Airtightness Tests in Tall Buildings

Challenges & Experiences

Presenter: Stefanie Rolfsmeier

TrIIIple Tower Vienna
Project Leader
- *Emanuel Mairinger, Dr. Ronald Mischek, ZT GmbH, Wien*

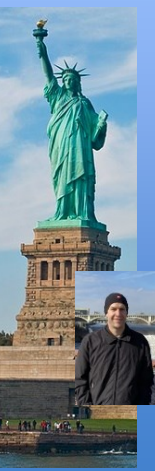
Partner
- *Johannes Neubig, Thomas Gayer, MA39, Stadt Wien*
- *Gary Nelson, Collin Olson, The Energy Conservatory*
- *Stefanie Rolfsmeier, BlowerDoor GmbH*

1

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)

2

Agenda

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

3

Test Objects and Requirements

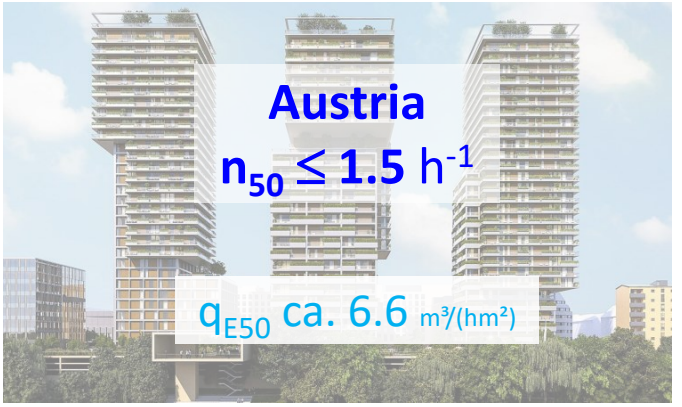
4

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 m³	68.779 m³	71.280 m³	104.000 m³
A_E →	15.652 m²	17.933 m²	16.079 m²	ca. 25.000 m²

5

Requirements for building airtightness



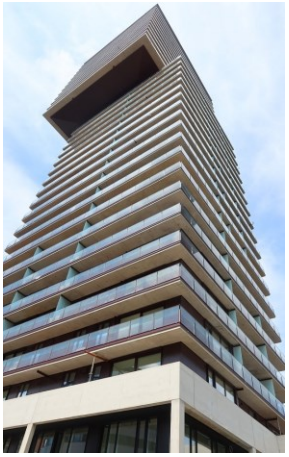
Tower 3	Tower 2	Tower 1	Building 4

6

Challenges

7

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**

8

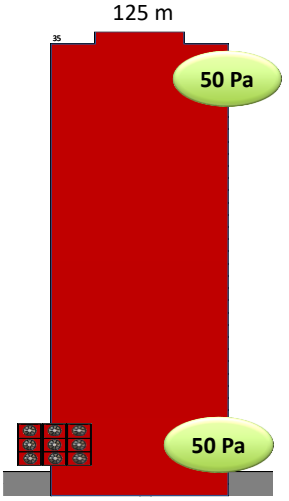
Where is the best place to install the measuring fans?

Best location(s) to install the measuring fans?

Exchange with:

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

Is it possible to create a uniform induced pressure difference?



Single Zone Building

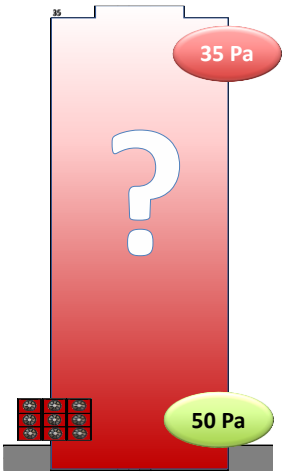
Is it possible to create a uniform induced pressure difference

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

Exchange with:

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

11

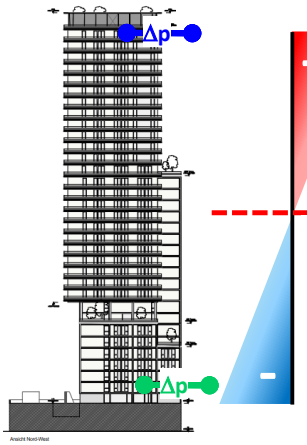
Weather Conditions

12

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**



54 Pa

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

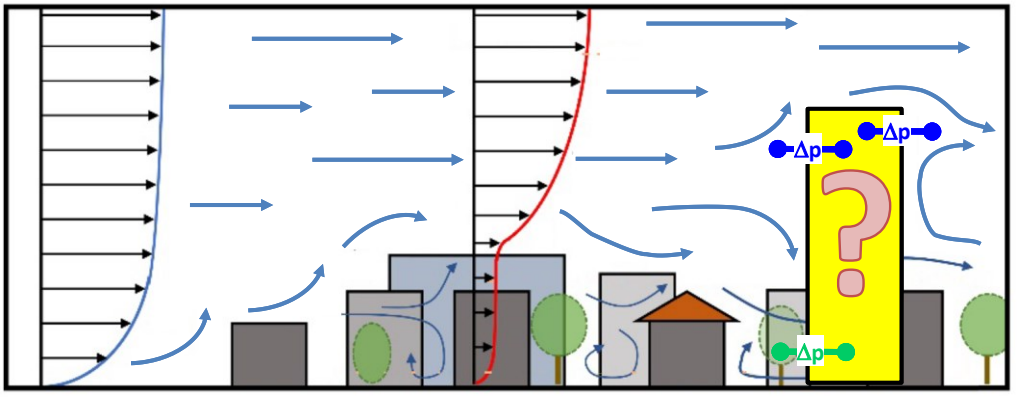
$$\Delta p = -0{,}04 \frac{Pa}{m * K} * \frac{H}{2} * (T_{in} - Tout)$$

-54 Pa

Source: Airtightness measurement of high-rise buildings, PHI

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

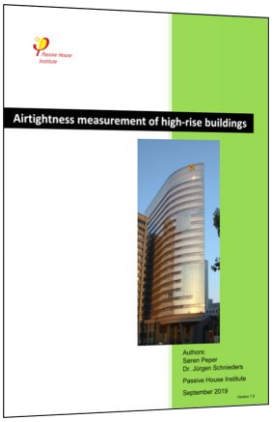
Wind



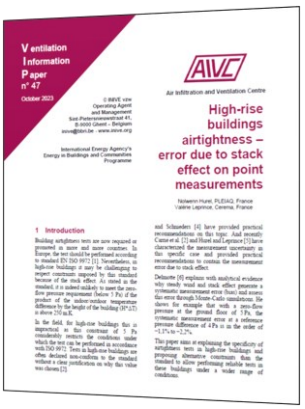
Source: Professur für Bauphysik – ETH Zürich: Wind bei Hochhäusern

15

Airtightness measurement of high-rise buildings



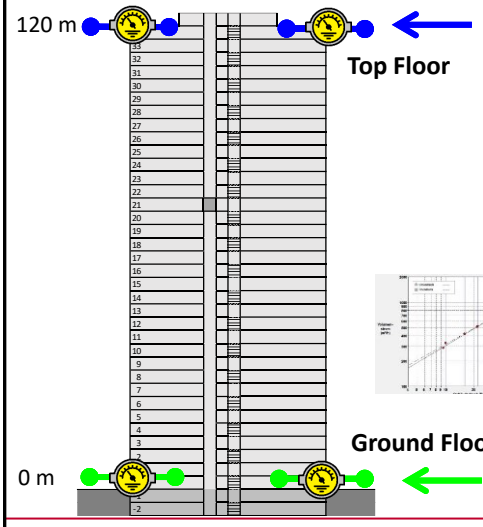
Airtightness Measurement of High-Rise Buildings Guidelines
from Søren Peper, Dr. Jürgen Schnieders
Passivhaus Institut, September 2019



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

16

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

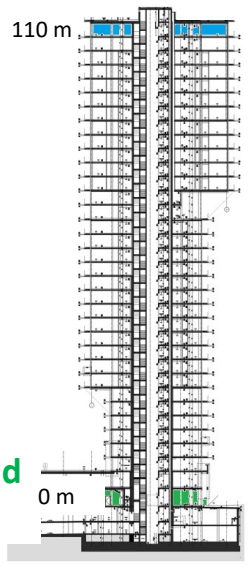
1 - 4 envelope pressure diff. between inside / outside

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

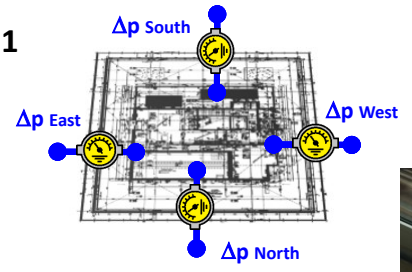
17

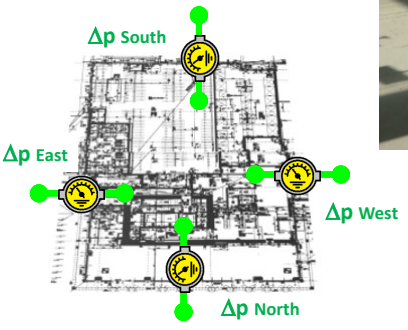
Example Triiiple Tower 1

33. Floor



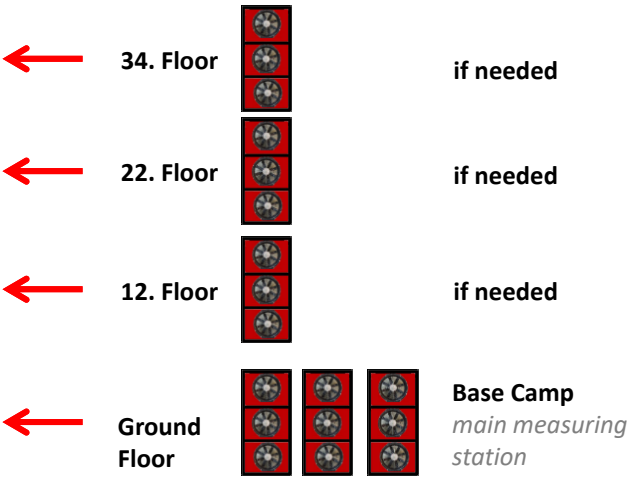
Ground Floor





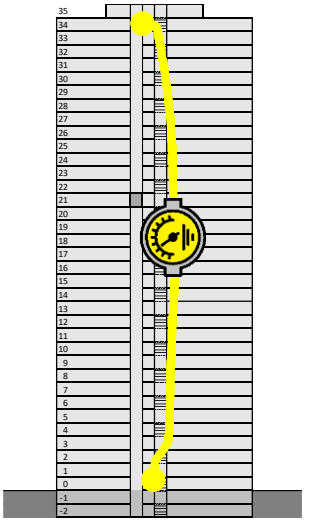
18

Fan Locations (Example: Triiipel Tower 3)



19

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



Internal

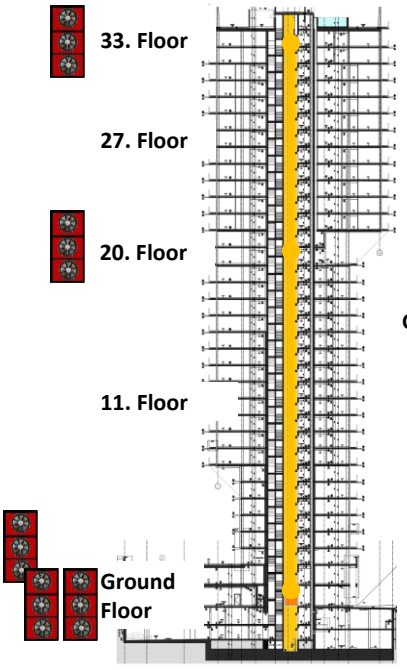
Check if there is a pressure drop of induced pressure

Target / Wish:

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

20

Triiiple Tower 1: Internal Pressure Differences



20 - 27. Floor

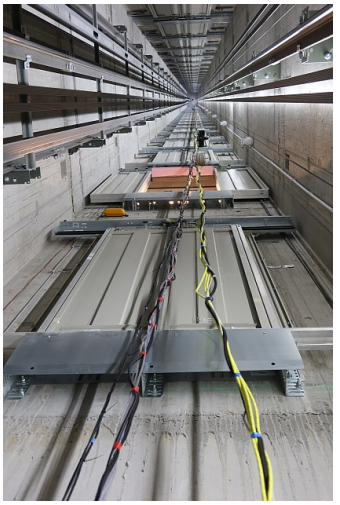
Ground Floor - 33. Floor

Ground Floor - 20.Floor

Ground Floor - 11.Floor

Ground Floor - 2. Basement

Industrial climbers



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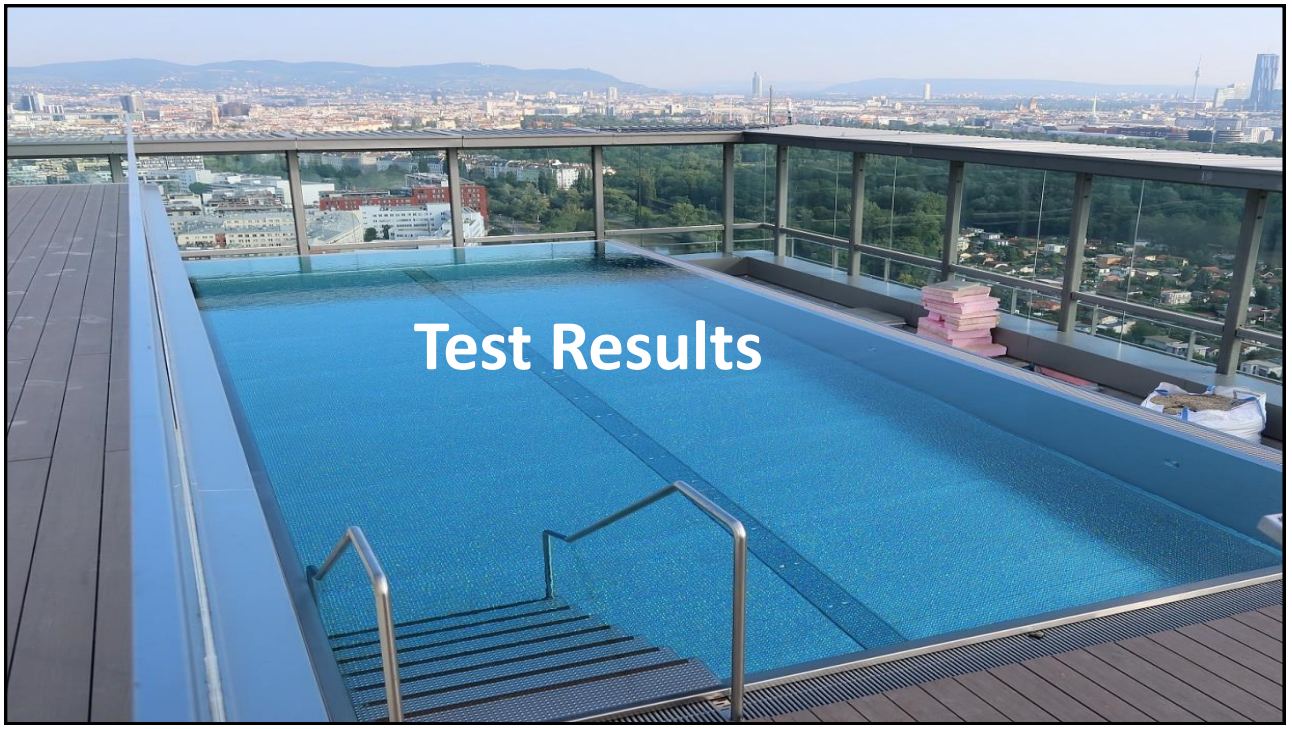

Test Results

	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** m^3/hm^2	**4.2** m^3/hm^2	**4.3** m^3/hm^2	**0.9** m^3/hm^2
q_{50} Depress. →	52700 m^3/h	75970 m^3/h	69937 m^3/h	22700 m^3/h
q_{50} Press. →	66800 m^3/h	75760 m^3/h	69222 m^3/h	23000 m^3/h

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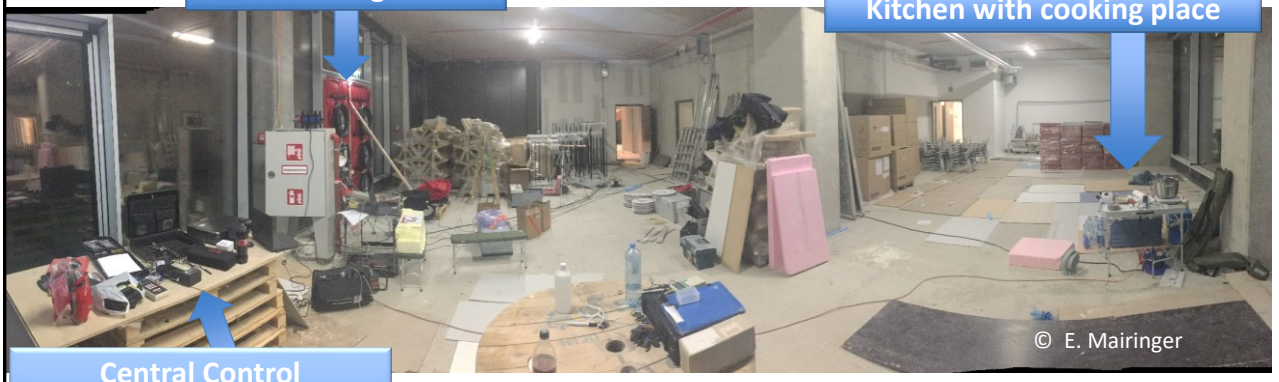
Lessons learned

Base Camp (Ground Floor)

Measuring fans

Kitchen with cooking place



Central Control of fans and pressure differences

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

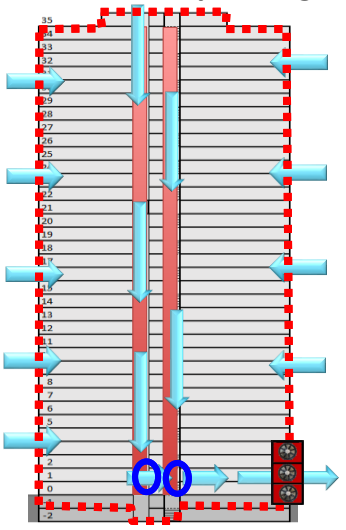
„leaky“ building envelope

Fans needed on higher floors

„Tight“ building envelope

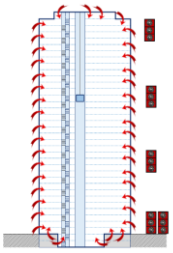
Fans required only on ground floor

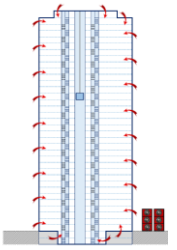
Position of fans, depending on Vertical / Horizontal AirFlow Paths / Openings



- **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

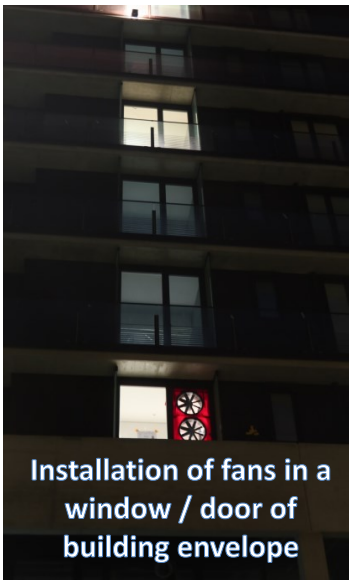
Fans needed on higher floors

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

Fans required only on ground floor

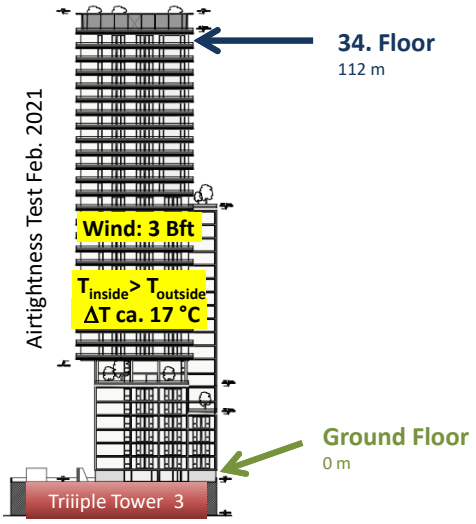
29

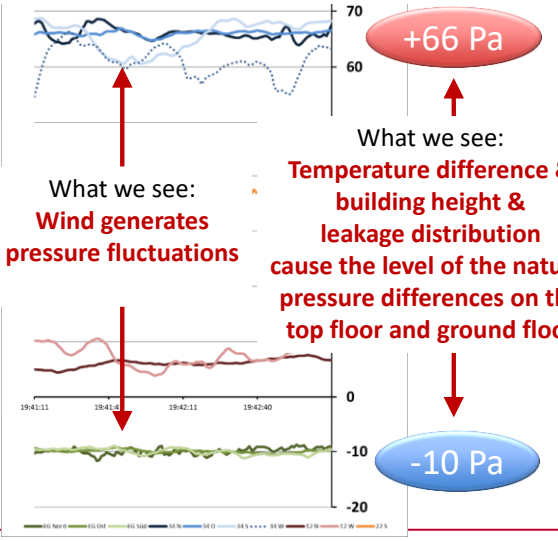
30



31

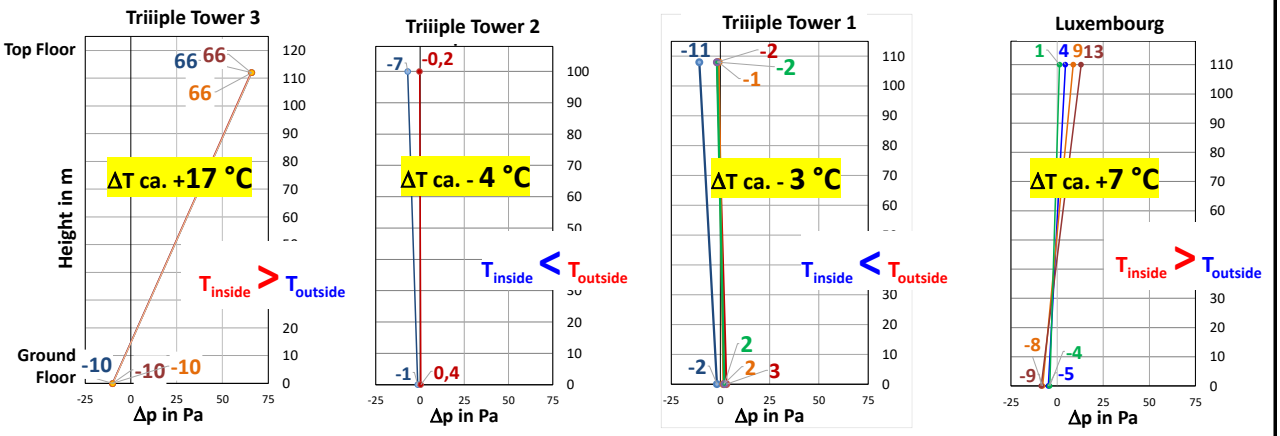
Real natural pressure differences caused by wind and temperature differences





32

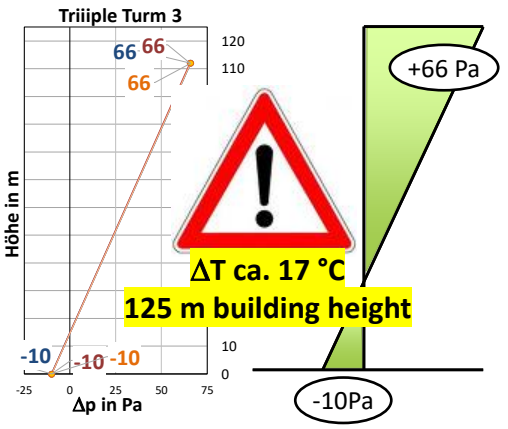
Impact of difference in Temperature and Building Height – Nat. Δp MEASURED



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

33

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

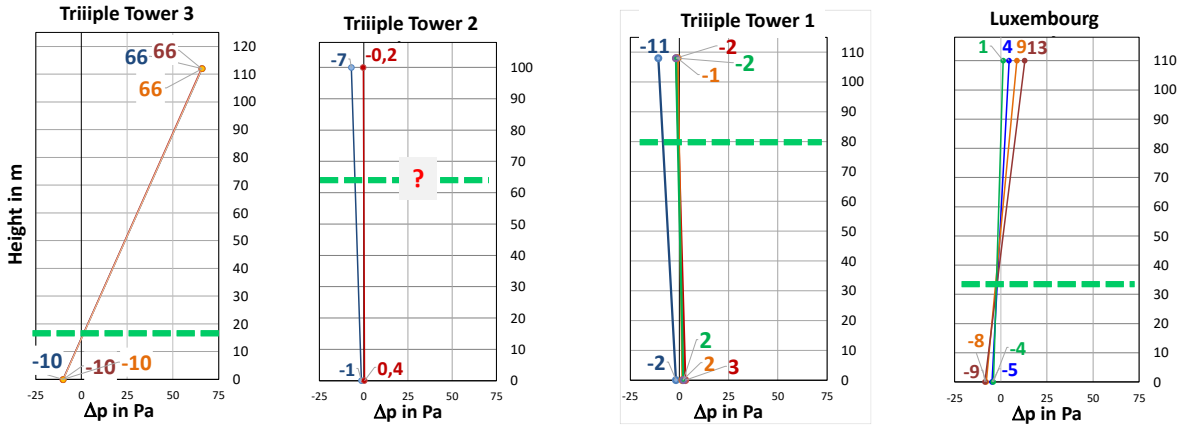
Recommendation:

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)

34

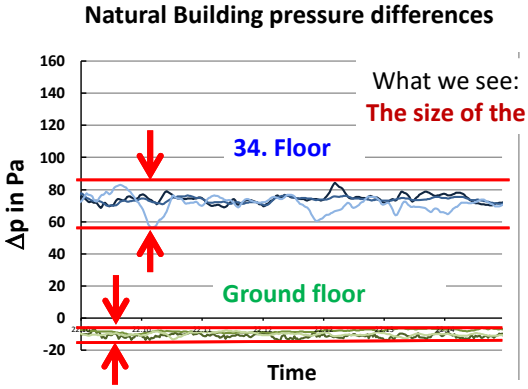
Effect of leakage distribution over the height of the building



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

35

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



What we see:

The size of the pressure fluctuations increases on higher floors

Recommendation:

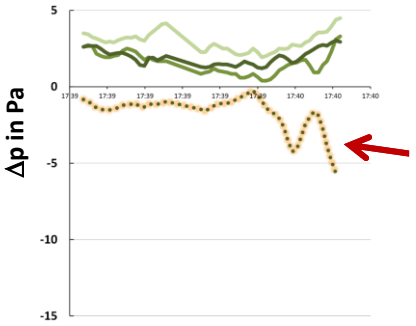
- **Install the fans on the ground floor level**
  → Measuring Fans see smaller pressure fluctuations
- **Only test at Wind force ≤ 3 Beaufort**
- **At windy conditions increase measuring time per test point (e.g. 60 s -120 s)**

36

Impact of the wind direction (Triiiple Tower 1)

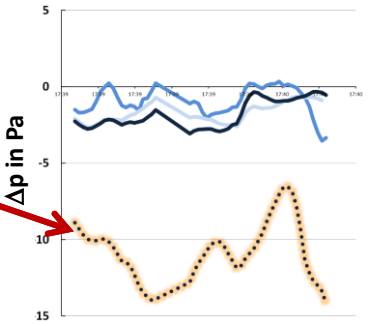
Natural building pressure differences on the four sides of the building (North, East, South, West)

Ground Floor



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

33. Floor

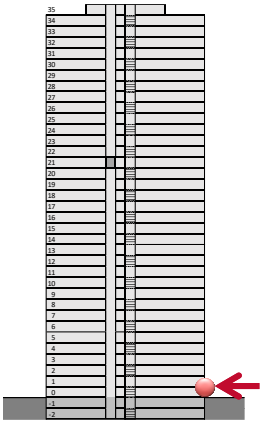


Recommendation: **If possible, install the test equipment NOT on windward side of building**

37

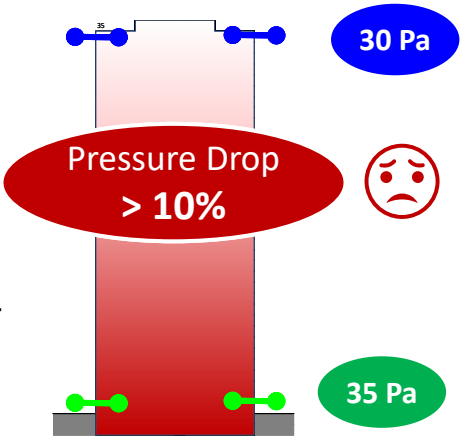
Situation: Pressure Drop (between two points inside the building) > 10 %

Setup Fans



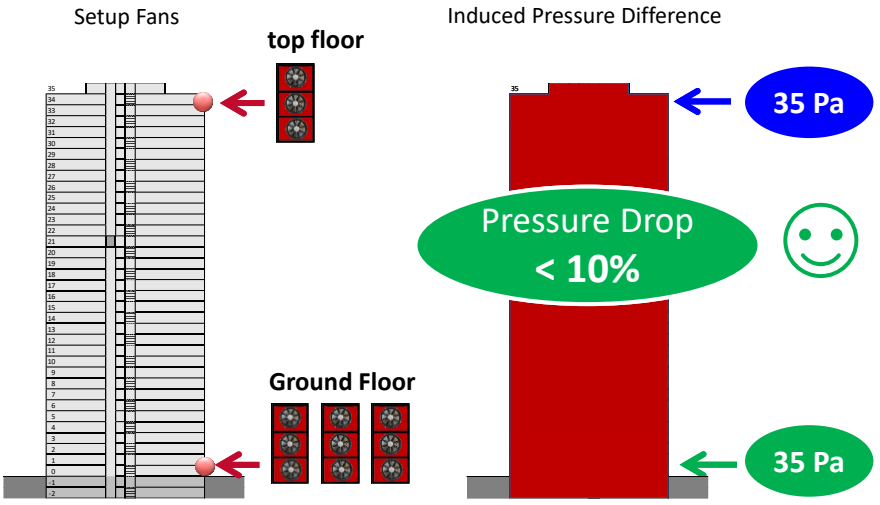
Ground Floor

Induced Pressure Difference



38

Solution: Activate fans on upper floors



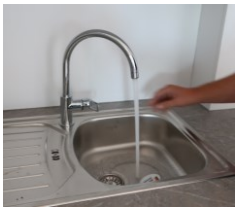
39

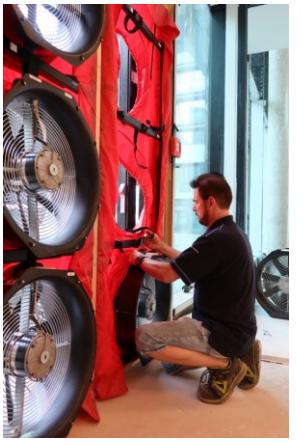
- Manpower - Womanpower - and More -

40

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 equimpent and building preparation
  - Second day rest of setup, 50 Pa Leakage detection, Multipoint tests
  - Third day take down of test equimpent





41

Building preparation

Triiiple Tower 3

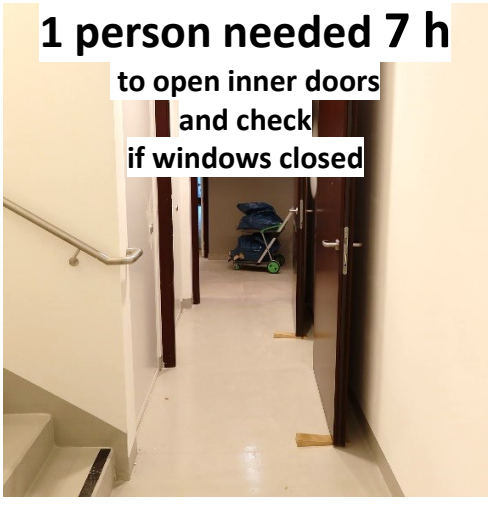
1200

timber wedges to fix self-closing doors open

Triiiple Tower 1

1 person needed 7 h

to open inner doors and check if windows closed



42

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

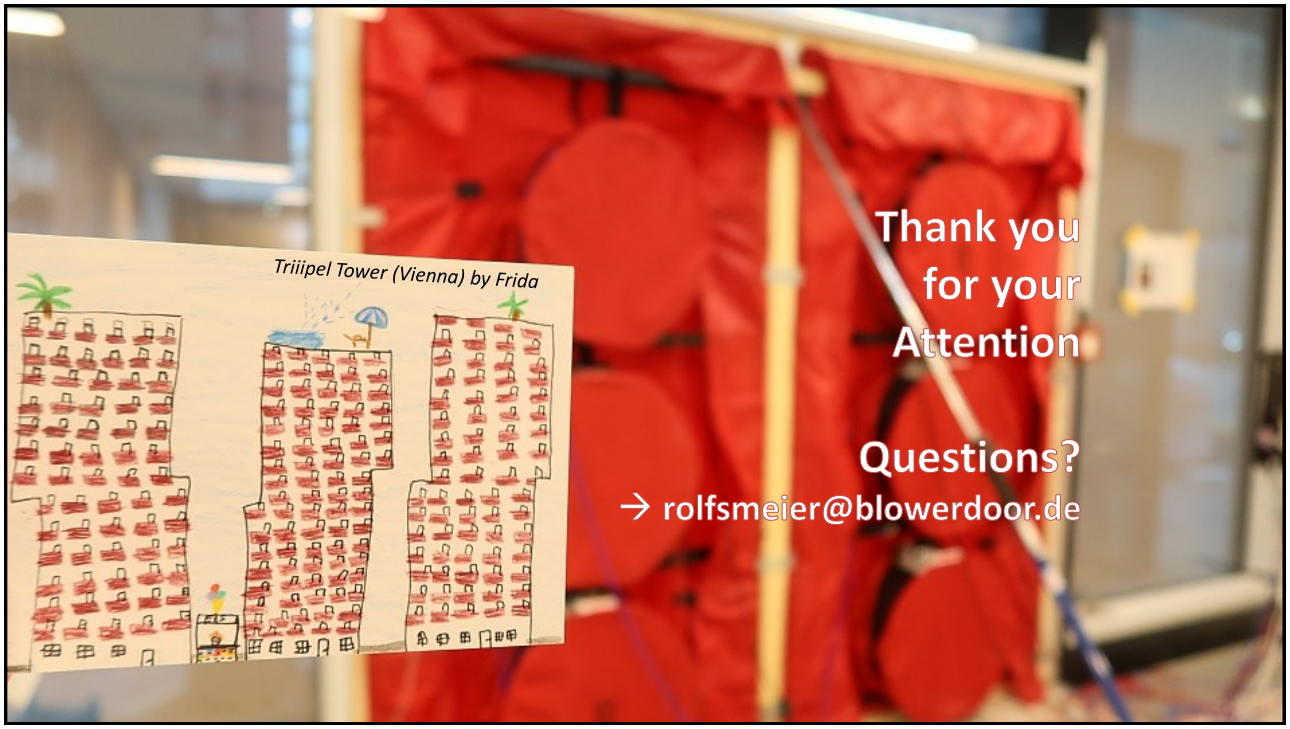
Fire protection devices top floor

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