Lab for Measurement Technology

UNIVERSITÄT DES SAARLANDES

ASIC Air Sensors International Conference
May 11-13, 2022

Session 4C: Indoor Sensing for Air Quality and Ventilation Applications

Standardized test instructions and test gases for VOC detectors for indoor air quality measurement

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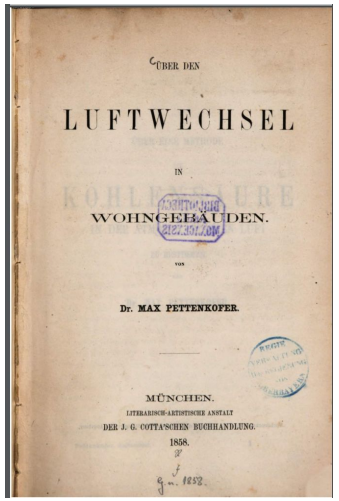
May 12, 2022

Introduction: Pettenkofer Limit

- Max von Pettenkofer (1818 – 1901) wrote 1858:

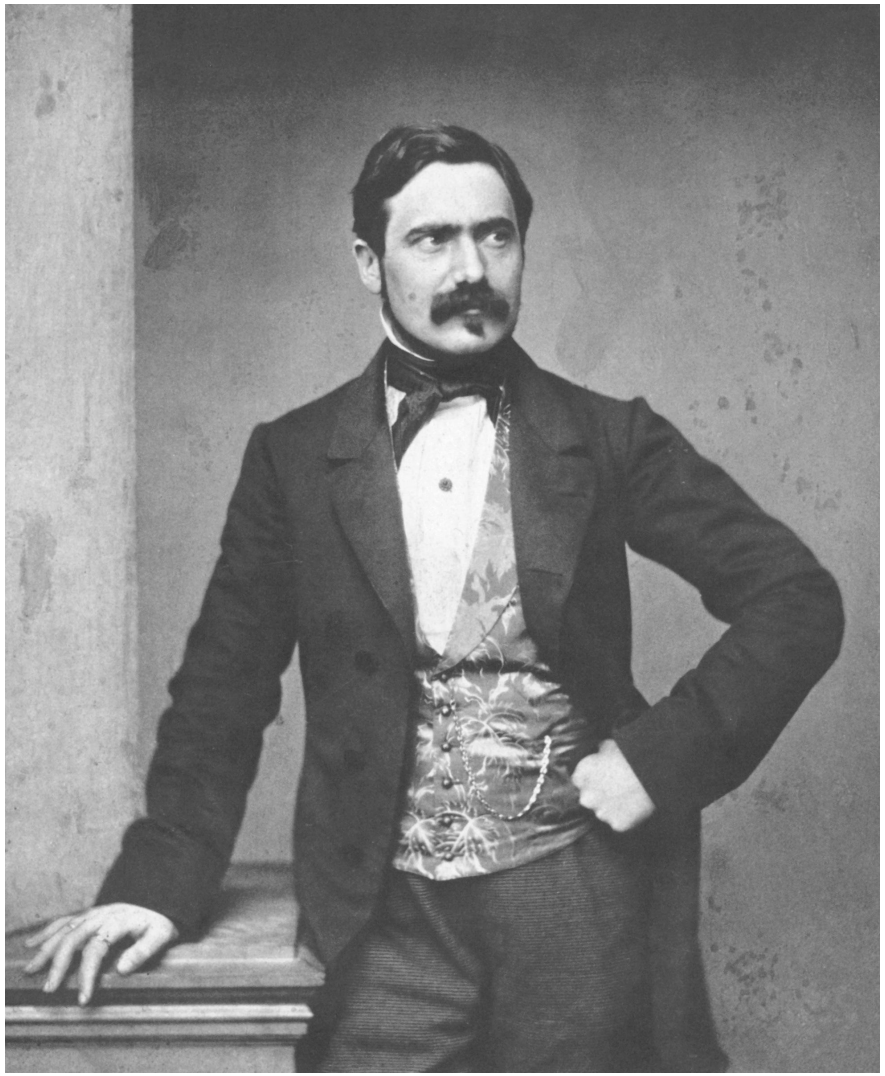


Above all, the organic compounds, "which betray themselves by the smell when they accumulate", can serve as a benchmark for the air quality, "but unfortunately we have no method of determining it quantitatively". "So we have no other clue than the carbon dioxide."

  - CO_2 as indicator or proxy for VOCs emitted by people (VOC: volatile organic compounds)

- **Shouldn´t we rather measure VOCs directly?**

  Can also indicate pollutants from furniture, building materials, cooking, air fresheners, etc.



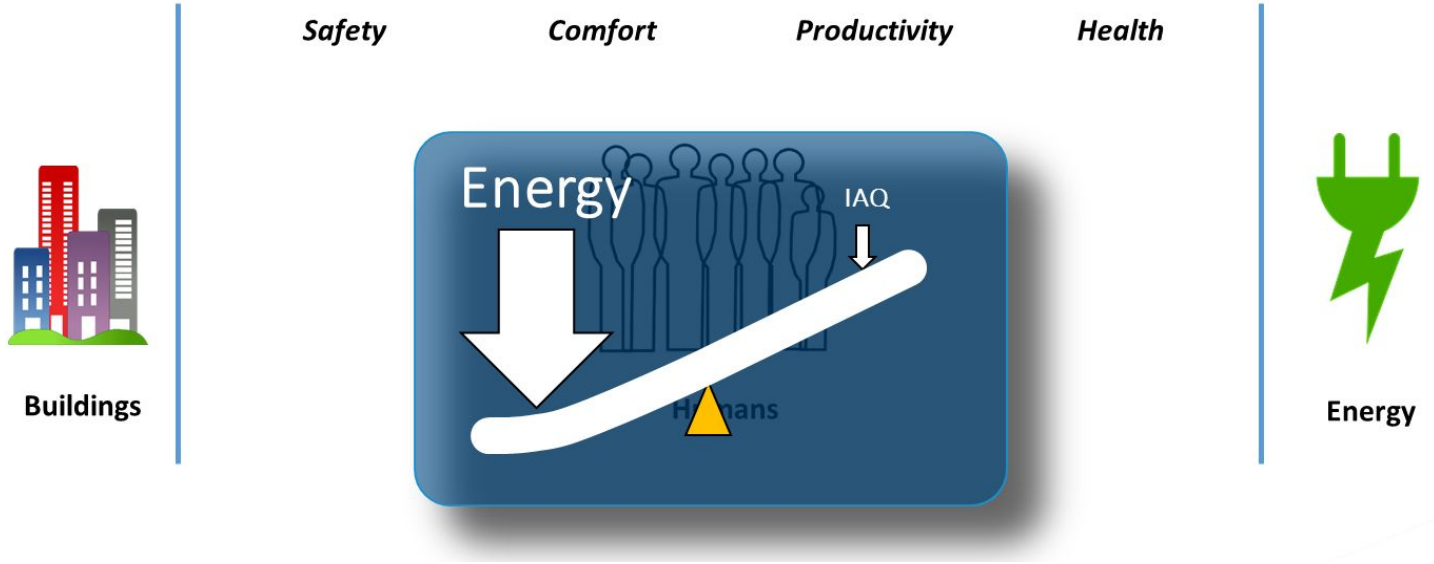
Max von Pettenkofer, https://en.wikipedia.org/wiki/Max_Joseph_von_Pettenkofer

Indoor Air Quality

Pollutants in indoor air

- Chemicals from furniture, building materials
- PM (smoking, candles!)
- CO, NO_2 (stoves, fireplaces,…)
- Mold
- Radon
- Outdoor air

- **People**
  we „consume“ the air



Mats Sándor (Systemair AB, Sweden): Presentation at Indoor Air 2016, Ghent, Belgium

Solution: ventilation

… but ventilation is costly (increased energy consumption)

Monitoring Indoor Air Quality

Air quality is one target in the sustainable development goals set by the United Nations for 2030

- Accurate monitoring of Indoor Air Quality
- Volatile organic compounds are one of the main pollutants of concern indoors

Demand for sensors and measuring devices for continuous monitoring indoors

- Low-cost gas sensors for quantification of the total concentration of volatile organic compounds (TVOC)

https://www.andatechdistribution.com.au/blogs/resources/indoor-air-quality-infographic

New Generation of Gas Sensors

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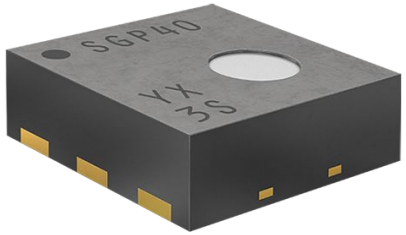
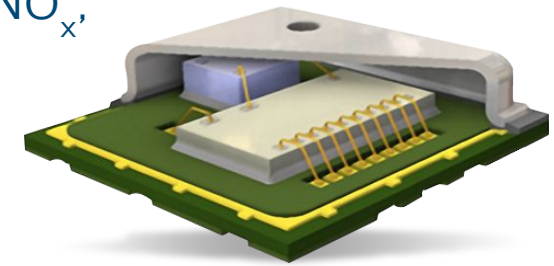
Metal oxide semiconductor (MOS) gas sensors

- Tremendous effort from many industrial players to provide novel “digital” gas sensors
- Small & low-cost for mobile applications
- Low-power consumption
- Integrated microprocessor and signal processing
- For reducing (VOC, CO) and oxidizing gases (NO_x, O_3)
- **Monitoring TVOC for IAQ**
- **Problem: VOC value outputs differ from manufacturer to manufacturer and are not comparable**

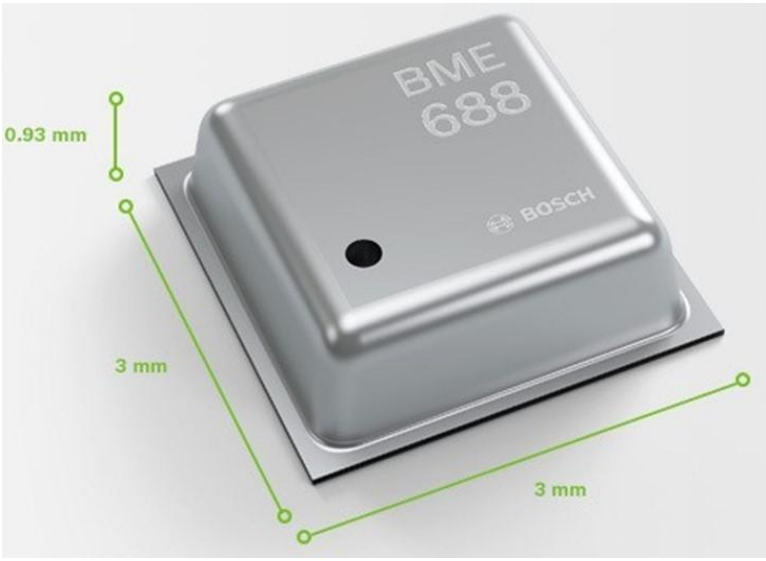


SGP40: Sensirion AG, Stäfa, Switzerland

ENS160: Sciosense B.V., Eindhoven, Netherlands



ZMOD4410: Renesas Electronics Corporation, Tokyo, Japan



BME688: Bosch Sensortec GmbH, Reutlingen, Germany

Existing Standard ISO 16000-29

Test gas mixture depends on detector type

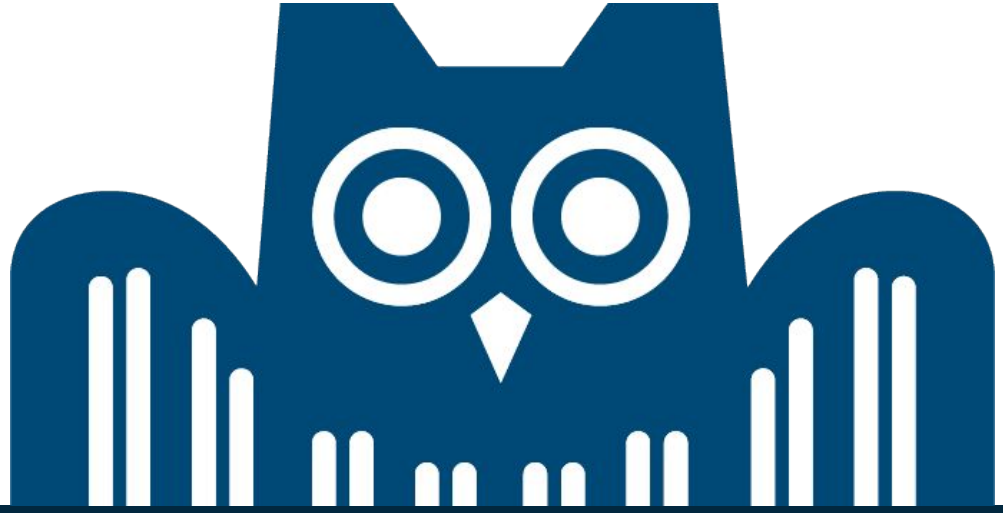
- MOS gas sensor: mixture of n-Octane and Xylene
- PID-type: mixture of Toluene, n-Decane, α-Pinene & Methyl isobutyl ketone (MIBK)
- Interference-Enhanced-Reflector-Type: mixture of Toluene, n-Decan, α-Pinene, Methyl isobutyl ketone (MIBK), 1,4-Dichlorobenzene & Butyl acetate
- Fixed ratio between components

Ignoring interfering gases (except CO_2)

- MOS gas sensor: Hydrogen and carbon monoxide background and variation have to be considered

Tests are sensor specific and do not reflect complex gas mixtures in real environment

Developing a Guideline



VDI/VDE-GMA FA 2.62 Multigas Sensors

- Committee initiated by the workshop “Setting standards for low-cost Air Quality sensors” held in Berlin in 2019
- VDI/VDE-GMA, the society for measurement and automation technology of the two leading German engineering associations VDI and VDE
- Developing a technology-agnostic guideline for VOC detectors for indoor air quality measurements
- As starting point for an international standard

Members

Representatives of leading companies and institutions related to VOC sensors and IAQ:

- Dr. Richard Fix
- Dr. Carlo Tiebe
- Tobias Baur
- Christoph Hammer
- Dr. Frank Kuebart
- Dr. Christian Meyer
- Prof. Dr. Andreas Schütze
- Dr. Ulf Struckmeier
- Hendrik Wölper
- and other experts

Simulating the Complex Indoor Environment

Contrary to the analytical classification of VOCs dividing in VOC substance groups

- Suitable for sensors, since the measuring principle is based on reactions with molecules

Testing sensor systems with complex mixtures of VOCs

- Realistic environmental mixtures with variable rations of the individual components

Add permanent background gases

- CO_2, CO, H_2, NO_x plus humidity

VOC Representatives according to AGÖF, UBA

AGÖF (2007): Supply of a data base about the occurrence of volatile organic compounds in indoor air

AGÖF (2014): Conflict of Goals between Energy-efficient Buildings and Good Indoor Air Quality - Data Collection of Volatile Organic Compounds in Indoor Air of Residential and Office Buildings

UBA (2010): German Environmental Survey on Children (GerES IV)

AGÖF: Association of Ecological Research Institutes, Germany

UBA: German Environment Agency

VOC substance group	Representative 1	Representative 2	Representative 3	Source
Aldehyde	Formaldehyde	Acetaldehyde	Hexanal	Food, fragrance additives
Alkane	Hexane	Undecane	Cyclohexane	From outside: exhaust & fuel
Alcohol	Ethanol	2-Propanol	1-Propanol	Cleaner, disinfectant
Aromatics	Toluene	Xylene	-	Solvents
Ester	Ethyl acetate	n-Butyl acetate	-	Solvents, cooking
Ketone	Acetone	Butanone	-	Solvents, human metabolism
Organic Acid	Acetic acid	Propiolic acid	Caproic acid	Cleaning products
Terpene	Limonene	Alpha-pinene	3-Carene	Fragrance additives

- Alkene, Halocarbons, Glycols & Glycol ethers: negligible
- Cyclic siloxanes (D3 – D6): very low concentrations, but relevant as sensor poison → separate investigation

Test Scenario

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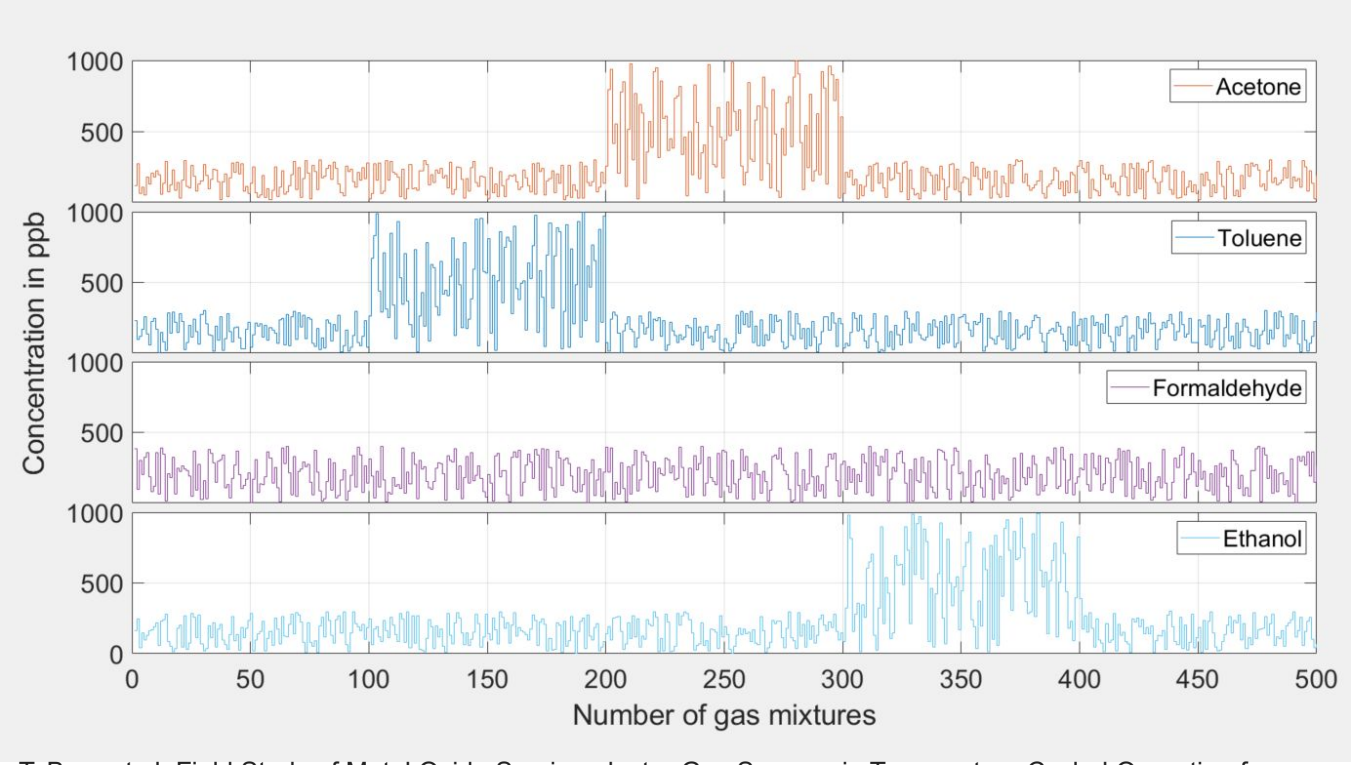
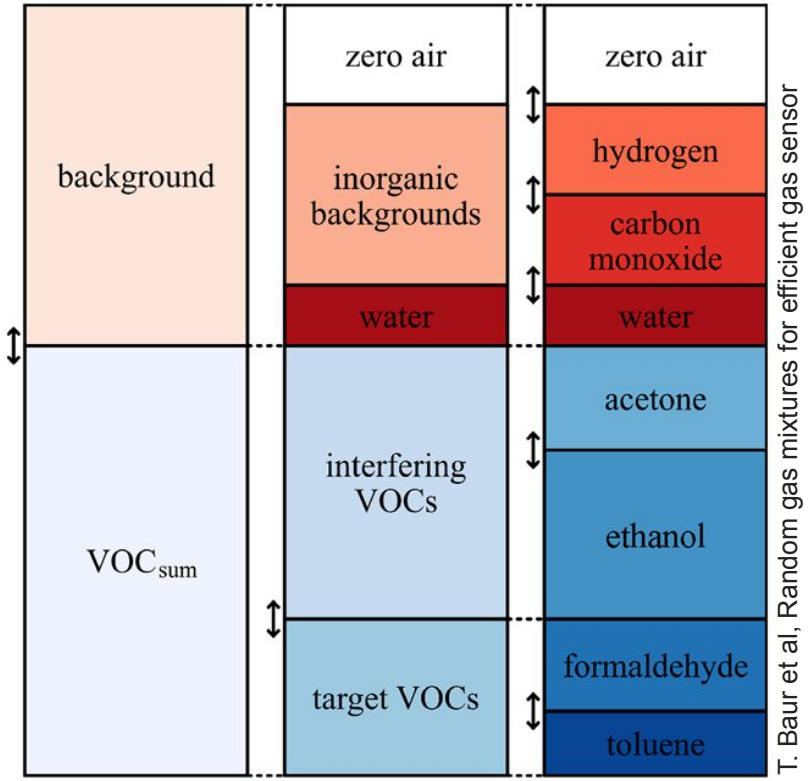
Tests are based on random mixtures in the relevant concentration ranges for each gas component to simulate real-world environments in a well-controlled laboratory test



T. Baur et al. Field Study of Metal Oxide Semiconductor Gas Sensors in Temperature Cycled Operation for Selective VOC Monitoring in Indoor Air. *Atmosphere*. 2021; 12(5):647.



T. Baur et al, Random gas mixtures for efficient gas sensor calibration. *Journal of Sensors and Sensor Systems*, 2020; 9(2), 411-424. DOI: https://doi.org/10.5194/jss-9-411-2020

Indoor Air Quality Index

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One further goal is to define a simplified Indoor Air Quality Index (IAQI) based on VOC concentrations similar to the six level AQI of the EPA for outdoor pollutants.

Daily AQI Color	Levels of Concern	Values of Index	Description of Air Quality
Green	Good	0 to 50	Air quality is satisfactory, and air pollution poses little or no risk.
Yellow	Moderate	51 to 100	Air quality is acceptable. However, there may be a risk for some people, particularly those who are unusually sensitive to air pollution.
Orange	Unhealthy for Sensitive Groups	101 to 150	Members of sensitive groups may experience health effects. The general public is less likely to be affected.
Red	Unhealthy	151 to 200	Some members of the general public may experience health effects; members of sensitive groups may experience more serious health effects.
Purple	Very Unhealthy	201 to 300	Health alert: The risk of health effects is increased for everyone.
Maroon	Hazardous	301 and higher	Health warning of emergency conditions: everyone is more likely to be affected.

The U.S. Air Quality Index (AQI), Technical Assistance Document for the Reporting of Daily Air Quality – the Air Quality Index (AQI), EPA 454/B-18-007, September 2018, https://www.airnow.gov/sites/default/files/2020-05/aqi-technical-assistance-document-sept2018.pdf

- TVOC ↔ IAQI: Establish a conversion from a $TVOC_{sens}$ value to an index
- Difficult to recommend a health classification

Outlook

- Next presentation in this session 4C: *Low-cost high-performance VOC sensor systems: comparison with analytical measurements and long-term stability*
- National project VOC4IAQ to provide a scientific base for standardization
  - Extensive lab and field experiments
  - Ensure high test standard

Industrielle Gemeinschaftsforschung

Forschungsnetzwerk Mittelstand

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