In-situ dew point measurements: no need to worry about sampling uncertainties?

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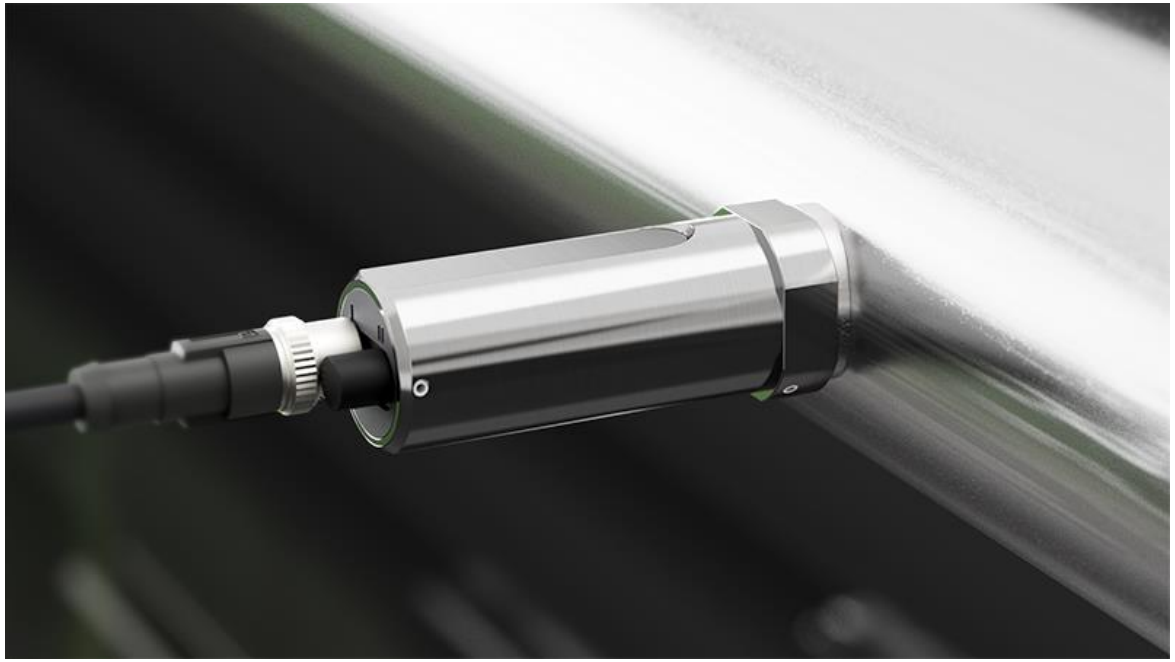
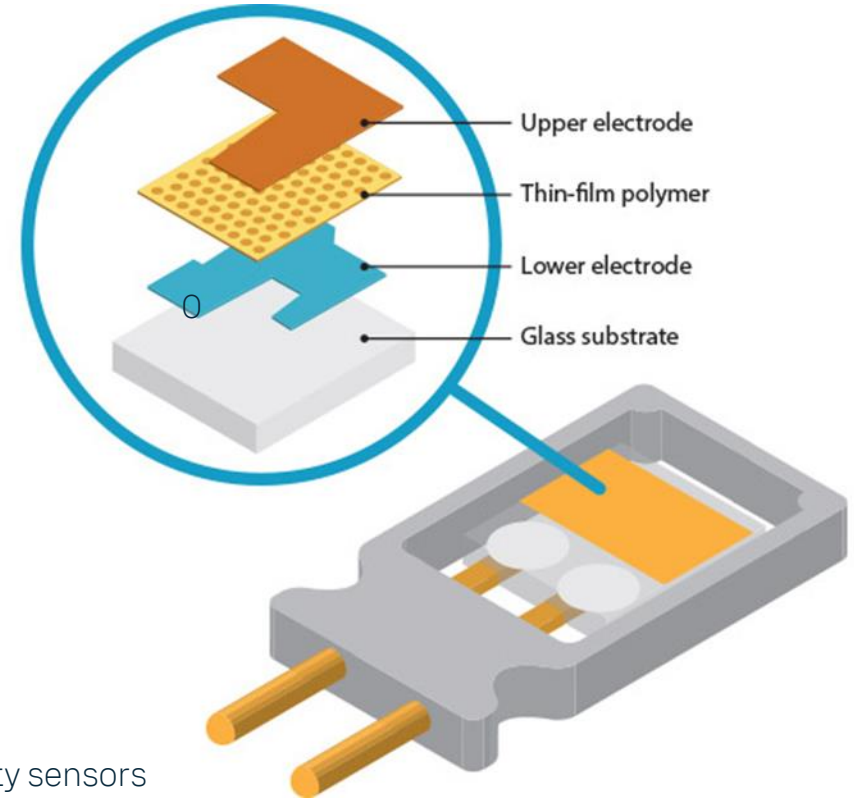


Background

- My background is in humidity metrology
  - In charge of MIKES, the national metrology institute in Finland, humidity lab at the end of my MIKES career
  - Doctoral thesis about humidity metrology, 2015
- Vaisala
  - www.vaisala.com: "Taking every measure for the planet"
  - >2300 employees, 28% works in R&D, >25 offices globally, sensors on two planets
  - Established in 1936, developed capacitive humidity sensors in 1973
  - 2023 net sales 540.4 M€
- In-situ vs laboratory measurements
  - New R&D building and bad laboratory temperature control + performance of new humidity sensors
    - → Humidity sensors could be used to measure temperature
    - → Similar bad "temperature control" must exist in industry and outdoors



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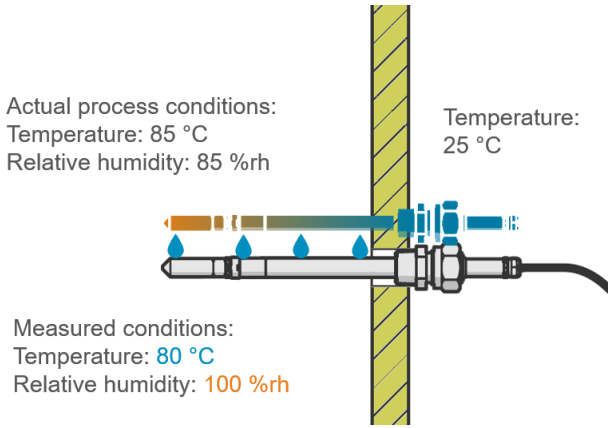
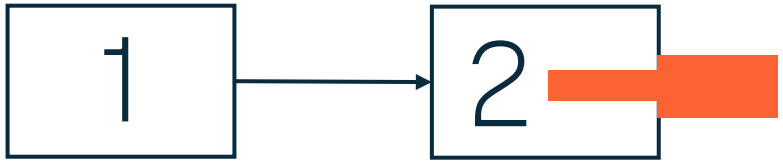
Uncertainties in humidity measurements - not as straightforward as commonly thought

- Uncertainties of "accuracy":
  - Calibration
  - Resolution
  - Adjustment
- Uncertainties from instruments:
  - Drifts
  - Dependencies
    - E.g. temperature, pressure, flow
  - Direct vs indirect effects
    - E.g. sensor vs. electronics
  - Response time
  - Averaging
- Uncertainties from application:
  - Stability of environment
  - Heat conductance
  - Leakages
  - Representativity of readings
  - Impurities



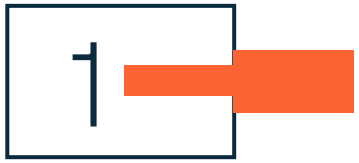
In-situ vs laboratory measurements – more or less uncertainties?

- Typical laboratory measurement set-up:



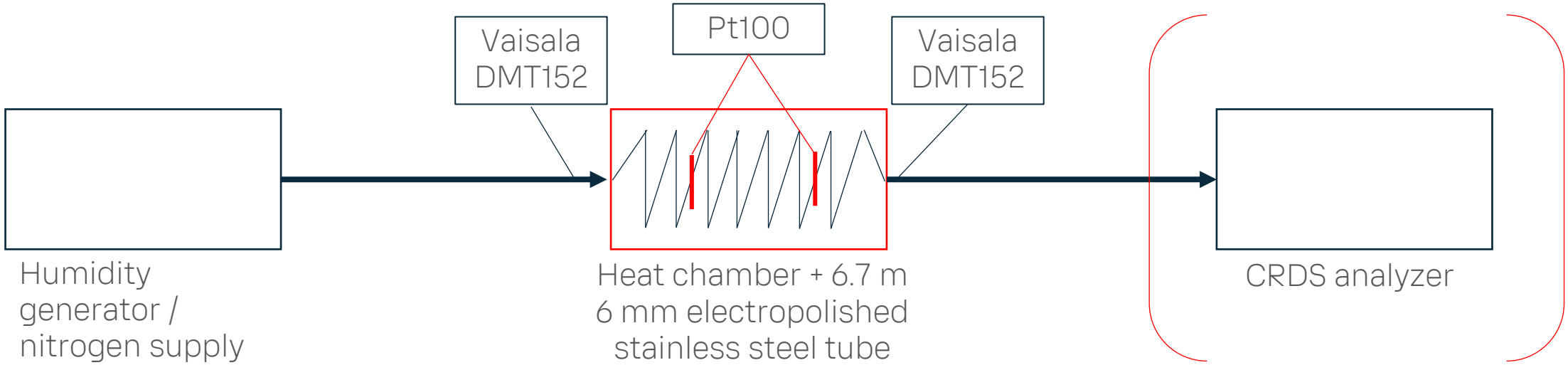
  - 1 = Gas source, humidity that you are interested in
  - 2 = Measurement instrument
- Pros & cons:
  - Better environment for the measurement instrument?
  - Gas sampling i.e. tubing & connectors?
  - Averaging?

- Typical in-situ set-up:

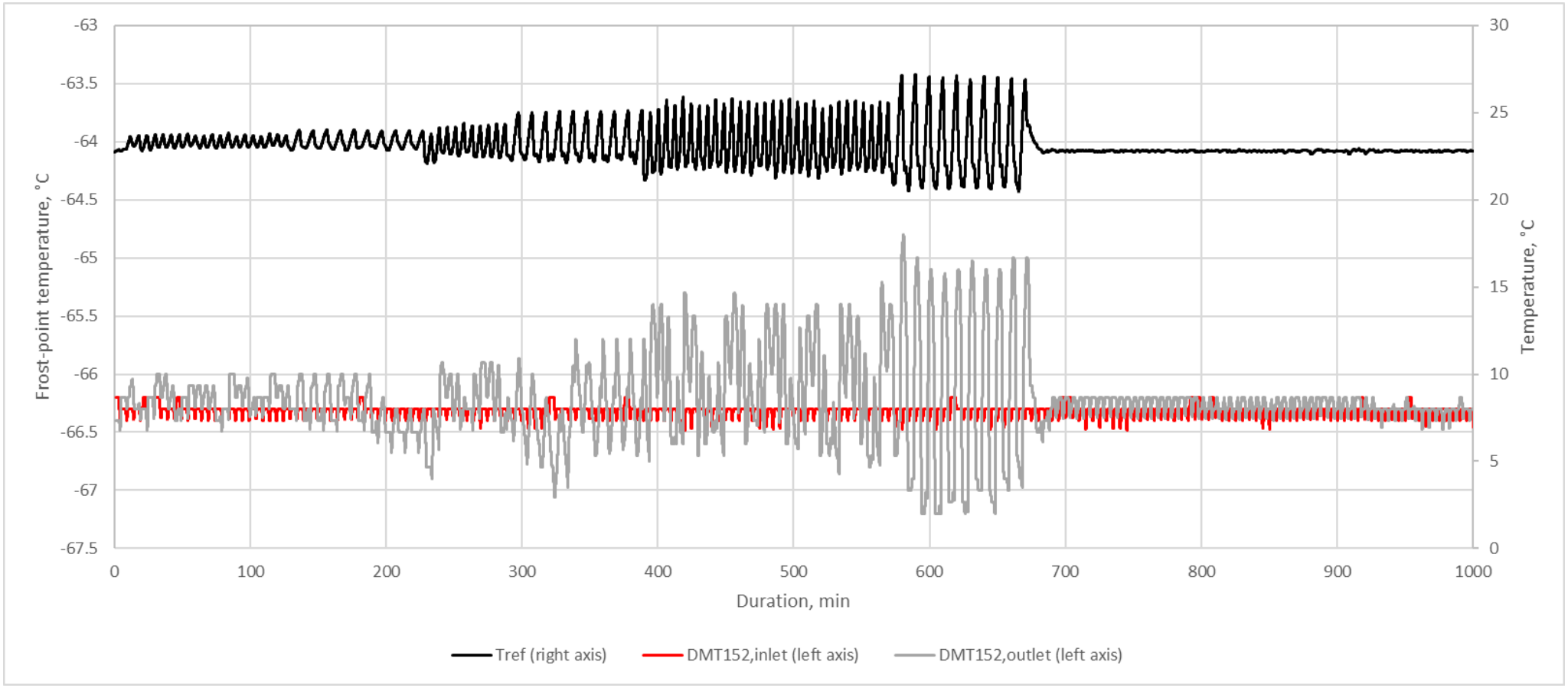


  - 1 = Gas source and in-situ measurement
- Pros & cons:
  - Only the actual gas effects?
  - More challenging environment for the instrumentation?
  - Representativity of measurement?

Experiments

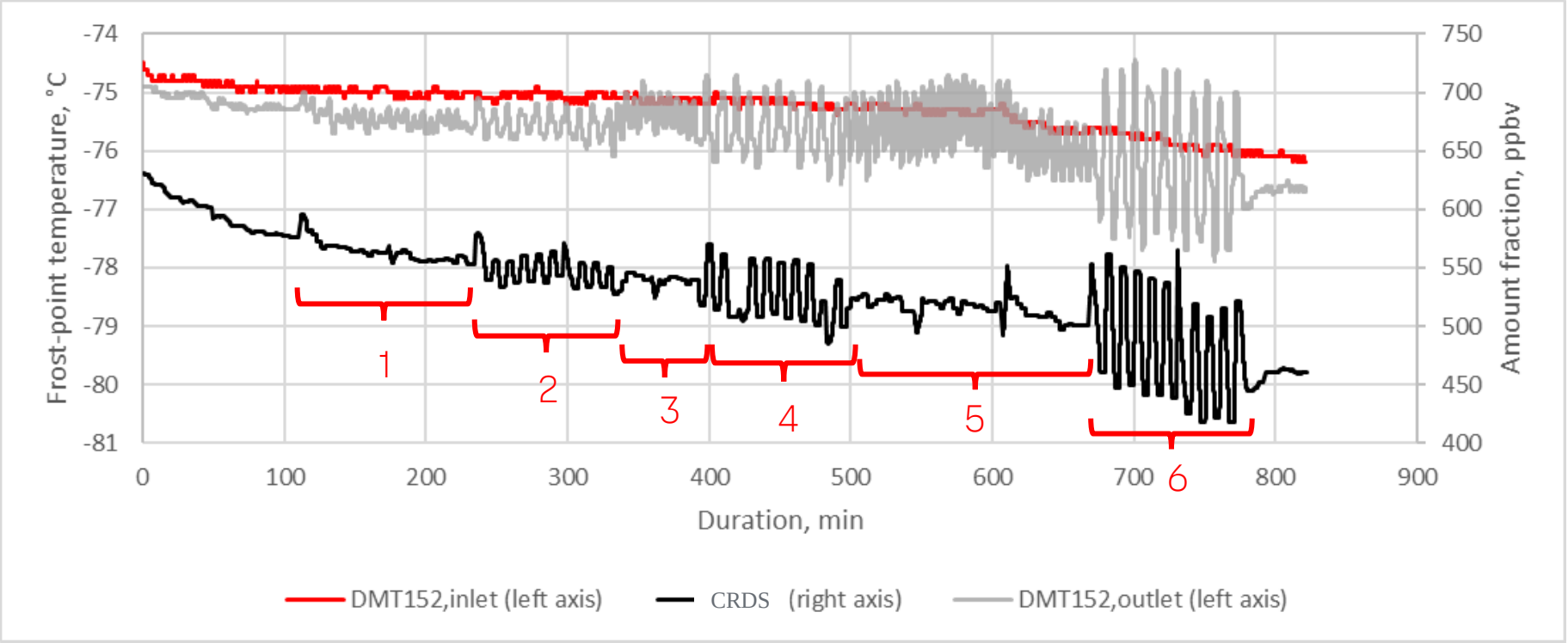


Experiments



Experiments

- Temperature ramp (setpoints):
  1. +/- 1 °C / 3 min
  2. +/- 1 °C / 5 min
  3. +/- 3 °C / 3 min
  4. +/- 3 °C / 5 min
  5. +/- 6 °C / 3 min
  6. +/- 6 °C / 5 min
- Time constants?
  - Real temperature?
    - Chamber vs tube?
- Real ramp?



Truth & comparison of accuracy specifications

- About 15 transmitters/probes from about 10 different manufacturers were tested
  - For Vaisala goal was to understand market situation
  - All references in the measurements were SI traceable, “metrology institute level”
    - Tested transmitters were connected to the same environment at the same time
  - All test devices were “industrial” (< 5000 €) with specification of about +/- 2 °C

- Purpose of this presentation
  - Share knowledge about the wild west of dew point transmitter markets
  - Provide ideas/things to consider or test when sourcing a dew point transmitter
  - Not to sell Vaisala products ☺ - anonymous results

Dew point error at constant +30 °C temperature

- Measured errors vary from -16 °C to + 27 °C
  - According to the specs errors should have been within about +/- 2 °C
- Most of the instruments were out of their specs at some measurement point

Temperature dependency at dew point -50 °C

- Measured errors vary from -15 °C to +15 °C
  - According to the specs errors should have been within about +/- 2 °C
- Most of the instruments were out of their specs at some measurement point
- All instruments were more or less within their specifications at about +21 °C which is likely their adjustment temperature and therefore their performance is optimized for that temperature
  - In some cases the +21 °C temperature point was the only point within the specs

Repeatability

- In the test dew point temperature was kept constant while temperature was ramped from 0 °C → 20 °C → 40 °C → 20 °C → 0 °C
- For two instruments repeatability was worse than +/- 2 °C
- In case of some instruments temperature dependency was seen: measured values formed 3 groups, one for each temperature
- For most of the instruments repeatability was better than +/- 0.5 °C

Short-term stability @ Tf -50 °C

- Most of the test devices drifted in a 3-day period after 3 days of stabilization time 0.3 °C – 0.5 °C
- No drift was detected from two instruments
- One sensors drifted more than 2 °C (note! specs +/- 2 °C)
- Few instruments indicated noisy readings
- Few instruments did not drift at all
- Generally, sensors based on aluminum oxide technology drifted more than the others

Response times

- Response times were longer for wet (-40 °C) to dry (-75 °C) than dry to wet
- Results indicated huge variation (rounded to closest integer)
  - From dry to wet t63 measured response times varied between 0 min - 4 min
  - From dry to wet t90 measured response times varied between 0 min – 9 min
  - From wet to dry t63 measured response times varied between 1 min – 54 min
  - From wet to dry t90 measured response times varied between 4 min – 284 min
- Slowest responses especially toward dry were indicated by aluminum oxide sensors

Other remarks

- Some instruments are calibrated against references that cannot meet all the calibration points!
- Similarly specifications may reveal something e.g. lack of response time → slow
- Does the instrument measure dew point or frost point temperature?

Conclusions & Discussion

- Adsorption/desorption can be a significant source of uncertainty in humidity measurements
  - In this study, by disturbing only tube temperature, maximum frost-point temperature change is more than 4 °C
  - For labs: does humidity noise decrease linearly with temperature noise?
- Some manufacturers have taken significant shortcuts
  - Is the calibration too difficult & expensive and thus the real performance has not been revealed?
- Pay attention to calibration certificates and ask an example before decision to buy
  - Some conclusions can be drawn from lack of uncertainties
- Ask, if it is possible to have a calibration (certificate) for your specific calibration points?
  - Factory calibration certificates covering "only adjustment points" do not represent the whole measurement range

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