MOS VOC sensors’ properties and suitability for DCV control

Analysis based on laboratory measurements

IEA Annex 68 & AIVC joint Webinar “Using Metal Oxide Semiconductor (MOS) sensors to measure Volatile Organic Compounds (VOC) for ventilation control” | 4 September 2018

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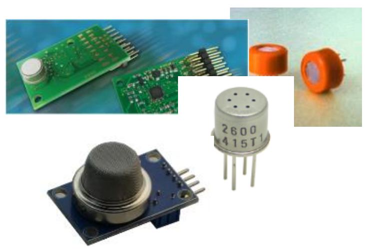

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Introduction – MOS VOC an obvious choice?

- Application of MOS VOC seems to be an obvious step towards cheaper and better control of Demand Controlled Ventilation (DCV)
- They offer possibility to not only account for pollution related to occupancy, like CO_2 sensors, but also for diverse odorous events taking place in a space
- Moreover the MOS technology allows producing sensor units that are significantly (about three times) cheaper than current non dispersive infrared (NDIR) CO_2 sensors
- Other advantages claimed by producers include small energy consumption, small size and high durability
- This not only makes whole ventilation systems cheaper, but also allows for use of larger amount of sensors – IOT applications

Introduction – are there disadvantages?

- MOS VOC sensors are non-selective = they react to many pollutants!
- It is a relative measurement and "non-selectivity" makes calibration difficult
- Some producers solve this by interpretation of measured signal as so called CO_2 equivalent; Herberger et al. (2010), Burdack-Freitag et al. (2009)
- They are cross-sensitive to water vapour/humidity

Basic idea

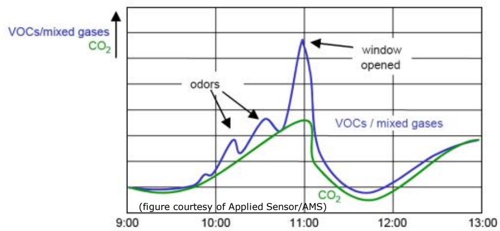


Figure 1: Illustrative development of VOC and CO_2 signals; marketing materials courtesy of Applied Sensor/AMS)

Introduction – MOS VOC vs. CO_2 in practice

- One year measurement campaign at The Czech Technical University in Prague as a part of Clear-up project (EU FP7); Kolarik (2014)

CONCLUSIONS:

- Signals form compared VOC and CO_2 sensors were in agreement w 49% of occupied time
- VOC sensor would clearly trigger the mechanical ventilation in contradiction with CO_2 sensor 11% of occupied time
- During periods without human occupancy the VOC sensor indicated demand for ventilation in 8.5% of time
- **It is not possible to just replace CO_2 sensor with MOS VOC sensor even if its response is expressed in CO_2 equivalents**

Objectives and Approach

- Study **response** of commercially available MOS VOC sensors to pollutants emitted during **activities typical for residential spaces**

- Utilize exposure to residential activities to determine sensor properties: Linearity, sensitivity and hysteresis

- Investigate how the data from exposure activities can be used to determine suitability of the particular MOS VOC sensors for Demand Controlled Ventilation

Approach: Activities typical for residences

Figures: www.pixbay.com

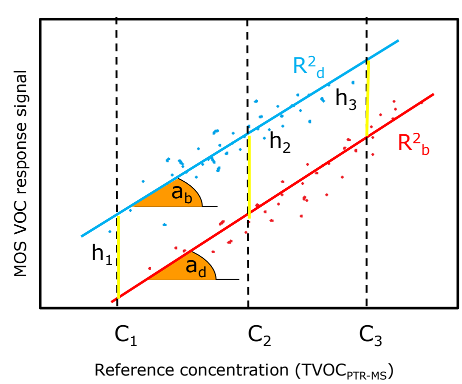
Methods

Sensor properties under dynamic conditions/activities

- **Response patterns** for different sensors and activities
  - Absolut response signals (previous presentation by Nadja L. Lyng ☺)
  - Relative response – signal normalized by a background response measured before each activity

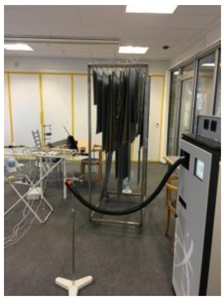
- **Characteristic curves** (Fahlen et al. (1992) – sensor response as a function of reference concentration – TVOC determined by PTR-MS measurements
  - Separate for build up and decay

- **Sensitivity**, **Linearity** and **hysteresis** derived from a linear regression fit to the characteristic curves
  - Sensitivity: slope of the regression line a_b, a_d
  - Linearity: R^2 of the regression fit
  - Hysteresis: max(h_1, h_2, h_3)



Methods – lab. facilities and sensors

TESTROOM



- EnergyFlexOffice (EFO) at Danish Technological Institute
- 7 x 7.5 x 2.6 m, 31.5 m²
- Mechanical ventilation, constant air-change ~0.5 h^{-1}
- Temperature and relative humidity was kept constant at 23 °C and 50% respectively
- Continuous measurements of VOC by Proton Transfer Reaction-Time Of Flight-Mass Spectrometer (PTR-MS)

ACTIVITIES (pollution events)

Activity	Description
Cooking	Warming up ready-made karri soup
Cleaning with detergent	Cleaning of smooth surfaces with commercially available universal detergent (60 ml in 5 l water)
Cleaning with dry cloth	Cleaning of smooth surfaces with dry cloth
Linoleum	Old linoleum flooring (17 m2) placed in a steel rack
Painting	Paint 11.6 m2 plasterboard (1.54 kg paint used)
Human Bioeffluents	6 sedentary adults with laptop computers
Ethanol emission	34.186 g of ethanol (99%) evaporated

SENSORS

Producer	Model	Output [unit]	Sensing range	Auto-calibration	N of tested sensors
SGX Sensortech	MiCS-VZ-89TE	CO_2 eq. [ppm] TVOC [ppb]	400-2000 ppm 0-1000 ppb*	(yes)	2
AMS	iAQ-Core	CO_2 eq. [ppm] TVOC [ppb]	450-2000 ppm 125-600 ppb**	yes	2
Omelix	MQ-135	0 – 5 [V]	10-300 ppm NH3 10-1000 ppm C6H6 10-300ppm Alcohol	no	5
Siemens	QPA1000	0-100 % air quality	0-10 V	yes	1
S+S Regel-teknik	RLQ-W	0-100 % air quality	0-10 V	yes	1

Results – Absolute vs. relative response

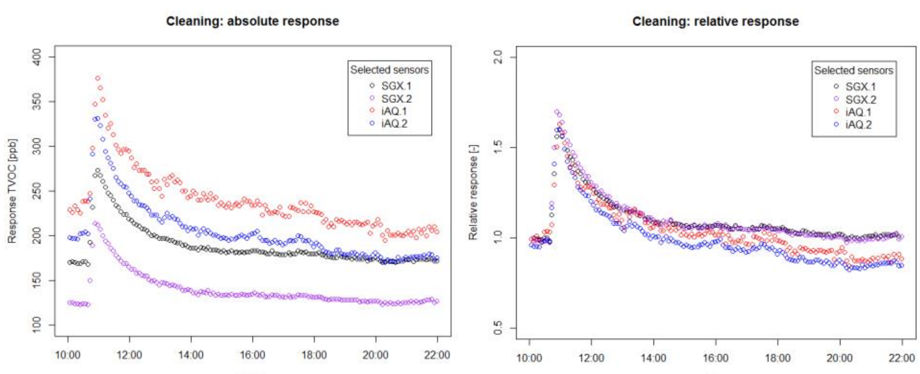


Figure 3: Response of SGX and iAQ sensors to cleaning with detergent: Left-absolute signal, Right-relative signal normalized by background concentration before activity

- Absolute responses are shifted as each sensor has a different background concentration
- Normalized response shows that the sensors reacted comparably

Results - Characteristic curve (SGX sensor)

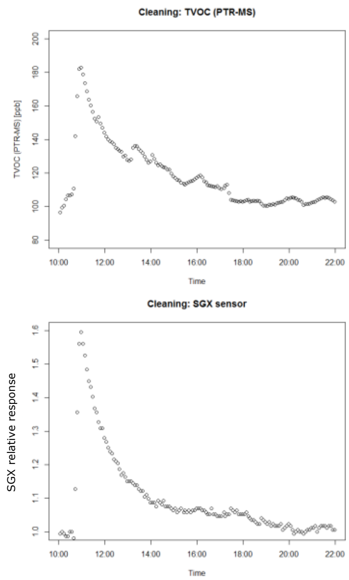


Figure 4: Cleaning with detergent: Top-TVOC signal determined by PTR-MS, Bottom-response of SGX sensor

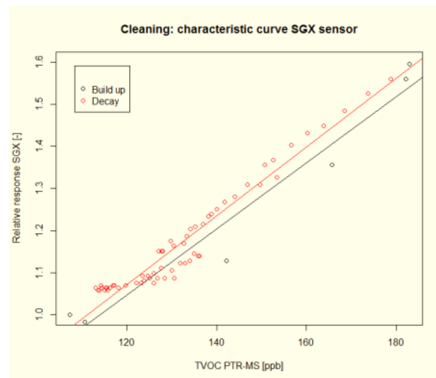


Figure 5: Characteristic curves (build-up and decay) for SGX sensor during cleaning with detergent

Results – Analysis of linear regression fit

Sensitivity – the aggregated picture

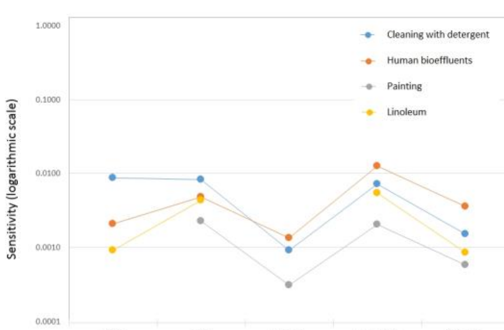


Figure 6: Sensitivity for tested sensor types during exposure to cleaning with detergent, bioeffluents, painting and linoleum

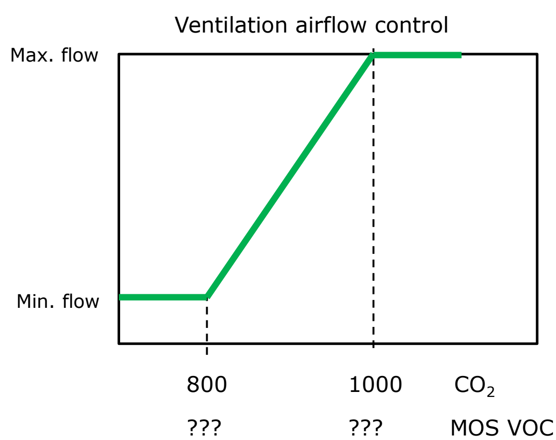
- Sensitivity of a particular sensor differs among activities
- iAQ sensor had most consistent sensitivity
- Sensitivity of SGX, iAQ and QPA1000 to cleaning was comparable
- Lowest sensitivity values were observed for painting

Issues regarding ventilation control

- Information regarding sensor properties are often missing
- Relative signal, even several sensors from one producer can present different response to the same conditions
- "Auto-calibration" may be a disadvantage
- Definition of set-point value is problematic due to
  - Broad range sensitivity
  - Relative nature of the response

Ventilation control – using relative response from different activities

- Pollutant driving the response is not known
- Definition of response for maximum airflow can be based on a chosen activity **"reference" activity**



Based on relative response to Ethanol (extreme IAQ event)	1	3.7	$C_{r(VOC)}$
Based on relative response to Cleaning	1	1.7	$C_{r(VOC)}$

Ventilation control – using relative response from different activities

- How much of the response range defined for chosen activity was used during other activities?
- The choice of reference activity has to correspond with expected usage of the ventilated space

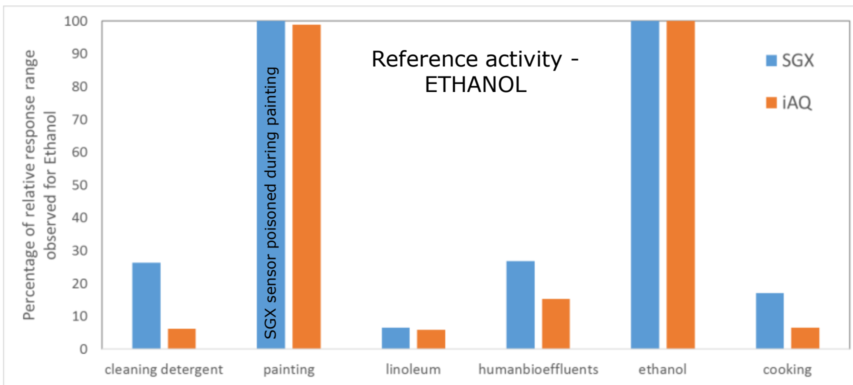


Figure 7: Percentage of relative response calculated based on exposure to Ethanol utilized during other tested activities

Concluding remarks and future work

- Normalization of the MOS VOC sensor signal gives a possibility for direct comparison of response patterns among different sensors exposed to the same condition.
  - However, normalization does not eliminate the danger of a sensor “auto calibrating” itself to polluted environment
- The experiments showed that the sensitivity of tested sensors differed with respect to particular activities (pollution events)
  - Future work will focus on identification of pollutants that “drive” the sensor response with respect to particular activities
- If “driving” pollutant/s is/aren’t not known, a characteristic activity can be used to determine a relative response change that should correspond to maximum airflow provided by ventilation
  - Aforementioned approach needs to be practically tested in the future

Acknowledgements

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