m.K. : Test possible for **< 20%** of simulated configurations

New criteria suggested

- Test possible for **every leakage distribution**

→ Increased possibilities of tests

- Maximum error **always higher** for a given repartition

- Maximum error < 10%

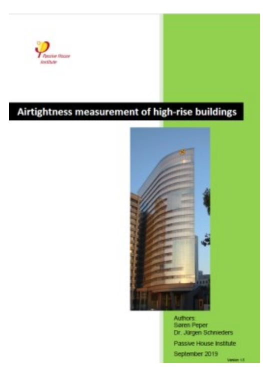
→ Reduced maximum error

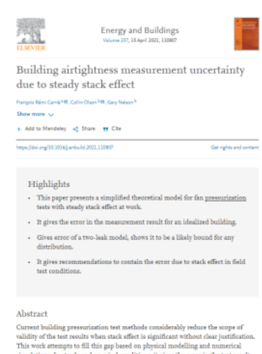
- New criteria
- Error due to stack effect
- Test methodology & practical advices

TESTING METHODOLOGY

Two main references:

- Passive House Institute Guideline
  (Peper and Schnieders 2019)
- "Building airtightness measurement uncertainty due to steady stack effect"
  (Carrié, Olson and Nelson 2021)




Energy and Buildings
Volume 237, 15 April 2021, 110807

Building airtightness measurement uncertainty due to steady stack effect

François Rémi Carrié, Collin Olson, Gary Nelson

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Highlights

- This paper presents a simplified theoretical model for fan pressurization tests with steady stack effect at work.
- It gives the error in the measurement result for an idealized building.
- Gives error of a two-leak model, shows it to be a likely bound for any distribution.
- It gives recommendations to contain the error due to stack effect in field test conditions.

Abstract

Current building pressurization test methods considerably reduce the scope of validity of the test results when stack effect is significant without clear justification. This work attempts to fill this gap based on physical modelling and numerical simulations. In steady and no-wind conditions, it gives the error in the test result

TESTING METHODOLOGY

1) Reduce as much as possible the temperature difference between inside and outside

- massive **airing and ventilation** before the test
- **closing shutters** or other solar protections
- performing the test during the **night** (sunny weather) and/or in **mid-season**
- etc.

Credit: Trendsideas

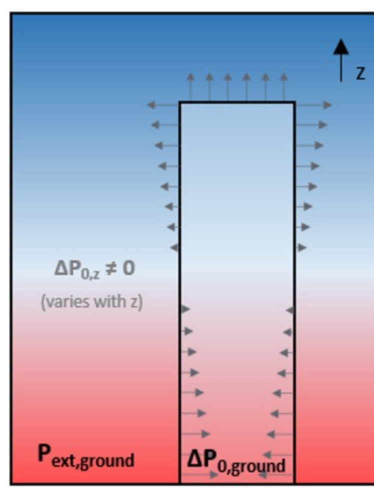
TESTING METHODOLOGY

2) Measure the zero-flow pressure $\Delta P_{0,ground}$ and check that:

- standard deviation < 5 Pa
- $H*\Delta T$ < 2000 m.K

  (Ideally < 1250 m.K for multiple points < 100 Pa)

A first check a few days before the test according to the weather forecast is recommended to reschedule the test if necessary



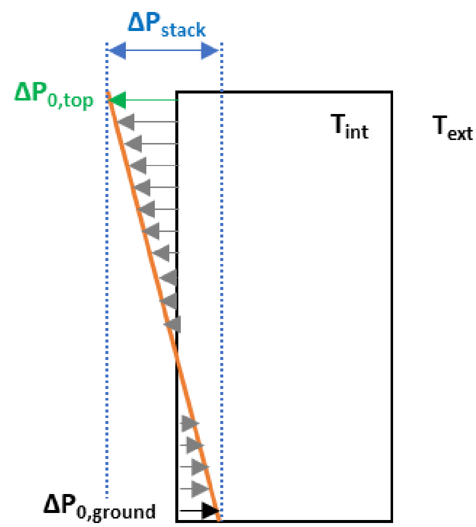
TESTING METHODOLOGY

3) Calculate ΔP_{stack} :

$$\Delta P_{stack} \approx 0.044 \times H \times (T_{int} - T_{ext})$$

and estimate the zero-flow pressure at the top of the building $\Delta P_{0,top}$:

$$\Delta P_{0,top} = \Delta P_{0,ground} + \Delta P_{stack}$$



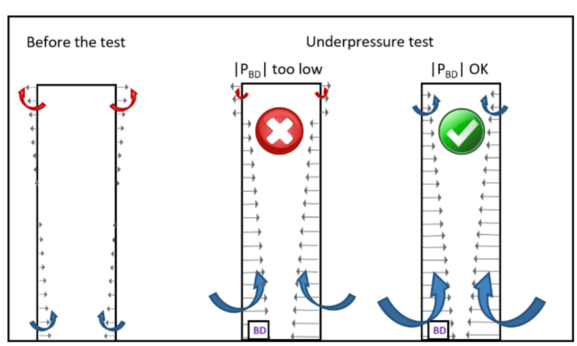
TESTING METHODOLOGY

4) Determine the minimum absolute pressure that shall be generated to guarantee that the building is fully pressurized

$$|P_{BD,min}| = \max(|\Delta P_{0,top}|; |\Delta P_{0,ground}|) + margin$$

*Recommended margin: **10 Pa** to compensate for:*
- *The pressure measurement uncertainty*
- *The pressure fluctuation in time and around the building's envelope (wind)*

*For **winds ≥ 3** (Beaufort scale) : measure the zero-flow pressure all around the building's envelope to make sure that the margin is high enough*



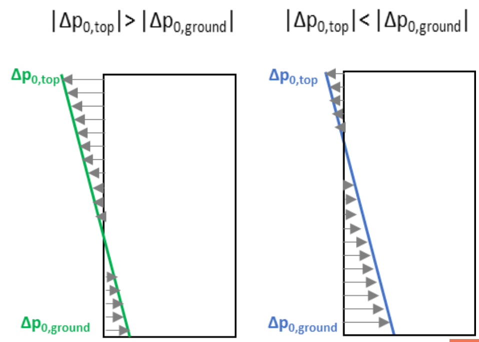
TESTING METHODOLOGY

5) Calculate the pressure difference at the ground floor to be reached for the first test pressure difference

To ensure same absolute values in pressurization and depressurization:

$\Delta p_{s,ground}$	$\lvert\Delta p_{0,top}\rvert > \lvert\Delta p_{0,ground}\rvert$	$\lvert\Delta p_{0,top}\rvert < \lvert\Delta p_{0,ground}\rvert$
Press.	$\Delta p_{stack} + 2 \times \Delta p_{0,ground} + 10$	10
Depress.	$-\Delta p_{stack} - 10$	$2 \times \Delta p_{0,ground} - 10$

Alternative (≠ absolute values):
- ***pressurization:*** $\Delta ps,ground,p+ = margin$
- ***depressurization:*** $\Delta ps,ground,p- = -\Delta pstack - margin$



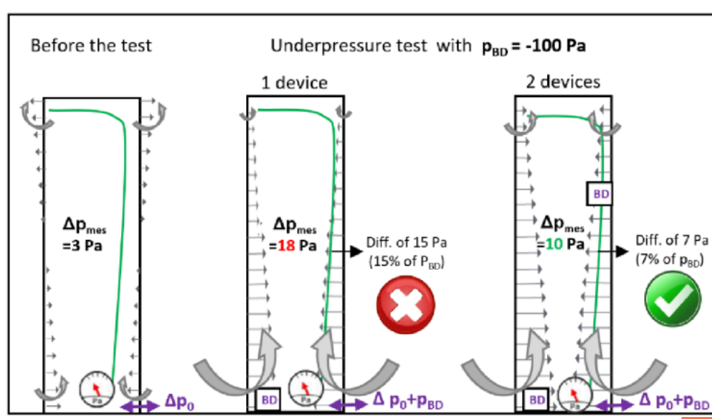
TESTING METHODOLOGY

6) Check the pressure homogeneity inside the building

Verify that the **pressure difference between the top and bottom of the building does not vary by more than 10% of p_{BD}** when comparing before and during the test (pressure deviation)

Fan location:
- *In a large room as close as possible to the stairwell(s)/lift.*
- *Usually: easier at the ground floor, Ideally: at neutral pressure plane*

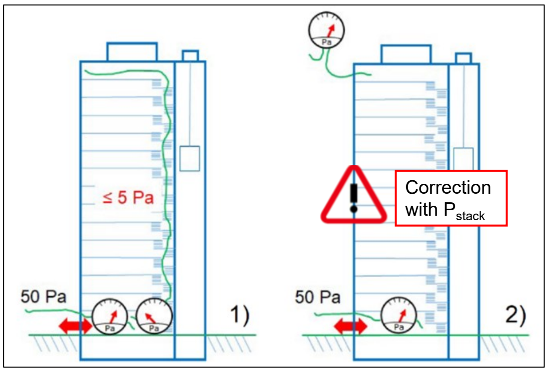
Homogeneity NOT verified:
→ Try to install additional fan(s) distributed along the envelope



TESTING METHODOLOGY

6) Check the pressure homogeneity inside the building

Two possibilities for measuring the pressure deviation :

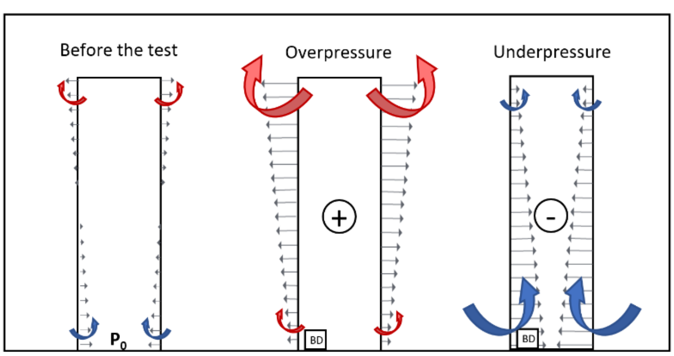


(Peper and Schnieders 2019)

***To avoid the wind impact** on the upper measurement, **option 1) is preferable.** When only option 2) is possible, the pressure can be measured on several façades and averaged (if possible)*

TESTING METHODOLOGY

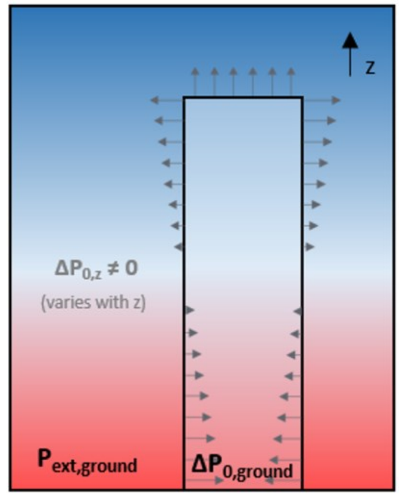
7) Conduct the air leakage measurement at several pressure stations in pressurization and depressurization modes



*As recommended by standard ISO 9972, **the highest test pressure difference** should be above 25 Pa and as high as possible up to 100 Pa.*

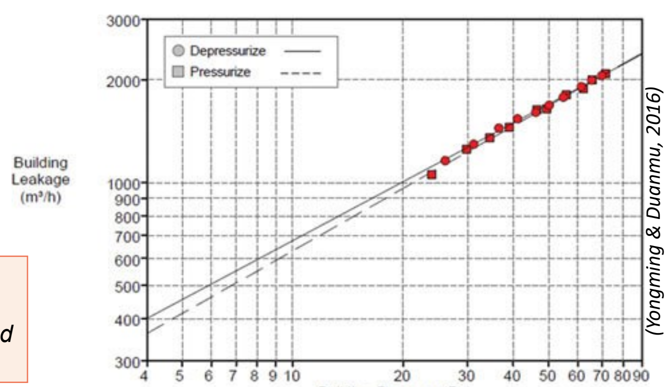
TESTING METHODOLOGY

8) **Measure the the zero-flow pressure $\Delta P_{0,ground}$ after the test and check that its standard deviation is less than 5 Pa**



TESTING METHODOLOGY

9) **Calculate the result by averaging the pressurization and depressurization tests results after regression**



If this methodology cannot be followed: consider dividing the building for the test (sampling allowed in some countries as UK & France)

THANK YOU FOR YOUR ATTENTION