HUMANIC CBT4

Experimental Techniques for Analyzing and Visualizing the Performance of Air Distribution Systems

PROJECT 101119726 — HumanIC — HORIZON-MSCA-2022-DN-01

Simo Kilpeläinen

Outline

1. Introduction
2. Measurement techniques
3. Visualization techniques
4. How to choose the right methods?
5. Group exercise

Aalto University
Funded by the European Union

Introduction

- Plenty of techniques available for both measurement and visualization so a solution for your research probably exists

- Choice comes down to certain key factors but more on that later...

- Now let’s have a look at some of the methods

Aalto University
Funded by the European Union

Measurement techniques - Anemometers

Aalto University
Funded by the European Union

Anemometers - General

- Used for measuring air movement
- Four typical variants
  - Hot-wire
  - Hot-sphere
  - Rotating vane
  - Ultrasonic

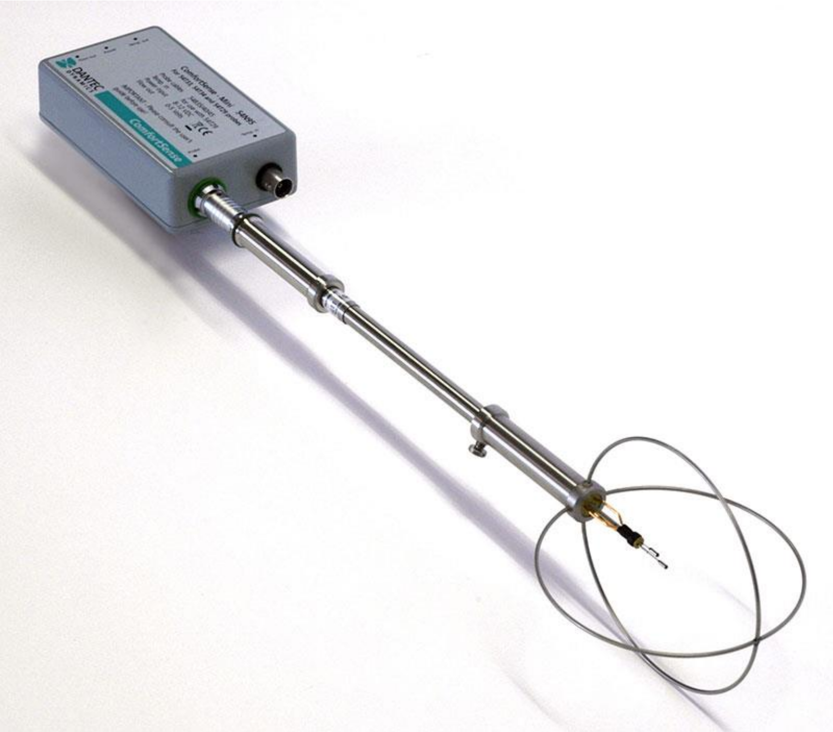


Image source: https://www.dantecdynamics.com/solutions/thermal-comfort/comfortsense-mini/

Aalto University

Funded by the European Union

Anemometers – Hot-wire anemometer

- Works by heating thin wire with electric current
  - Wire resistance depends on temperature
  - Moving air cools the wire down → decreased resistance
  - Most common variant keeps T constant and air velocity can be obtained from change in I
- 2D-sensor so needs to be aligned with the flow
- Accuracy typically 3-5 % of reading
- Small in size so fits tight spaces

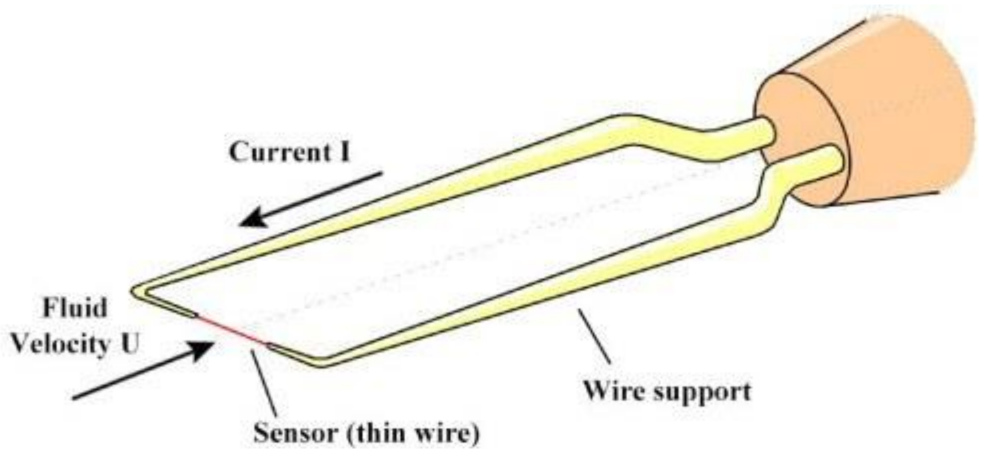


Image source: https://site.unibo.it/ciclope/en/work-with-us/cfd-study-of-the-flow-inside-ventilation-helmet

Aalto University
Funded by the European Union

Anemometers – Hot-sphere anemometer

- Similar working principle as hot-wire
- Has two spheres; one heated and one not
  - Constant T difference kept between them
  - Airflow results in change of I required for maintaining this difference
- Omnidirectional so gives air speed instead of velocity
- Has a thermistor for T measurement
- Accuracy similar to hot-wire
- Can detect very small air speeds (>0.05 m/s)

Image source https://vbn.aau.dk/files/213980388/Air_Temperature_Measurements_Using_Dantec_Draught_Probes.pdf

Aalto University

Funded by the European Union

Anemometers – Rotating vane anemometer

- Based on rotating blades, like a small wind turbine
- Needs to be aligned with the flov
- Velocity detection limit ~0.2 m/s
- Large size prevents use in tight spaces
- Typically more accurate (~1 % of reading) than hot-wire/-sphere types

Aalto University

Funded by the European Union

Image source https://tsi.com/getmetafile/9a70bdb5-2b66-434f-ac4f-a2c528304605/995

Anemometers – Ultrasonic anemometer

- Measures the propagation of ultrasound in air
- True omnidirectional measurement, gives all 3 velocity components
- Accurate (1 % of reading)
- Can measure velocities up from 0 m/s
- Often used for outdoor wind measurement but lab versions also exist
- Very expensive compared to other types

Image source https://www.mrclab.com/Media/Uploads/WindMaster_G(1).jpg

Aalto University

Funded by the European Union

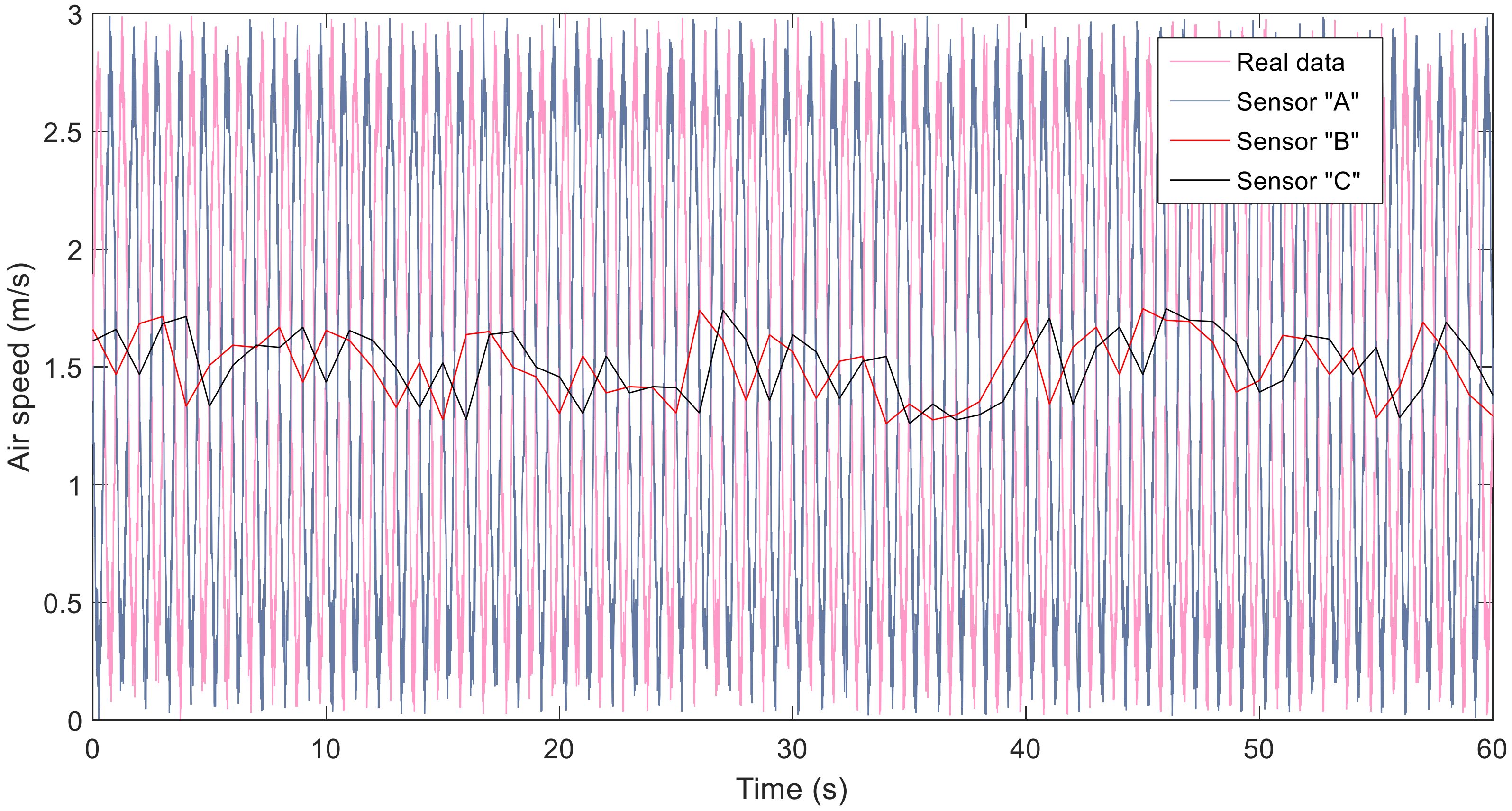
Anemometer case examples

Case 1: Rapidly varying airflow

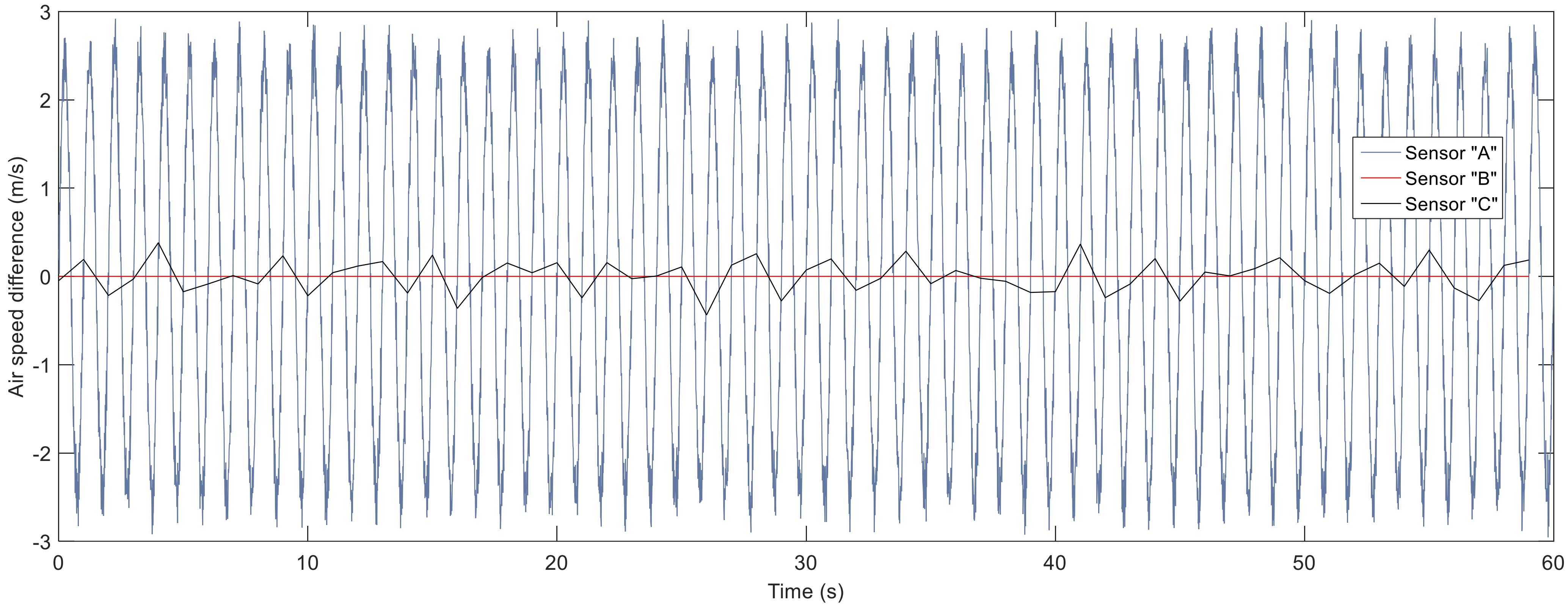
- Three different hypothetical anemometers:
  - A: real-time sampling, 350ms (step) response time
  - B: 10 Hz sampling frequency, instant response
  - C: 10 Hz sampling frequency, 100ms (step) response time

Aalto University
Funded by the European Union

Case 1: Rapidly varying airflow



Case 1: Rapidly varying airflow



Aalto University

Funded by the European Union

Case 1: Rapidly varying airflow

- Sinusoidal demo data → mean air speed same (1.5 m/s) for all anemometers
  - Not necessarily true in a real case
- Standard deviation much lower with 10 Hz sampling frequency (peaks cut out)
- Slow response time → measured and real data different at a given time instant
- Large sampling frequency → data points missed between measurements

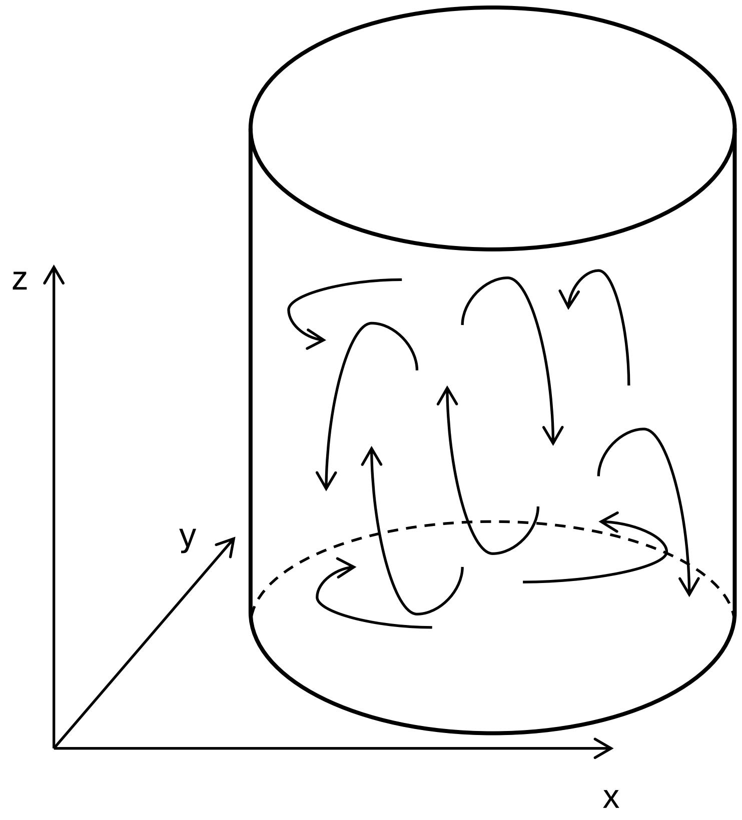
Aalto University

Funded by the European Union

Case 2: Very turbulent flow

- Two anemometers:
  - A: Hot-sphere anemometer
  - B: 3D Ultrasonic anemometer

- Example of 10 consecutive measurement readings



Aalto University

Funded by the European Union

Case 2: Very turbulent flow

	1	2	3	4	5	6	7	8	9	10
”A” v(m/s)	2.06	2.24	1.87	2.08	2.00	2.26	1.73	1.73	2.00	1.83
”B” v_x(m/s)	1.00	-1.00	0.50	1.20	0.00	-0.50	1.00	-0.50	2.00	1.80
”B” v_y(m/s)	-1.00	0.00	1.50	1.70	0.00	0.00	1.00	1.50	0.00	-0.30
”B” v_z(m/s)	1.50	2.00	1.00	0.00	2.00	-2.20	1.00	-0.70	0.00	0.10

Aalto University

Funded by the European Union

Case 2: Very turbulent flow

- Omnidirectional hot-sphere anemometer gives almost the same reading for all 10 measurements
  - False assumption of a stable flow field

- Ultrasonic anemometer that measures velocity instead of speed reveals the truth

Measurement techniques – Laser Doppler anemometry/velocimetry

Aalto University

Funded by the European Union

Laser Doppler anemometry - General

- Extremely accurate and fast method for measuring flow velocity in a single point
- Split laser beam is focused onto the measurement point
- Any particle passing the point scatters the light
  - Seed particles released into flow for this purpose
- Scattered light detected by photo detector
- Intensity of scattered light fluctuates according to Doppler shift between incident and scattered light
  - Frequency proportional to velocity component in the plane of the two laser beams

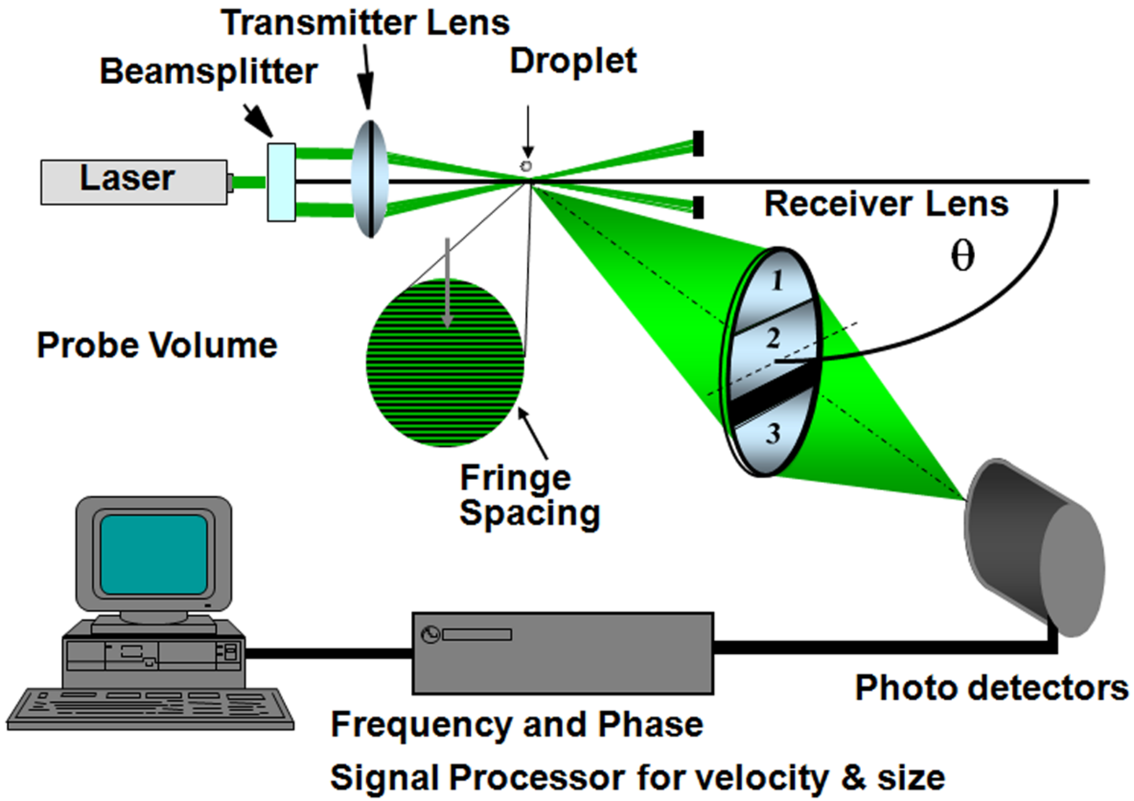


Image source https://www.lavision.de/cms_images/techniques/LDV-PDI.png

Aalto University
Funded by the European Union

Laser Doppler anemometry - Continued

- Very expensive due to lasers + high-precision optics
- Non-intrusive so does not disturb the flow
- As a laser-based technique often combined with PIV
- Possible to use multiple lasers to obtain 2 or 3 velocity components
- Best suited for uniform flow fields due to single-point measurement
  - Grid of points can be measured by moving the laser(s)

Aalto University

Funded by the European Union

Measurement techniques – Tracer gas

Aalto University

Funded by the European Union

Tracer gas - General

- Method for studying air movement in enclosed spaces
- Useful for obtaining mean age of air + ventilation effectiveness
- Based on releasing a gaseous tracer that moves along with the airflows and then measuring it from designated locations
- Typical gases include CO_2, SF_6, N_2O

Aalto University
Funded by the European Union

Tracer gas – Decay method

- Tracer gas released before the measurement and injection stopped when the measurement starts
- Concentration will decay exponentially
  - Rate of decay proportional to local ventilation effectiveness
- Requires uniform conditions (= full mixing) so not suitable for point sources unless only one location is considered

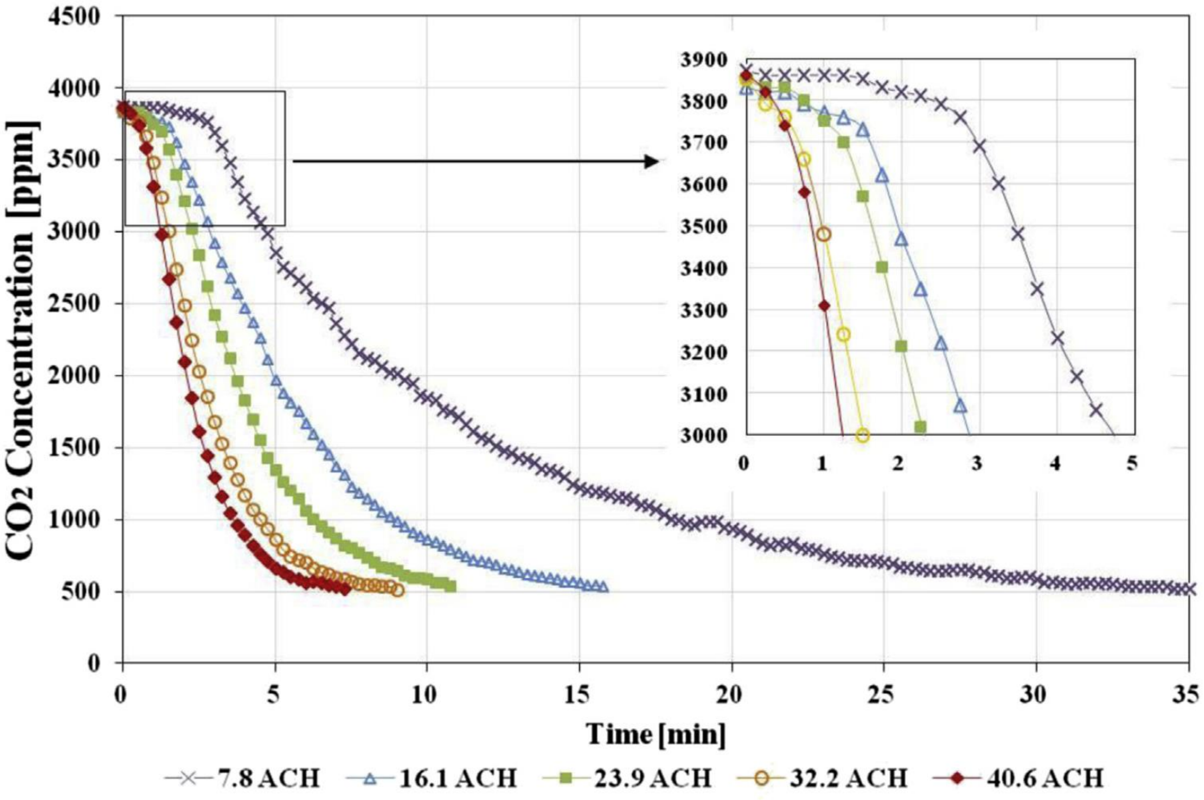


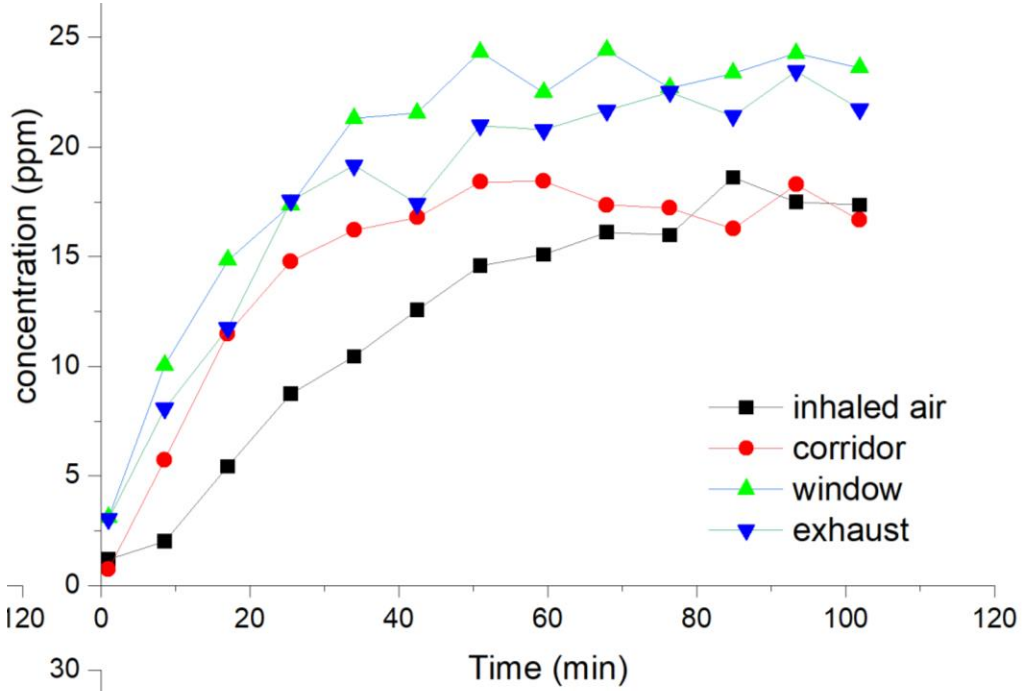
Image source S. Cui et al., Building and Environment 84 (2015) 162-169

Aalto University

Funded by the European Union

Tracer gas – Integral method

- Tracer gas release started at the start of measurement
- Concentration ramps up over time and eventually reaches equilibrium level in all measurement locations
  - Levels can be compared to assess local air quality
- Slower than decay method
- Useful also for point sources



Tracer gas – Selection of gas

- CO_2
  - 1.5 times heavier than air → moves well with airflows
  - Non-toxic
  - Present in atmosphere and exhaled by breathing organisms → background level + source consideration
- SF_6
  - 5 times heavier than air → trajectories can be somewhat different than air especially in weak flow fields
  - Non-toxic
  - Not naturally present anywhere
- N_2O
  - 1.5 times heavier than air → moves well with airflows
  - Can be toxic in long-term exposure, “laughing gas”
  - Present in atmosphere in very small concentrations, similarly sized molecules present and can cause false positives

Aalto University
Funded by the European Union

Tracer gas – Release into the room

- Can be released via supply air when studying an external contaminant source or using the decay method
- Point source can be modelled either with a simple gas tube (continuous release directly into the room) or by releasing the tracer gas into a chamber e.g. lungs of a breathing manikin

Aalto University
Funded by the European Union

Tracer gas – Measurement

- Typically measured with a (multi-)gas analyzer
  - Can detect very small concentrations down to ppb range
  - Accuracy ~1-5 %
  - Long response time (~10 s)
  - Can be connected to multipoint sampler for multi-channel measurement
  - With multiple channels response time N*10 s for each channel (N = number of channels)
  - Expensive (10000€+)

- In case of CO_2 also logging sensors available
  - Accuracy similar at high (> 1000 ppm) concentrations but worse at lower ones
  - Response time even longer than gas analyzer (30 s – 1 min)
  - Calibration needed often due to sensor drift
  - Inexpensive (a few hundred euros each)

Aalto University
Funded by the European Union

Measurement techniques – Aerosols

Aerosols - General

- Not directly for assessing ventilation performance but relevant in this context
- Comprises measuring liquid droplets or solid particles from air (particulate matter)
- Typically used for simulating e.g. pathogens, dust, pollen and other fine particles in air

Aalto University

Funded by the European Union

Aerosols – Generation

- Test aerosols usually a mixture of pressurized air and either solid particles or a liquid
- Choice of particle source (mostly) defines size distribution of test aerosol
- Created with atomizers (liquid aerosol) or dust generators (solid aerosol)

HumanIC

Aalto University

Funded by the European Union

Aerosols – Release and measurement

- For releasing, principles largely the same as with tracer gas
  - Release via manikin not recommended as the droplets/particles may get stuck in the lung system's tubes
  - Decay and integral methods can be used in the same way
- Measurements with particle counters and sizers
  - PM1, PM2.5, PM10, custom-size bins
  - Number vs. mass concentration

Funded by the European Union

Visualization techniques – Smoke

Smoke – Theater smoke

- Generated by a smoke machine
- In HVAC applications, released into supply air ducts to visualize air distribution operation

Aalto University

Funded by the European Union

Smoke – Handheld smoke

- Generated by a handheld smoke machine or a single-use smoke tube
- Can be used to visualize e.g. heat gains, local flow patterns, air leaks

Visualization techniques – Particle Image Velocimetry

Aalto University

Funded by the European Union

Particle Image Velocimetry - General

- Laser-based visualization technique, probably more commonly known by its abbreviation “PIV”
- Can be used for visualizing both gas or liquid flows
- Also a measurement technique as it gives magnitudes of velocity vectors
- Accompanies high-speed camera(s) in addition to the laser
- Expensive, usually has a small area-of-interest
- Like LDA, non-intrusive so a good technique when you do not want to disturb the flow pattern

Aalto University
Funded by the European Union

Particle Image Velocimetry – Working principle

- Laser beam is widened into a sheet with optics
- Seed particles in the sheet are illuminated by the laser light
- High-speed camera captures consecutive images of the lit particles → it can be found where each particle moved in the time it took to shoot the two camera frames

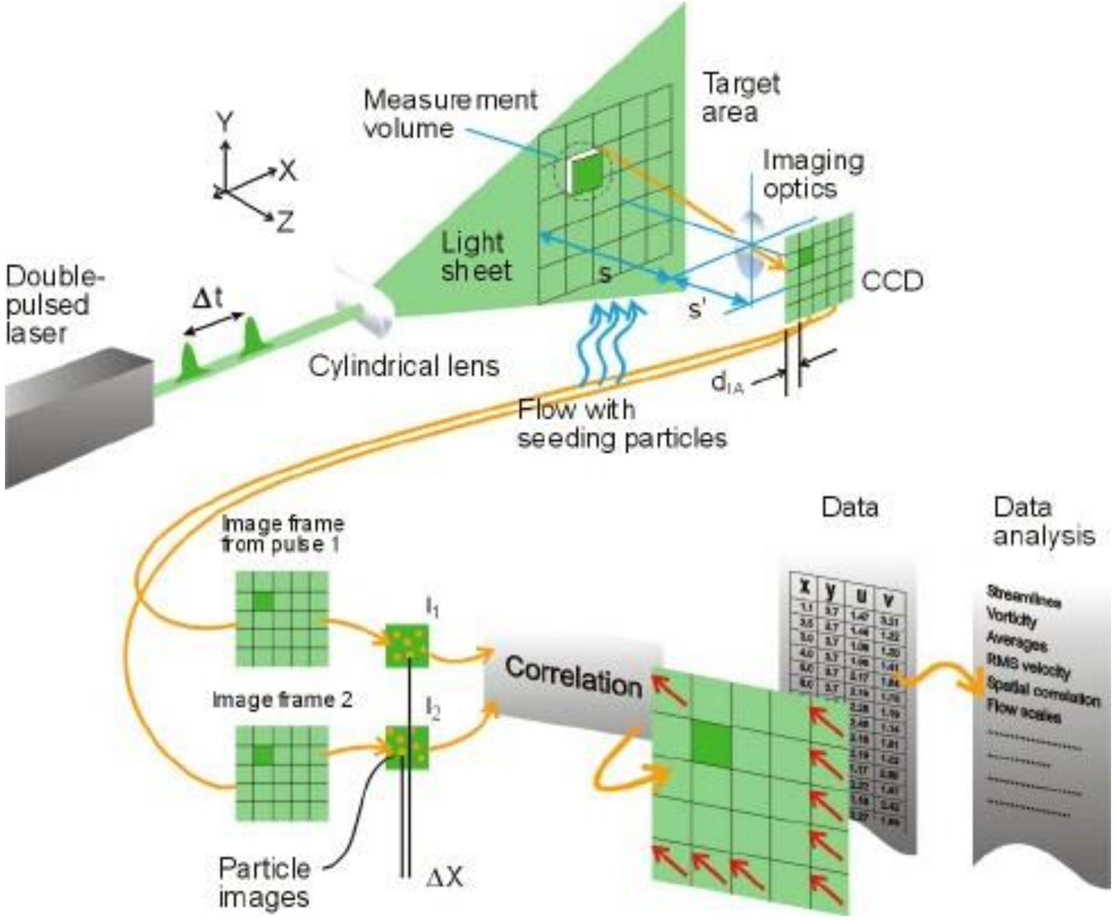


Image source https://www.dantecdynamics.com/wp-content/uploads/2019/11/piv_overveiw.jpg

Aalto University
Funded by the European Union

Particle Image Velocimetry – Variants

- Simplest configuration 2D-PIV
  - Single CCD camera, can obtain velocity components in the plane of the laser light sheet
- 2D3C-PIV (stereoscopic PIV)
  - Adds a second camera, uses Scheimpflug condition to calculate the 3rd velocity component
- 3D-PIV (tomographic PIV)
  - Utilizes 3,4 or even up to 8 cameras to capture true 3D particle movement

Aalto University
Funded by the European Union

How to choose the right methods?

How to choose the right methods?

- As seen in previous slides, plenty of techniques to choose from
- Answer to the question rarely unambiguous but choices can often be narrowed down

How to choose the right methods? Some general guidelines

- What are you measuring?
- What are you trying to find out?
- How accurate do you need your results to be?
- How much time do you have available for your project?
- What is your budget?

Aalto University
Funded by the European Union

Group exercise

Funded by
the European Union

Group exercise - Instructions

- You are charged with investigating and improving the air distribution system of a specific hospital space (group's choice, can be e.g., operation theatre, ward…)
- There is a fully functional mock-up of the space available but no instrumentation
- Discuss in the group which instruments you would need to purchase to complete the task. Justify your choices. Consider a realistic budget so you can't buy all the expensive equipment.
- Present your findings to the other groups

Aalto University

Funded by the European Union


Aalto-yliopisto
Aalto-universitetet
Aalto University
Funded by the
European Union

Thank you!