webinar
2020.11.30

Better Quantifying and Locating Building Leakages


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Better Quantifying and Locating Building Leakages

AGENDA

- 10:30 | **Building component performances as an answer for airtightness issues –existing quantification methods**, Martin Prignon, UCLouvain, Belgium
- 10:40 | **Uncertainty of effective leakage areas determination through reductive sealing technique**, Vitor Cardoso, FEUP, Portugal
- 10:55 | Questions and answers
- 11:00 | **Bias and precision errors in the measurement of building component airtightness with direct component test**, Martin Prignon, UCLouvain, Belgium
- 11:15 | Questions and answers
- 11:20 | **Comparison of airflow and acoustic measurements for evaluation of building air leakage paths in a laboratory test apparatus**, Benedikt Kölsch, DLR, Germany
- 11:35 | Questions and answers
- 11:45 | End of webinar

How to ask questions during the webinar

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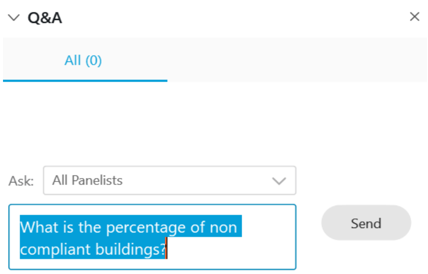
Select **All Panelists** | Type your question | Click on Send

<u>Note</u>: Please DO NOT use the chat box to ask your questions!



What is the percentage of non compliant buildings?

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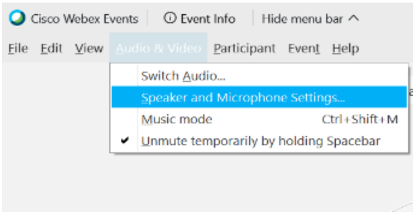

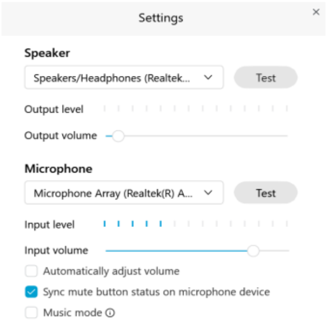

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- After the end of the webinar you will be redirected to our post event survey. Your feedback is valuable so take some minutes of your time ti fill it in.

Airtightness of building components

Building Component Performances as an Answer for Airtightness Issues – Existing Methods

Speaker
Martin Prignon

Project **AirPath50** (2016 – 2020), funded by INNOVIRIS

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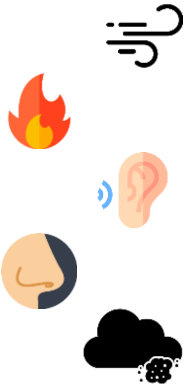
Infiltration, Consequences and Current Practice



Energy **Health** **Comfort**

- ➔ Improve Airtightness
- ➔ Develop Databases
- ➔ Develop Guides

Airtightness paradox in current practice

We promote fan pressurisation test

- It reports airtightness at 50 Pa.
- Assumes leakage uniformly distributed along the envelope.

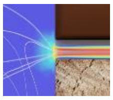
The consequences and the amount of air infiltration depend on leakage location and distribution.

e.g., Internal vs. External leakage

See [Rogers, 2019]
(40th AIVC Conference)

Looking at component scale in parallel with whole building performances.

Quantification of Building Component Airtightness



Numerical models

Airflow estimation through the development of fundamental equations of fluid mechanics.

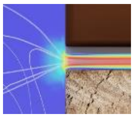
Laboratory testing

Measurement of $\Delta p - q$ relation of the component in a highly controlled environment.

***In-situ* testing**

Measurement of $\Delta p - q$ relation of the component directly on site.

Advantages and Drawbacks

	+	−
	- No planning constraints - Easy interpolation of models - Transferrable to larger models	- Representation of reality - Validation work needed - Lack of crack data
	- No planning constraints - Control of variables - Visualisation of the component	- Not "real configuration": o Component alone o No dust, enough space, etc.
	- Real configuration (i.e., includes workmanship quality)	- Planning constraints - Uncontrolled environment

Presentations in this Webinar

Old topic
TN 34: Air Flow Patterns within Buildings: Measurement Techniques

New perspectives
Regain interest in health and comfort
New directives for retrofit (Europe, 2018)

Uncertainty Of Effective Leakage Areas Determination Through Reductive Sealing Technique
Vitor Cardoso

Bias and Precision errors in the Measurement of Building Component Airtightness with Direct Component Test
Martin Prignon

Comparison of Airflow and Acoustic measurements for Evaluation of Building Air Leakage Paths in a Laboratory Test Apparatus
Benedikt Kölsch

Uncertainty of effective leakage areas determination through reductive sealing technique

Vitor Emanuel Martins Cardoso
Doctoral Program in Civil Engineering

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1 Air infiltration

2 Effective leakage areas

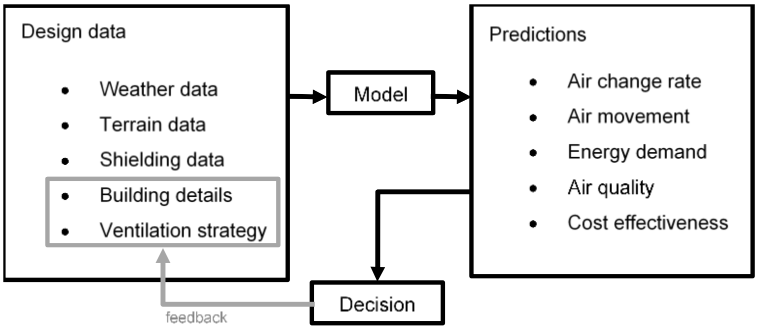
3 Reductive sealing

4 Regression models

5 Uncertainty propagation

6 Application and best practices

Air infiltration



Design data

- Weather data
- Terrain data
- Shielding data
- Building details
- Ventilation strategy

Model

Predictions

- Air change rate
- Air movement
- Energy demand
- Air quality
- Cost effectiveness

Decision

Effective Leakage Areas

The area of a single orifice that would produce the same leakage as the group of leakages it represents at a reference pressure difference

- Typical form of expressing air leakage characteristics
  - building components
  - whole envelopes

$$ELA = \frac{10q}{3.6}\frac{\sqrt{\frac{\rho_0}{2\Delta p}}}{C_D}$$

$$ELA = \frac{10}{3.6}C_{env}\left(\frac{T_0}{T}\right)^{1-n}\left(\frac{\rho_0}{2}\right)^{0.5}\Delta p^{n-0.5}$$

Effective Leakage Areas

- Available extensively in ASHRAE and AIVC documentation
  - repeated measurements
  - compilation of laboratory and in situ experiments

Results using ordinary least squares regression in the airflow

No propagation of uncertainty in incremental sealing

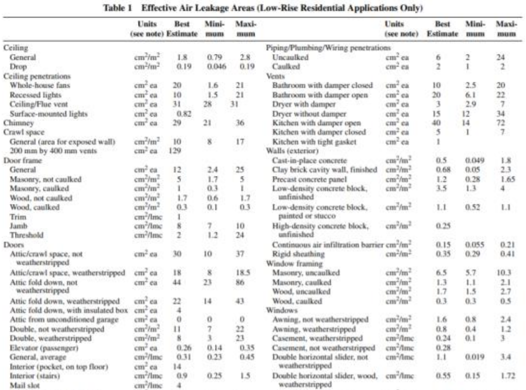


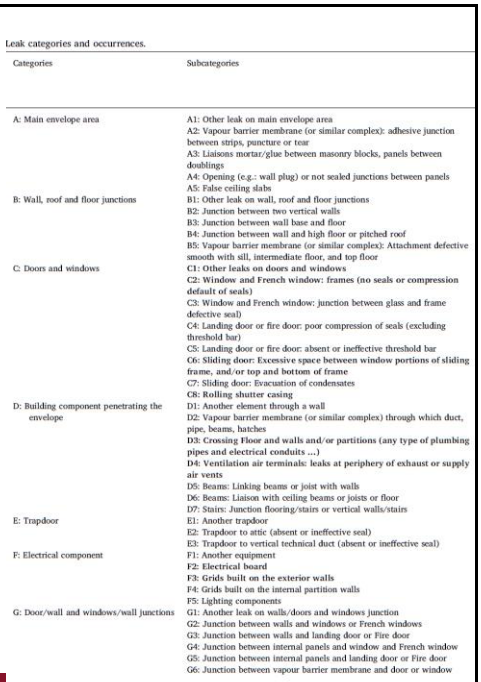
Table 1 Effective Air Leakage Areas (Low-Rise Residential Applications Only)

	Units (see note)	Best Estimate	Mini-mum	Maxi-mum
Ceiling				
General	cm^2/m^2	1.8	0.79	2.8
Drop	cm^2/m^2	0.19	0.046	0.19
Ceiling penetrations				
Whole-house fans	cm^2 ea	20	1.6	21
Recessed lights	cm^2 ea	10	1.5	21
Ceiling/Flue vent	cm^2 ea	31	28	31
Surface-mounted lights	cm^2 ea	0.82		
Chimney	cm^2 ea	29	21	36
Crawl space				
General (area for exposed wall)	cm^2/m^2	10	8	17
200 mm by 400 mm vents	cm^2 ea	129		
Door frame				
General	cm^2 ea	12	2.4	25
Masonry, not caulked	cm^2/m^2	5	1.7	5
Masonry, caulked	cm^2/m^2	1	0.3	1
Wood, not caulked	cm^2/m^2	1.7	0.6	1.7
Wood, caulked	cm^2/m^2	0.3	0.1	0.3
Trim	cm^2/lmc	1		
Jamb	cm^2/lmc	8	7	10
Threshold	cm^2/lmc	2	1.2	24
Doors				
Attic/crawl space, not weatherstripped	cm^2 ea	30	10	37
Attic/crawl space, weatherstripped	cm^2 ea	18	8	18.5
Attic fold down, not weatherstripped	cm^2 ea	44	23	86
Attic fold down, weatherstripped	cm^2 ea	22	14	43
Attic fold down, with insulated box	cm^2 ea	4		
Attic from unconditioned garage	cm^2 ea	0	0	0
Double, not weatherstripped	cm^2/m^2	11	7	22
Double, weatherstripped	cm^2/m^2	8	3	23
Elevator (passenger)	cm^2 ea	0.26	0.14	0.35
General, average	cm^2/lmc	0.31	0.23	0.45
Interior (pocket, on top floor)	cm^2 ea	14		
Interior (stairs)	cm^2/lmc	0.9	0.25	1.5
Mail slot	cm^2/lmc	4		
Sliding exterior glass patio	cm^2 ea	22	3	60
Sliding exterior glass patio	cm^2/m^2	5.5	0.6	15
Storm (difference between with and without)	cm^2 ea	6	3	6.2
Single, not weatherstripped	cm^2 ea	21	12	53
Piping/Plumbing/Wiring penetrations				
Uncaulked	cm^2 ea	6	2	24
Caulked	cm^2 ea	2	1	2
Vents				
Bathroom with damper closed	cm^2 ea	10	2.5	20
Bathroom with damper open	cm^2 ea	20	6.1	22
Dryer with damper	cm^2 ea	3	2.9	7
Dryer without damper	cm^2 ea	15	12	34
Kitchen with damper open	cm^2 ea	40	14	72
Kitchen with damper closed	cm^2 ea	5	1	7
Kitchen with tight gasket	cm^2 ea	1		
Walls (exterior)				
Cast-in-place concrete	cm^2/m^2	0.5	0.049	1.8
Clay brick cavity wall, finished	cm^2/m^2	0.68	0.05	2.3
Precast concrete panel	cm^2/m^2	1.2	0.28	1.65
Low-density concrete block, unfinished	cm^2/m^2	3.5	1.3	4
Low-density concrete block, painted or stucco	cm^2/m^2	1.1	0.52	1.1
High-density concrete block, unfinished	cm^2/m^2	0.25		
Continuous air infiltration barrier	cm^2/m^2	0.15	0.055	0.21
Rigid sheathing	cm^2/m^2	0.35	0.29	0.41
Window framing				
Masonry, uncaulked	cm^2/m^2	6.5	5.7	10.3
Masonry, caulked	cm^2/m^2	1.3	1.1	2.1
Wood, uncaulked	cm^2/m^2	1.7	1.5	2.7
Wood, caulked	cm^2/m^2	0.3	0.3	0.5
Windows				
Awning, not weatherstripped	cm^2/m^2	1.6	0.8	2.4
Awning, weatherstripped	cm^2/m^2	0.8	0.4	1.2
Casement, weatherstripped	cm^2/lmc	0.24	0.1	3
Casement, not weatherstripped	cm^2/lmc	0.28		
Double horizontal slider, not weatherstripped	cm^2/lmc	1.1	0.019	3.4
Double horizontal slider, wood, weatherstripped	cm^2/lmc	0.55	0.15	1.72
Double horizontal slider, aluminum, weatherstripped	cm^2/lmc	0.72	0.58	0.8
Double-hung, not weatherstripped	cm^2/lmc	2.5	0.86	6.1
Double-hung, weatherstripped	cm^2/lmc	0.65	0.2	1.9
Double-hung with storm, not	cm^2/lmc	0.97	0.48	1.7

Reductive sealing

Offsetting results from blower door tests to attain the performance of individualized elements or groups

French database has 46 subcategories of leaks



Leak categories and occurrences.

Categories	Subcategories
A: Main envelope area	A1: Other leak on main envelope area A2: Vapour barrier membrane (or similar complex): adhesive junction between strips, puncture or tear A3: Liaisons mortar/glue between masonry blocks, panels between doublings A4: Opening (e.g.: wall plug) or not sealed junctions between panels A5: False ceiling slabs
B: Wall, roof and floor junctions	B1: Other leak on wall, roof and floor junctions B2: Junction between two vertical walls B3: Junction between wall base and floor B4: Junction between wall and high floor or pitched roof B5: Vapour barrier membrane (or similar complex): Attachment defective smooth with sill, intermediate floor, and top floor
C: Doors and windows	**C1: Other leaks on doors and windows** **C2: Window and French window: frames (no seals or compression default of seals)** C3: Window and French window: junction between glass and frame defective seal) C4: Landing door or fire door: poor compression of seals (excluding threshold bar) C5: Landing door or fire door: absent or ineffective threshold bar **C6: Sliding door: Excessive space between window portions of sliding frame, and/or top and bottom of frame** C7: Sliding door: Evacuation of condensates **C8: Rolling shutter casing**
D: Building component penetrating the envelope	D1: Another element through a wall D2: Vapour barrier membrane (or similar complex) through which duct, pipe, beams, hatches **D3: Crossing Floor and walls and/or partitions (any type of plumbing pipes and electrical conduits ...)** **D4: Ventilation air terminals: leaks at periphery of exhaust or supply air vents** D5: Beams: Linking beams or joist with walls D6: Beams: Liaison with ceiling beams or joists or floor D7: Stairs: Junction flooring/stairs or vertical walls/stairs
E: Trapdoor	E1: Another trapdoor E2: Trapdoor to attic (absent or ineffective seal) E3: Trapdoor to vertical technical duct (absent or ineffective seal)
F: Electrical component	F1: Another equipment **F2: Electrical board** **F3: Grids built on the exterior walls** F4: Grids built on the internal partition walls F5: Lighting components
G: Door/wall and windows/wall junctions	G1: Another leak on walls/doors and windows junction G2: Junction between walls and windows or French windows G3: Junction between walls and landing door or Fire door G4: Junction between internal panels and window and French window G5: Junction between internal panels and landing door or Fire door G6: Junction between vapour barrier membrane and door or window

Reductive sealing

Most frequent

- windows
- doors
- shutters

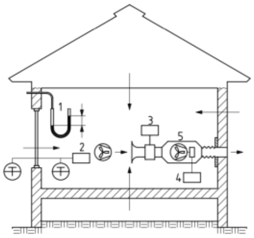
Most impactful

- lighting components
- junction between floor and wall
- electrical board
- junction between window and wall
- trapdoors to attics

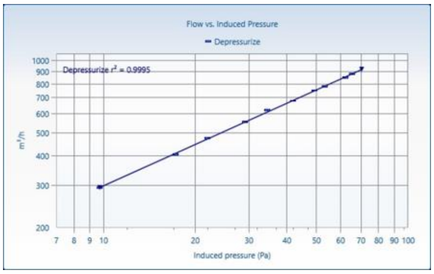
Leakage type assessment often qualitative – smoke tracer/thermography

Background leakage after initial assessment usually ranges from 45% to 75%

Regression models



1 pressure-measuring device
2 temperature-measuring device
3 air-flow measuring system
4 air-moving equipment
5 fan



Regression models

OLS – Ordinary least squares

WLOC – Weighted Line of Organic Correlation

OLS	OLS uncertainty	WLOC uncertainty
q readings: distance to regression values	q readings: fan accuracy t readings: sensors accuracy and resolution	q readings: fan accuracy t readings: sensors accuracy and resolution Δp and Δp0 readings: manometer accuracy and resolution zero-flow approximation

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Uncertainty propagation

- Uncertainty propagation to the ELA

$$u(ELA) = \sqrt{\begin{gathered}\left(2.155C_{env}\Delta p^{n-0.5}\left(\frac{T_0}{T}\right)^{1-n}\ln\left(\Delta p\frac{T}{T_0}\right)u(n)\right)^2 + \left(2.155C_{env}\,\Delta p^{n-0.5}\left(\frac{T_0}{T}\right)^{1-n}u(\ln(C_{env}))\right)^2 + \\ \left(2.155\frac{C_{env}\Delta p^{n-0.5}(n-1)}{T}\left(\frac{T_0}{T}\right)^{1-n}u(T)\right)^2 + \\ 2\left(2.155C_{env}\Delta p^{n-0.5}\left(\frac{T_0}{T}\right)^{1-n}\right)^2\ln\left(\Delta p\frac{T}{T_0}\right)u(n)\,u(\ln(C_{env}))\,r(n,\ln(C_{env}))\end{gathered}}$$

- Offset of uncertainties between sealing steps

$$ELA_{step,i} = ELA_{i-1} - ELA_i$$

$$u\left(ELA_{step,i}\right) = \sqrt{u(ELA_{i-1})^2 + u(ELA_i)^2}$$

Application and best practices

Smoke tracer provides info for:

- Identification of predominant leaks
- Sealing step sequence

Application and best practices

Exterior finishings can be a challenge

Application and best practices

12 sealing steps
11 leakage path types

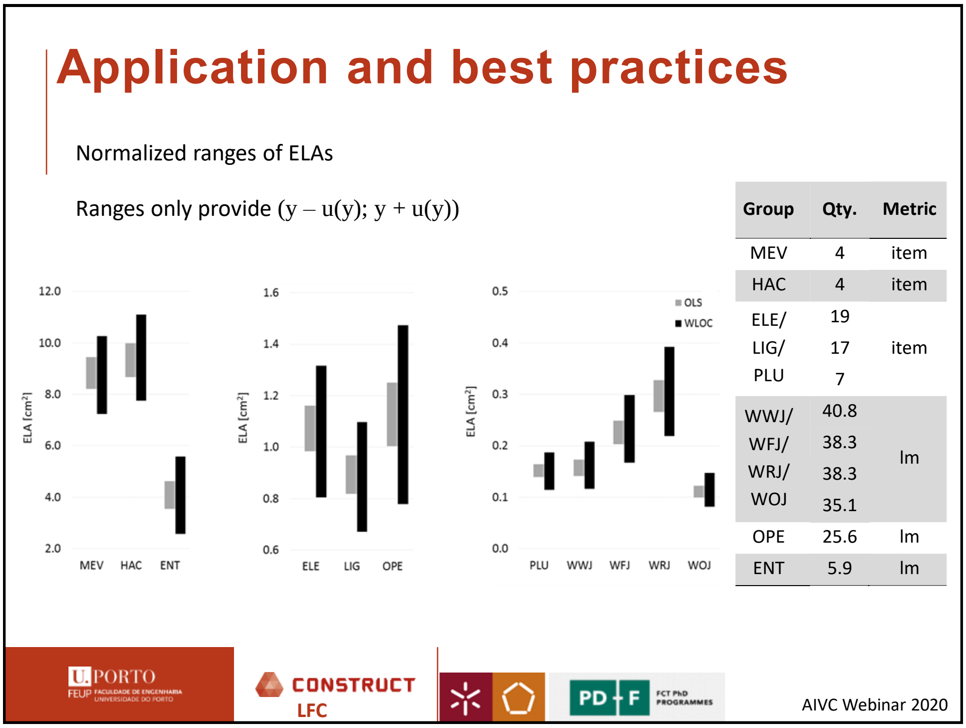
- default mode (DEF)
- mechanical ventilation (MEV)
- heating and air conditioning elements (HAC)
- electrical appliances (ELE)
- lighting (LIG)
- plumbing (PLU)
- wall/wall joints (WWJ)
- wall/floor joints (WFJ)
- wall/roof joints (WRJ)
- wall/openings joints (WOJ)
- openings (OPE)
- entrance door (ENT)

Application and best practices

- Significant dispersion of air flow rates between leakage paths
- No leakage path type exceeded 18% of the total air change rate
- WLOC provides higher calculated uncertainties in the airflow rates
- On average, 2.6 and 1.7 times greater than OLS and OLSu

Average effective leakage area uncertainty

Pressure difference	OLS [%]	OLSu [%]	WLOC [%]
4	9.9	18.8	27.5

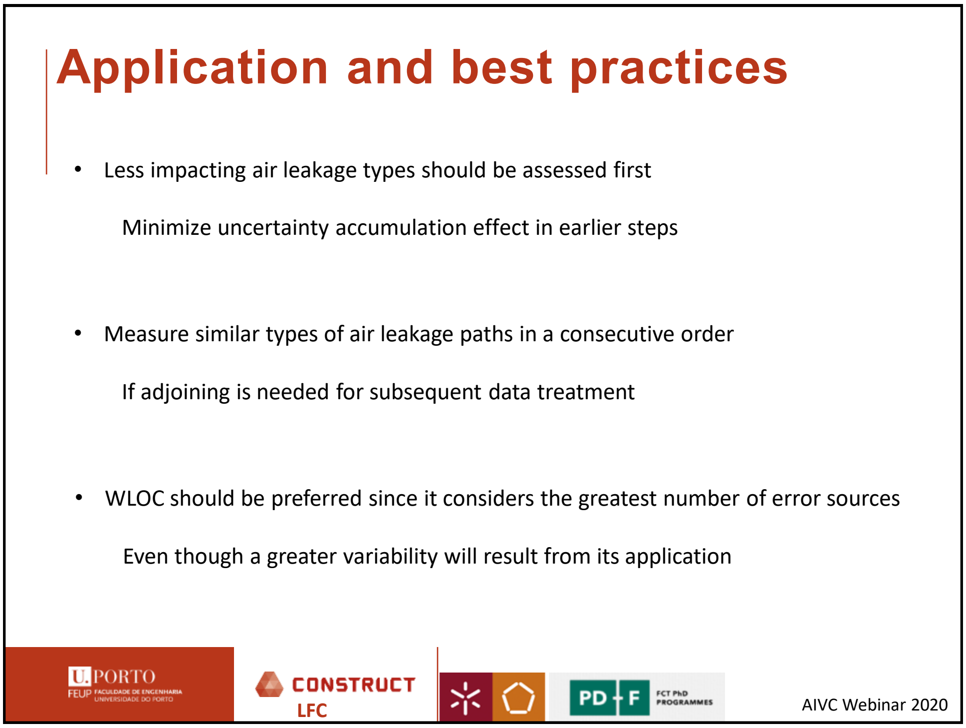


Application and best practices

Normalized ranges of ELAs

Ranges only provide (y – u(y); y + u(y))

Group	Qty.	Metric
MEV	4	item
HAC	4	item
ELE/ LIG/ PLU	19 17 7	item
WWJ/ WFJ/ WRJ/ WOJ	40.8 38.3 38.3 35.1	lm
OPE	25.6	lm
ENT	5.9	lm



Application and best practices

- Less impacting air leakage types should be assessed first

  Minimize uncertainty accumulation effect in earlier steps

- Measure similar types of air leakage paths in a consecutive order

  If adjoining is needed for subsequent data treatment

- WLOC should be preferred since it considers the greatest number of error sources

  Even though a greater variability will result from its application

Application and best practices

Effective Leakage Areas are used primarily for input in airflow models

Risk assessment on health-related issues:

- minimum air renovations
- comfort concerns

Energy relevant aspects :

- ranges of heating and cooling loads

Support decision on intervention scenarios by:

- Cost
- Invasiveness
- Labour
- Time

With **truer** uncertainties → Most adequate leakage paths for intervention

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THANK YOU FOR YOUR ATTENTION!

The author would like to acknowledge the support of FCT - Fundação para a Ciência e a Tecnologia, the funding of the Doctoral Grant PD/BD/135162/2017, through the Doctoral Programme EcoCoRe.

This work was financially supported by: UID/ECI/04708/2019- CONSTRUCT - Instituto de I&D em Estruturas e Construções funded by national funds through the FCT/MCTES (PIDDAC).

Airtightness of building components

Bias and Precision errors in the Measurement of Building Component Airtightness with Direct Component Test

Speaker
Martin Prignon

Project **AirPath50** (2016 – 2020), funded by INNOVIRIS

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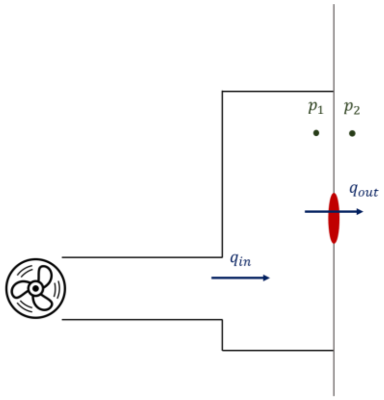
Direct testing of building components



At equilibrium:
q_{in} ➔ Δp constant
Δp ➔ q_{out}

Hypothesis :
$q_{\text{in}} = q_{\text{out}}$

Experimental setup

Pressure chamber

Duct linking the fan to the chamber

Manometer to measure airflows and pressure differences

Computer for data processing

Fan to pressurise or depressuise the chamber

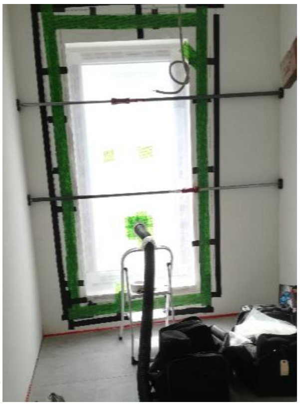
Calibrated disks to determine airflow

Range of measurement:

q_m = [0,17 ; 78,5] m^3/h

Δp_m = [0 ; 2500] Pa

Different experimental designs

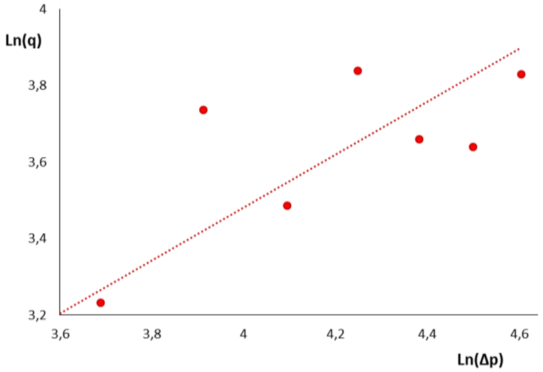


- Woodbox system
- Plastic-sheet system

Data processing (linear regression)

$$q = C(\Delta p)^n$$

$$\ln(q) = \underbrace{n}_{\text{Slope}}.\ln(\Delta p) + \underbrace{\ln(C)}_{\text{Intercept}} \longrightarrow C_L = e^{\ln(C)} \left(\frac{T_0}{T_i}\right)^{1-n}$$



$q_{50} = C_L(50)^n$

q_{50+} ; q_{50-} et q_{50m}
n_+ et n_-

OLS and WLOC

Experiments and methodology

① **Validation**

Large circular openings: $q = C_d\, A \sqrt{(2\Delta p)/\rho}$ **VS** *"In-situ"* measurement: $q = C_L(\Delta p)^n$

② **Bias errors**

Background leakage: airflow through the pressure chamber.

③ **Precision errors**

Repeatability tests:
- Direct with plastic sheet system
- Direct with wood-box system
- Direct with wood box system vs. indirect

Repeatability tests:
Multiple measurements on the same component conducted with the same equipment and by the same operator.

$$u(y) \approx \sigma$$

$$e(\sigma) = (2[N-1])^{-0,5}$$

Validation and background leakage

① and ②

	Calibrated Openings		Direct Component Test							
	A	q_{50}	$C_{L,+}$	n_+	$q_{50,+}$	$C_{L,-}$	n_-	$q_{50,-}$	q_{50}	
Opening 1	1.76	3.54	0.55	0.48	3.73	0.55	0.49	3.78	3.76	●
Opening 2	3.46	6.93	1.05	0.49	7.24	1.02	0.50	7.10	7.17	
Opening 3	7.07	14.15	2.21	0.48	14.48	2.10	0.49	14.23	14.36	
Opening 4	13.85	27.73	3.99	0.49	27.62	4.14	0.49	28.39	28.01	●

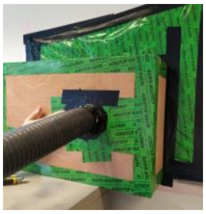
Δ_{max} in m³/h : 0,28 m³/h

Δ_{max} in % : 6,0 %

- Measurement error (random)
- Background leakage (systematic)

Background leakage:
measurement of a perfectly airtight component ($q_{50} \approx 0$).

$\delta q_b = 0{,}17$ m³/h at 50 Pa

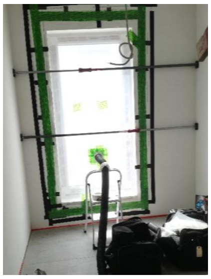


Repeatability of direct component testing

③

10 tests using the plastic-sheet system
wood window + interface with wall

➡ $u = 10\ \%\ (q_{50m})$; $4\ \%\ (n_+)$ and $10\ \%\ (n_-)$
$q_{50} = 0{,}56$ m³/(h.m) ; $n_+ = 0{,}85$ and $n_- = 0{,}81$



20 tests using the wood-box system
electrical outlet

➡ $u = 5\ \%\ (q_{50m})$; $3\ \%\ (n_+)$ and $2\ \%\ (n_-)$
$q_{50} = 0{,}84$ m³/h ; $n_+ = 0{,}69$ and $n_- = 0{,}69$

Comparison between direct et indirect methods ③

$q_{50,1}\ ;\ u(q_{50,1})$

$q_{50,2}\ ;\ u(q_{50,2})$

$$q_{50,c} = q_{50,2} - q_{50,1}$$

$$u(q_{50,c}) = \sqrt{u^2(q_{50,1}) + u^2(q_{50,2}) + 2\, r_{q_{50,1},q_{50,2}}\, u(q_{50,1})u(q_{50,2})}$$

Component measured:	Electrical outlet in a laundry room.
Direct testing:	20 tests using the woodbox system
Indirect testing:	20 tests of a limited zone (the laundry room) with an air leakage rate at 50 Pa ≈ 80 m³/h

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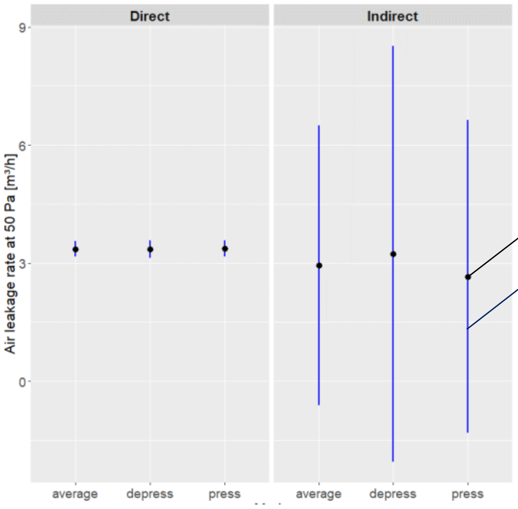
Results of the comparison ③



Mean of 20 tests

≈ 95% Confidence interval (2* standard deviation)

Direct method:
q_{50} = [3,16 ; 3,56] m³/h (u = 3 %)

Indirect method:
q_{50} = [0,0 ; 6,5] m³/h (u = 60,5 %)

Conclusions

The direct component test measures *in-situ* n and C values of building components with high reliability (between 3% and 10%, depending on the chamber design).

But:

- Must be replicated when measuring multiple components.
- Requires different pressure chambers depending on the component measured.
- Uses another equipment than the fan pressurisation test.

Most promising applications:

- Guarantee of good installation.
- Intermediate testing earlier in the construction process.
- Improving databases with reliable *in-situ* values including n.

Further work:

- Validation on components with $n > 0,5$.
- Study variables influencing uncertainty.
- Increase the upper limit of range of measurement (doors).

Comparison of airflow and acoustic measurements for evaluation of building air leakage paths in a laboratory test apparatus

AIVC Webinar – Better Quantifying and Locating Building Leakages

Benedikt Kölsch

German Aerospace Center (DLR) – Institute of Solar Research
Jülich, Germany

Supported by:
Federal Ministry
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on the basis of a decision
by the German Bundestag

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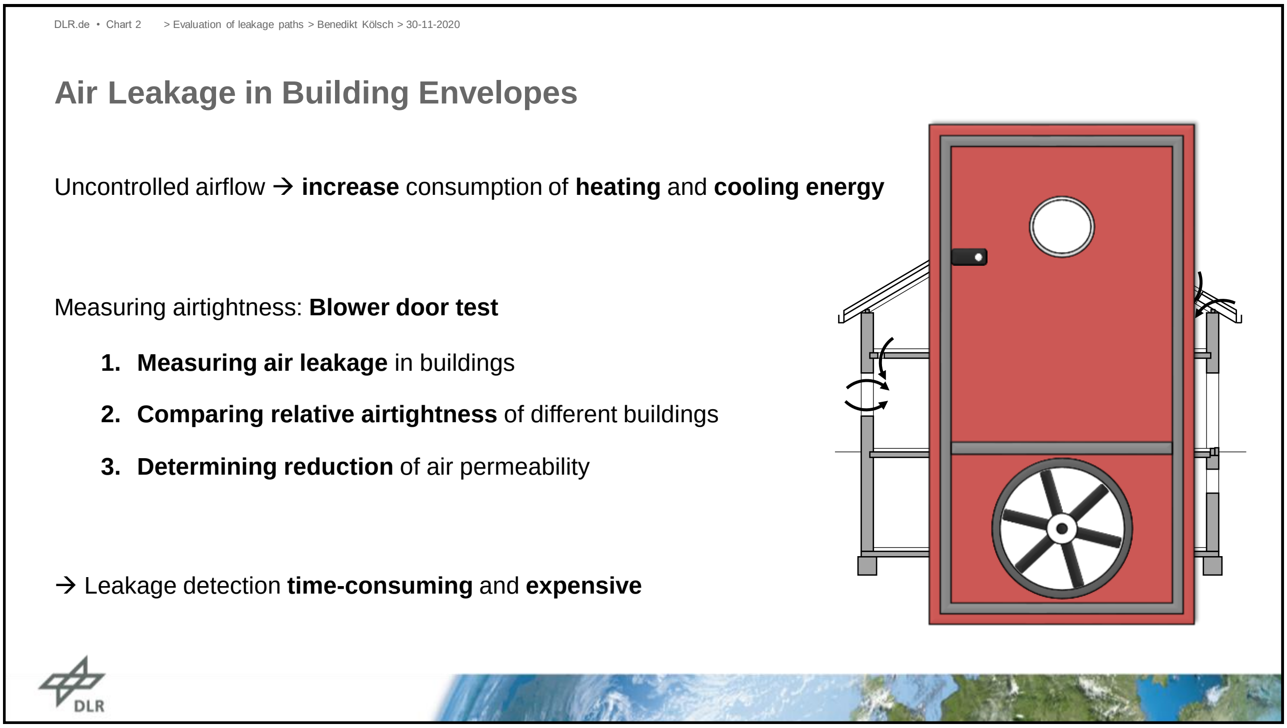
Knowledge for Tomorrow



Air Leakage in Building Envelopes

Uncontrolled airflow → **increase** consumption of **heating** and **cooling energy**

Measuring airtightness: **Blower door test**

1. **Measuring air leakage** in buildings
2. **Comparing relative airtightness** of different buildings
3. **Determining reduction** of air permeability

→ Leakage detection **time-consuming** and **expensive**

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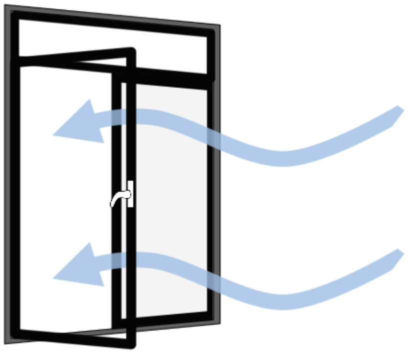
Why Acoustics?

Sound takes predominantly the **same paths** as **air** in fan pressurization method



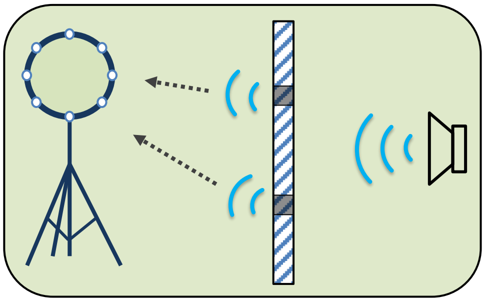
Why Acoustics?

Sound takes predominantly the **same paths** as **air** in fan pressurization method

Advantages:

- Can be applied while building is in use
- Independent from pressure or temperature differences
- Microphone arrays may localize leakage spots

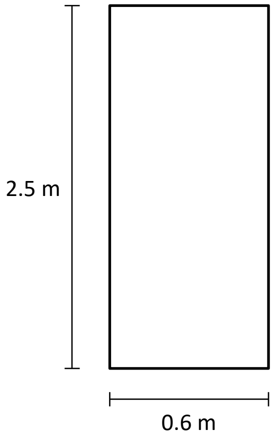
→ Size quantification difficult



Is leakage size quantification possible?

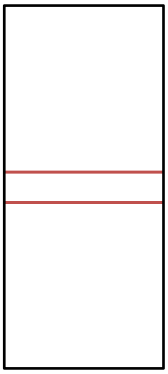
Laboratory Test Apparatus

Goal: Simulation of realistic leakage scenarios on model scale



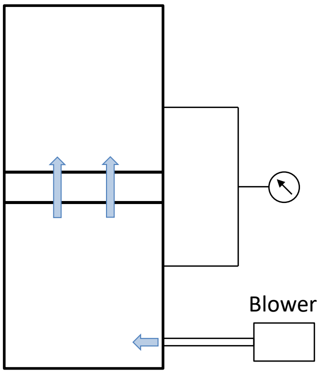
Laboratory Test Apparatus

Different wall configurations



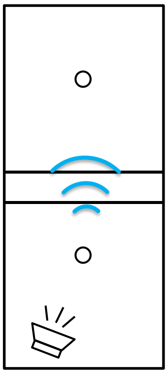
Laboratory Test Apparatus

Airflow Measurements



Laboratory Test Apparatus

Acoustic Measurements



Tested Leak Configurations

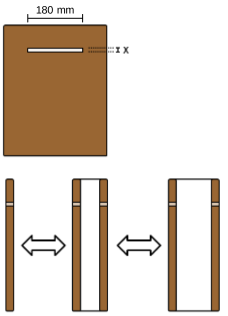
43 different wall configurations

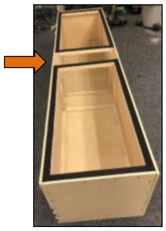
Tested Leak Configurations

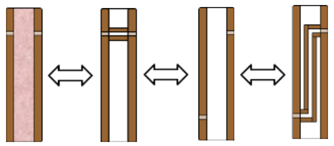
43 different wall configurations

Modified parameters:

- Variation of **slit heights**: 5, 1, 0.4, 0.25 mm
- **Number of walls**: Single wall or two walls with air gap
- **Distance** between **double-wall** constructions: 100 and 150 mm
- Measurements with/without **insulating material**
- **Connection of slits** at double wall with a channel
- **Non-parallel** leakage paths
- **Blank walls** without openings

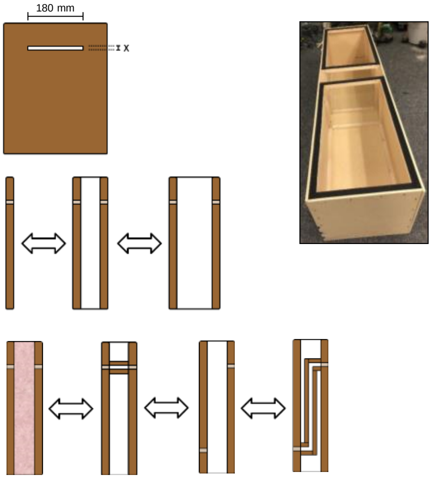




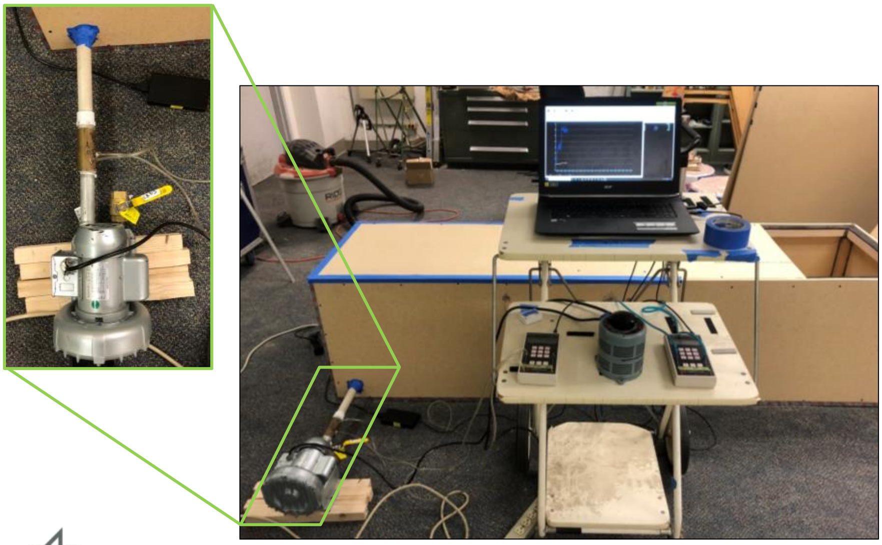


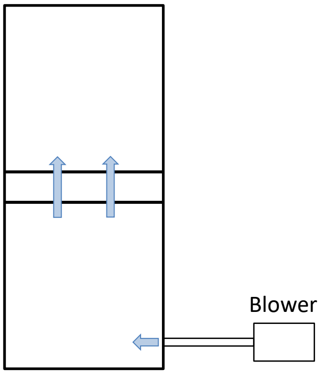
Tested Leak Configurations

43 different wall configurations

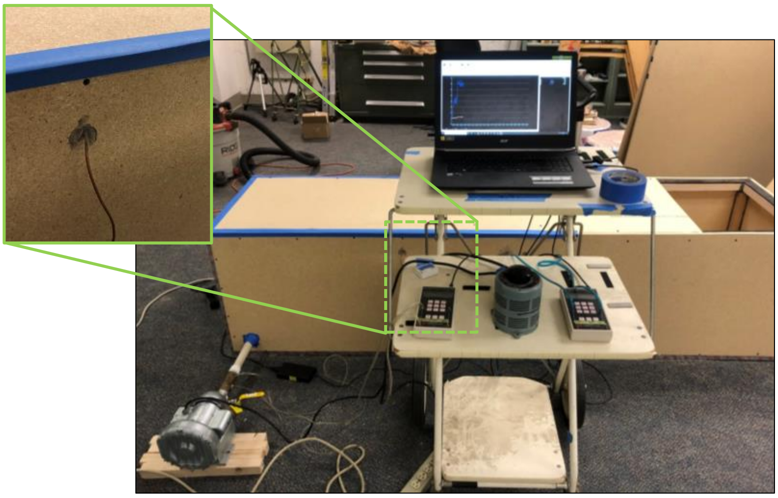


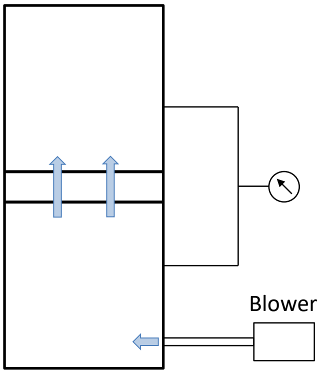
Airflow Measurements – Setup



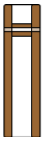


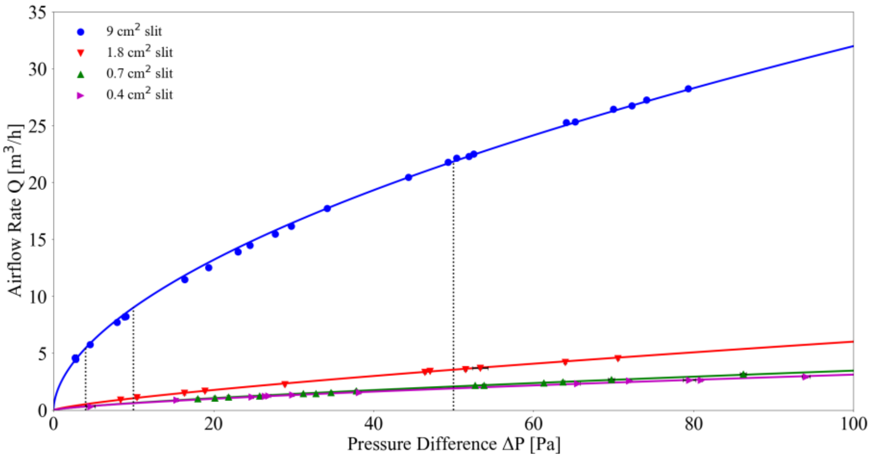
Airflow Measurements – Setup



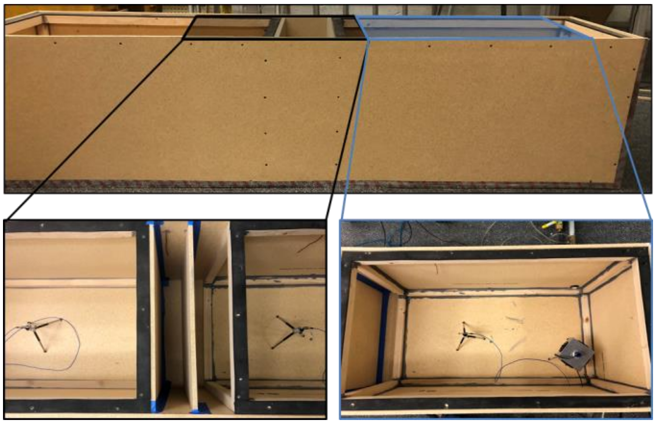


Airflow Measurements – Results





Acoustic Measurements – Setup



Microphones in both chambers

Speaker in one chamber

Excitation signal: White noise

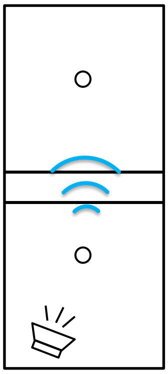
Frequency range: 0 – 40 kHz

Acoustic Measurements

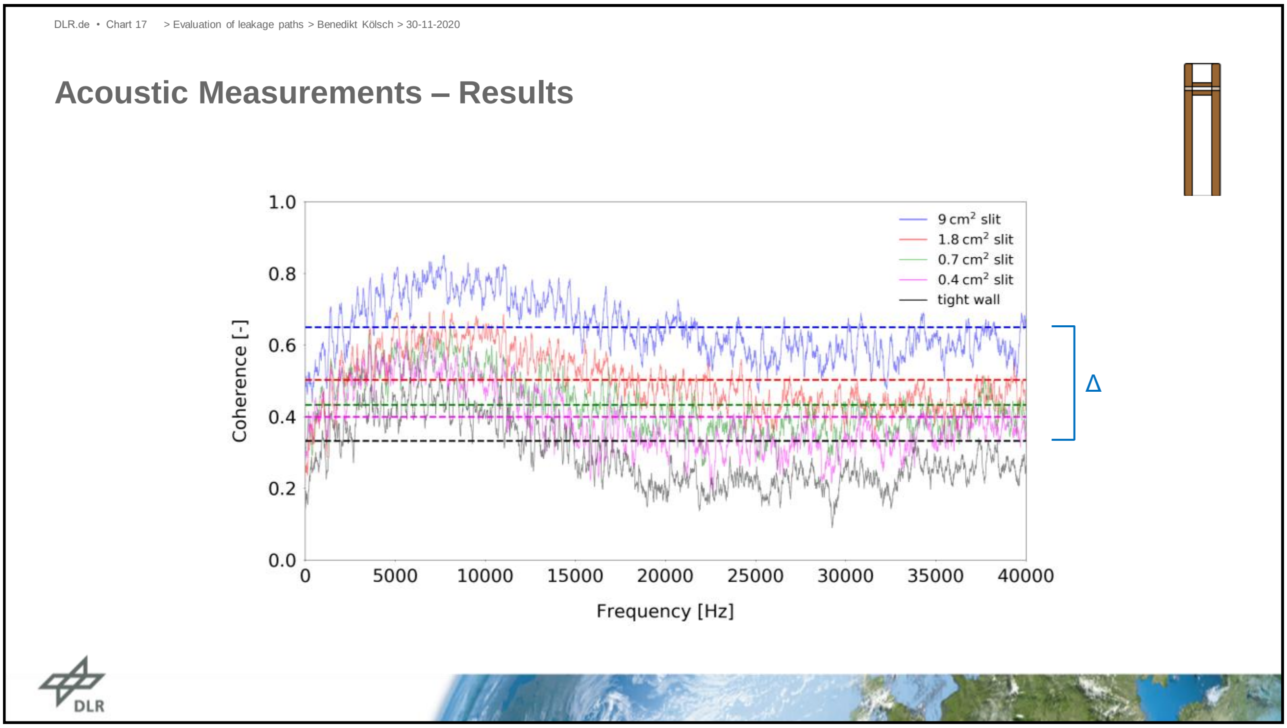
Coherence

Describes the fraction of an output signal from an input signal at a specific frequency

$$C_{xy}(f) = \frac{\left|G_{xy}(f)\right|^2}{G_{xx}(f) \cdot G_{yy}(f)}$$

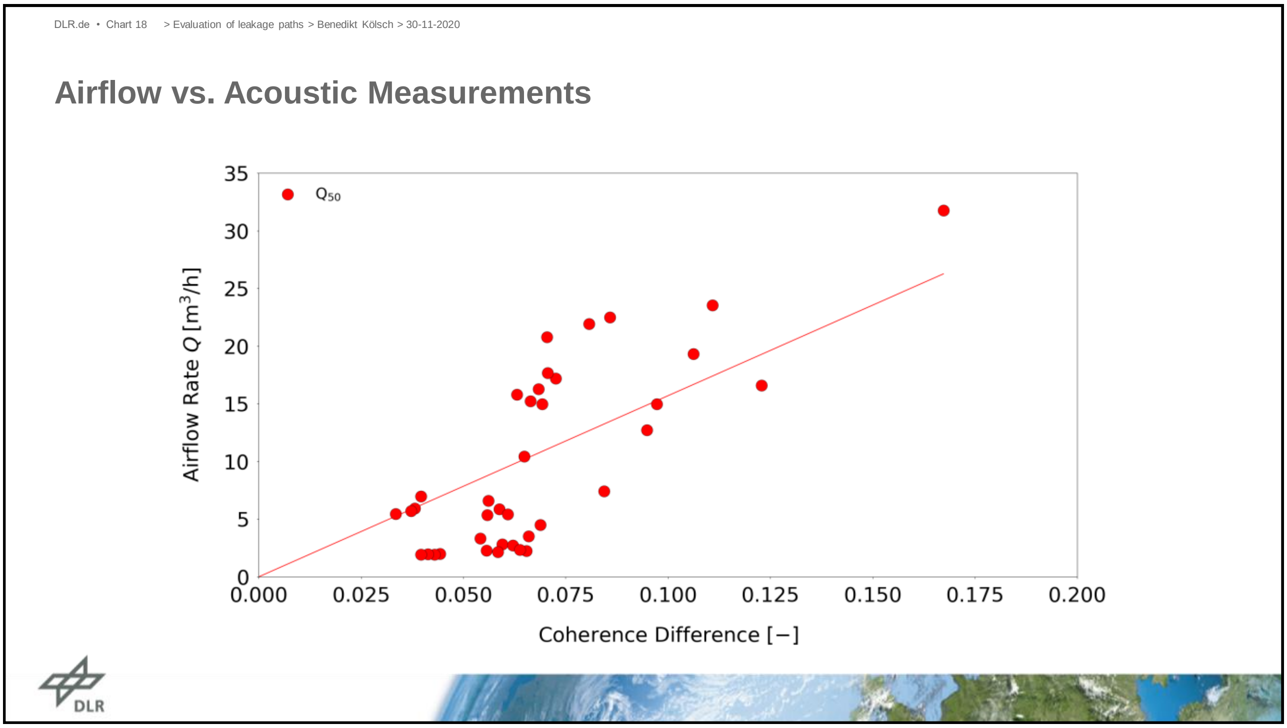


- Measure of the linear dependency between two discrete time signals x[n] and y[n]
- $0 \leq C_{XY}(f) \leq 1$



DLR.de • Chart 17 > Evaluation of leakage paths > Benedikt Kölsch > 30-11-2020

Acoustic Measurements – Results



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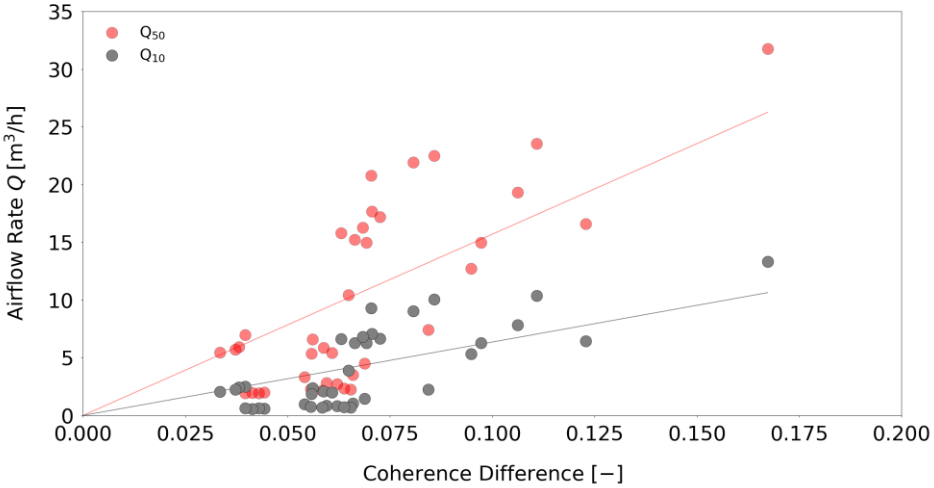
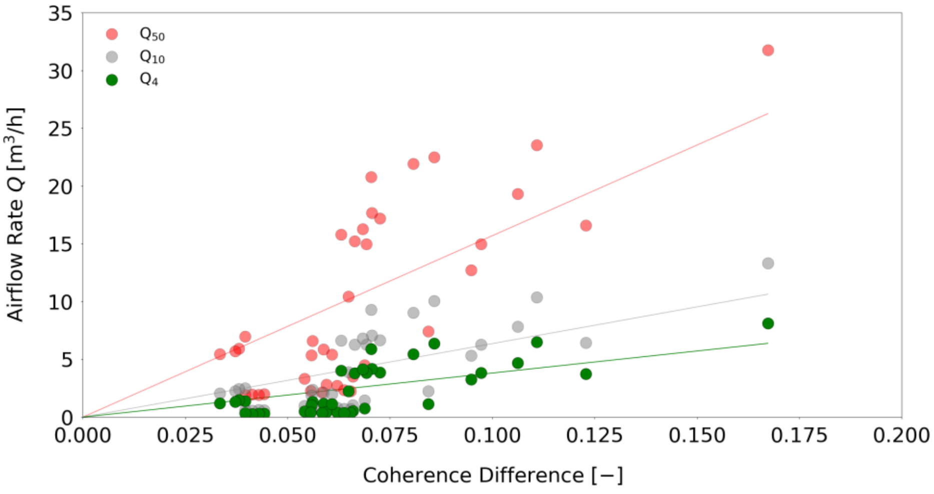
Airflow vs. Acoustic Measurements

Airflow vs. Acoustic Measurements



Airflow vs. Acoustic Measurements



Conclusion and Outlook

- **Airflow** and **acoustic measurements** in the same **laboratory** environment
- **43** different **leak configurations** were tested
- **Distinction** between different **leak sizes** possible

- **Weighting** of certain dominant **frequency bands**, instead of mean value may **increase** prediction **accuracy**
- More **complex** and **different leaks**
- Potential for **localization** of leaks using acoustics

Thank you

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