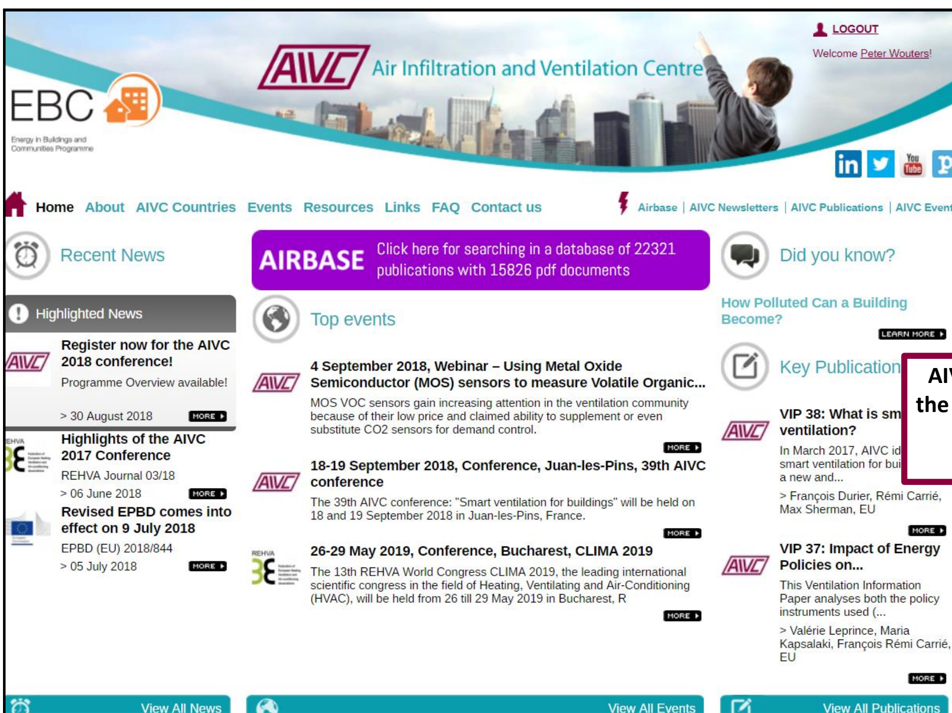
Webinar – Using MOS sensors to measure VOC for ventilation control

Peter Wouters – Operating Agent AIVC

Tuesday 4 September 2018



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Annex 68 is one of the 18 running projects of IEA EBC

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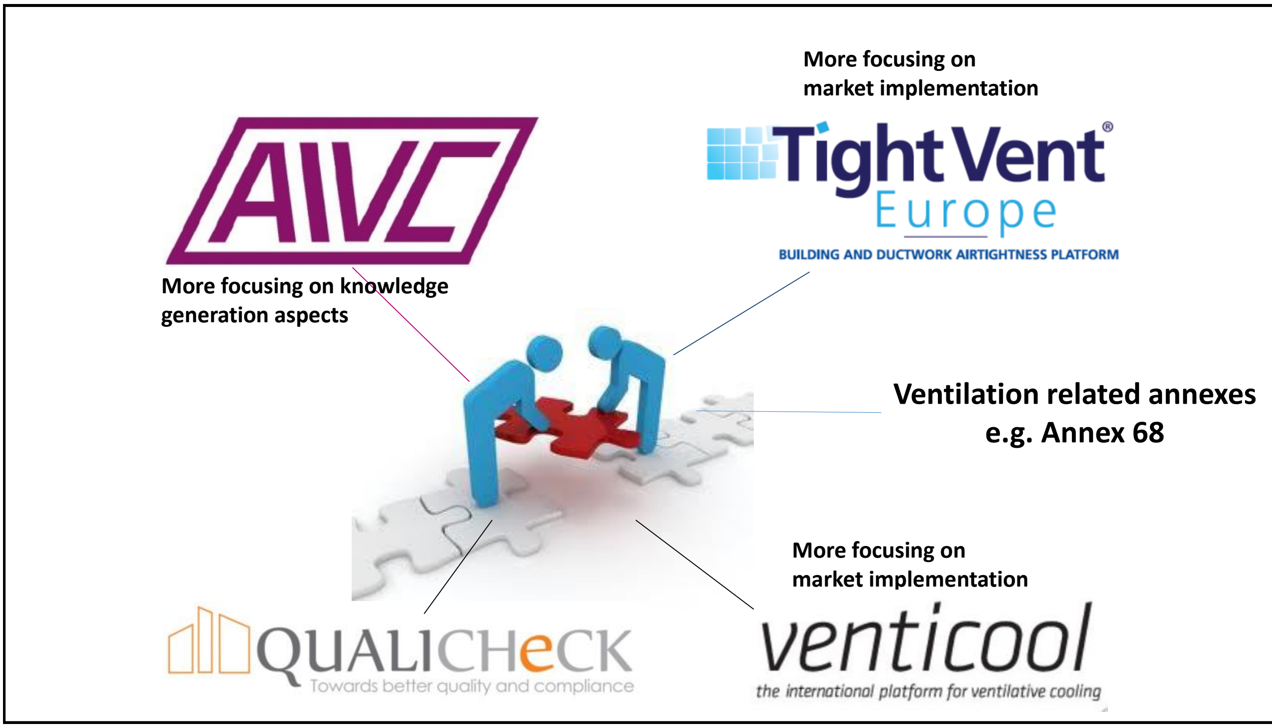
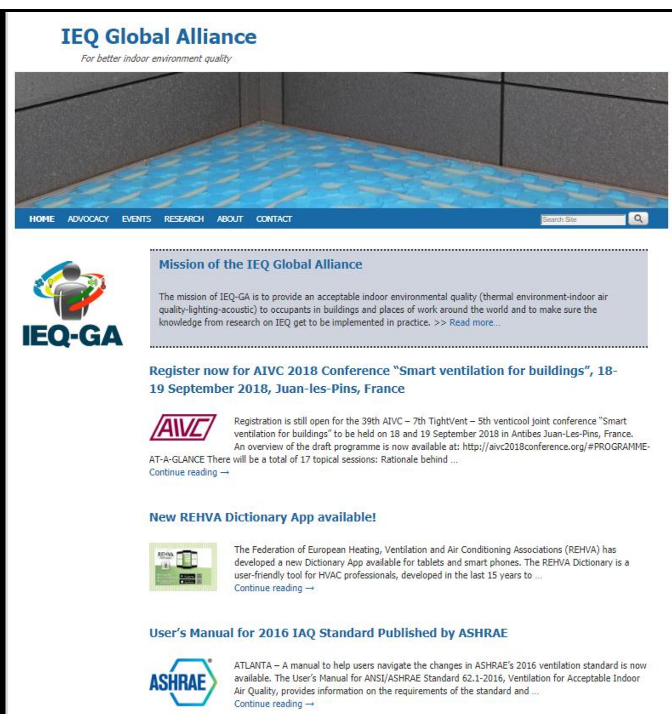
→ Interest from several other countries





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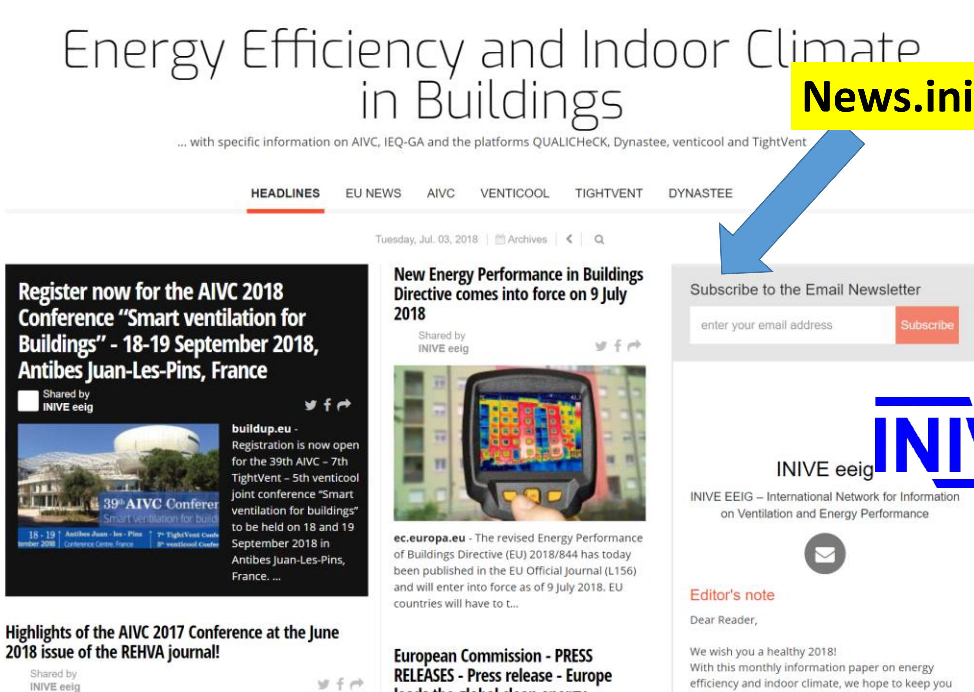

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Ventilation
Information
Paper
n° 38

March 2018

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and Management
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International Energy Agency
Energy Conservation in Buildings
and Community Systems Programme

Air Infiltration and Ventilation Centre

What is smart ventilation?

François Durier, CETIAT, France
Rémi Carrié, ICEE, France
Max Sherman, LBNL, USA

Smart ventilation for buildings

Topical sessions at 2018 conference …

1. **IAQ metrics**
2. **Smart ventilation control**
3. **Sensors for smart ventilation**
4. **Rationale behind ventilation requirements and regulations**
5. Utilization of heat recovery
6. Integrating uncertainties due to wind and stack effect in declared airtightness results
7. Ductwork airtightness
8. Residential cooker hoods
9. French initiatives for indoor air quality
10. **Demand controlled ventilation in French buildings – 35 years of wide scale experience**
11. Commissioning of ventilation systems – Improving quality of installed ventilation systems
12. Measurement Accuracy of air flow and pressure difference
13. **Air cleaning as supplement for ventilation**
14. New annex on resilient cooling
15. BIM and Construction 4.0 opportunities in relation to ventilation and airtightness

The 40th AIVC conference will be held in Ghent (Belgium) on October 15 and 16 2019

The website will be operational in the coming weeks

IEA EBC Annex 68 & AIVC Webinar:
Using Metal Oxide Semiconductor (MOS) sensors to measure Volatile Organic Compounds (VOC) for ventilation control

Carsten Rode, Ph.D.,
Technical University of Denmark
car@byg.dtu.dk

EBC Energy in Buildings and Communities Programme

IEA-EBC Annex 68
Indoor Air Quality Design and Control in Low Energy Residential Buildings

IEA EBC Annex 68
An International Project on:
Indoor Air Quality Design and Control in Low Energy Residential Buildings

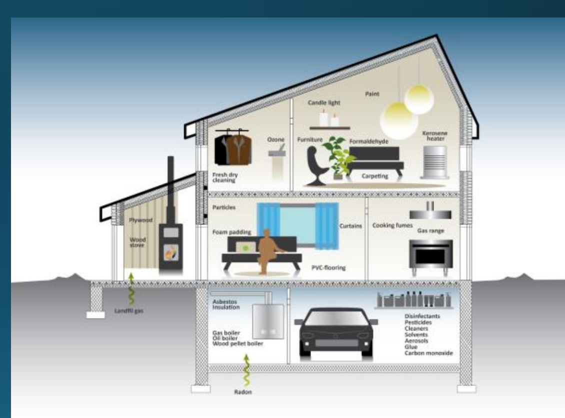
Project Motivation

As the general standard of insulation has been increasing, the focus is on other means to reduce energy consumption.

Ventilation (natural or mechanical) is another obvious candidate.

Less ventilation, however, can lead to increased levels of pollutants indoors.

How do we ensure that future low-energy buildings provide a comfortable and healthy indoor environment?



Energy Efficiency ⟷ IAQ

Knowledge Gap

Mission

With a basis in scientific data and tools, the project shall provide guides for design and operation of buildings towards highest energy efficiency while ensuring good & healthy indoor conditions

Specific target: New and refurbished residential buildings

Subtasks

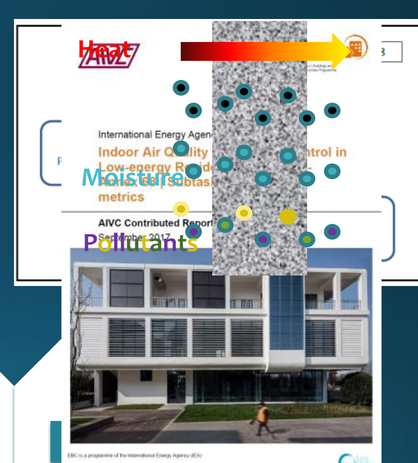
ST1 - Defining the metrics

ST2 - Pollutant loads in residential buildings

ST3 - Modelling

ST4 - Strategies for design and operation

ST5 - Field measurements and case studies



Participating countries (and institutions)

- Austria (UIBK)
- Belgium (UGent)
- Canada (BCIT, Health Canada)
- China (University of Shanghai for Science and Technology)
- Czech Republic (CVUT)
- Denmark (DTU, SBi/AAU, TI)
- Estonia (TUT)
- France (Univ. de La Rochelle, Univ. de Savoie Mont Blanc, Saint-Gobain)
- Germany (TU Dresden)
- Korea (Korea Institute of Civil Engineering & Building Technology)
- The Netherlands (TU/e)
- Norway (NTNU, NMBU)
- United Kingdom (UCL, Strathclyde Univ.)
- USA (Syracuse Univ.)

Visible Earth, NASA

Schedule

	2015		2016		2017		2018		2019		2020
Preparation Phase	x	x									
ST1			x	x							
ST2			x	x	x	x	x	x	x		
ST3			x	x	x	x	x	x	x		
ST4			x	x	x	x	x	x	x		
ST5			X	x	x	x	x	x	x		
Reporting Phase										x	x

Agenda - Webinar - September 4, 2018

15:00 **Introduction**
Peter Wouters, AIVC, Belgium
Carsten Rode, IEA-EBC Annex 68, Technical University of Denmark

15:10 **Can the TVOC-sensors be used for ventilation control?**
Nadja Lynge Lyng, Danish Technological Institute

15:35 **MOS VOC sensors' properties and suitability for DCV control: analysis based on laboratory measurements**
Jakub Kolarik, Technical University of Denmark

16:00 **VOC vs. CO_2 controlled DCV: A case study**
Jelle Laverge, Gent University, Belgium

16:30 **End of the webinar**

Each of Nadja, Jakub and Jelle's entries will be be for 20 minutes followed by 5 minutes Q&A

Information

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http://www.iea-ebc-annex68.org/

Can TVOC-sensors be used for ventilation control?

DANISH TECHNOLOGICAL INSTITUTE

Nadja Lynge Lyng
Specialist, PhD
nal@dti.dk
AIVC Webinar
September 4th 2018

Demand controlled ventilation

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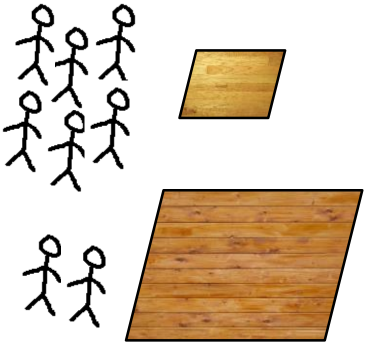
Temperature, Comfort,
Relative humidity, Mould risk
CO_2 Air quality



- Day Care Centers
- Classrooms
- Meeting rooms
- Offices

- Residential buildings

Other Activities
such as cleaning, painting, cooking
(VOC's)

Methods for measuring indoor air quality (VOC's)

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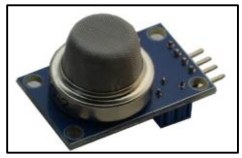
Passive sampling	Active sampling	PTR-MS	VOC sensors
Sorbent material	Air flow through Sorbent sampling tube	Transportable chemical analysis equipment	Electronic and small built-in sensors
h/days to weeks $\bar{X}$	Min to h $\bar{X}$	Real time - online	Real time - online



TVOC/VOC sensors

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Types; MOS, PID, FID (ionization detector)

Inexpensive MOS sensors (Metal Oxide Semiconductor), suitable for measuring VOC's.

Little documentation on how the sensors work

Little documentation on sensor performance

Figarosensor.com

Selection of suitable sensors for indoor purposes:

Producer	Model	Short name	Sensor/ integrated in a box	Price pr. Unit in €	No. of tested sensors	Output
SGX Sensortech	MiCS-VZ-89TE	SGX	Sensor	18.5	2	TVOC (ppb)
AMS	iAQ-Core C	iAQ	Sensor	19.8	2	TVOC (ppb)
Omelix	MQ-135	MQ135	Sensor	5.5	5	Volt
Winsen	MQ503	MQ503	Sensor	2.4	2	Volt
Siemens	QPA1000	QPA1000	Box	148.5	1	Volt
S+S Regeltechnik	RLQ-W	RLQ	Box	163	1	Volt

Tested MOS sensors

- AMS, iAQ-core C
- SGX, MiCS-VZ-89TE
- Olimex, MQ-135
- Winsen, MQ503

- S+S Regelteknik, RLQ-W
- Siemens, QPA1000
  (Figaro, TGS2600)





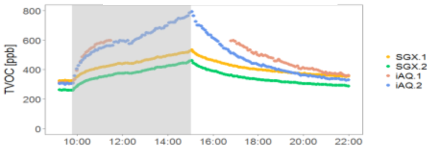

Method

- Full Scale Test Facility (EnergyFlexOffice) – Constant T, RH & ACH
- Activities;

  Painting, Cooking, Cleaning, Candles burning, Human emissions, Humidity, Linoleum flooring, Ethanol, Background



Human emission



H_3O^+ ?

Conclusion

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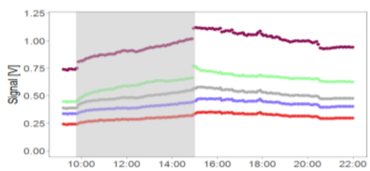
- They were good at detecting changes in the air quality (compared to PTR-MS)
- Differences between sensor models
  - Measuring interval
  - Sensitivity
  - Which VOC's
  - Response to changes in RH
  - Temperature ?



- Variations between sensors of the same model
- Limited documentation from manufacturers & suppliers
  → need for testing
- Requirements for controlling ventilation, e.g. normalization of the signal
- Interpretation of signal e.g. Volt/TVOC (ppb)
- What happens over time?
- Can TVOC sensors be used for ventilation control?

  Not *Plug & Play*, but possible.

The preformed tests was part of two different projects

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GI GRUNDEJERNES INVESTERINGSFOND

TEKNOLOGISK INSTITUT

TVOC-sensors use in evaluating air quality

EUDP Energiteknologisk udvikling og demonstration

DTU

AARHUS UNIVERSITET

RoomVent Solutions

DANISH TECHNOLOGICAL INSTITUTE

ekolab Ingeniørrådgivning indenfor bæredygtige energiløsninger

SUSTAIN SOLUTIONS

Smock VENTILATION

IC-Meter Indoor Climate

Advokaterne Arup & Hvidt

ebmpapst

rönby.dk

Test is performed by:

DANISH TECHNOLOGICAL INSTITUTE






AARHUS UNIVERSITET — Rossana Bossi

TEKNOLOGISK INSTITUT — Nadja Lynge Lyng, Thomas Witterseh

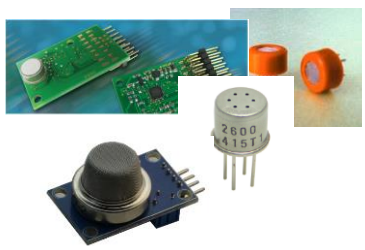
DTU — Jakub Kolarik, Kevin Smith, Pawel Wargocki

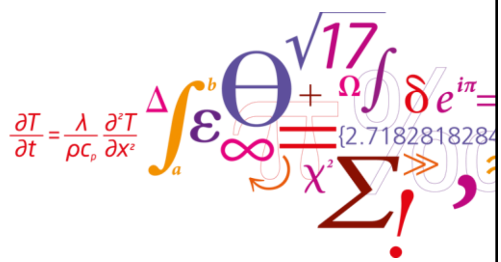
MOS VOC sensors' properties and suitability for DCV control

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

Jakub Kolarik, Technical University of Denmark
jakol@byg.dtu.dk





The team:
Technical University of Denmark: Pawel Wargocki, Kevin Smith
Danish Technological Institute: Thomas Witterseh, Nadja L. Lyng
Aarhus University: Rossana Bossi

DTU Civil Engineering
Department of Civil Engineering

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

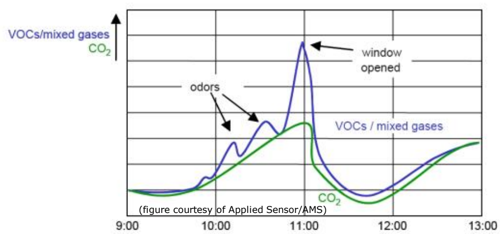


Figure 1: Illustrative development of VOC and CO_2 signals; marketing materials courtesy of Applied Sensor/AMS)

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

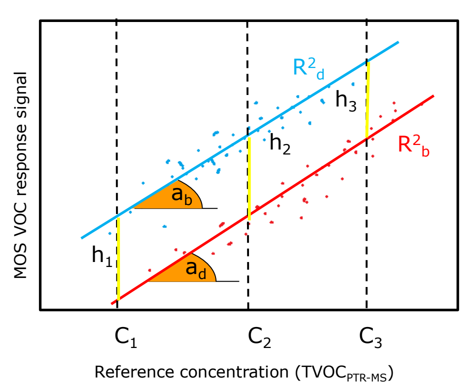
Approach: Activities typical for residences

Figures: www.pixbay.com

Methods

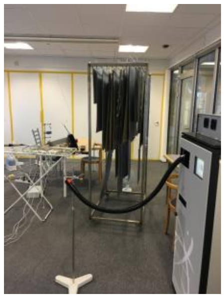
Sensor properties under dynamic conditions/activities

- **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)

niv

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

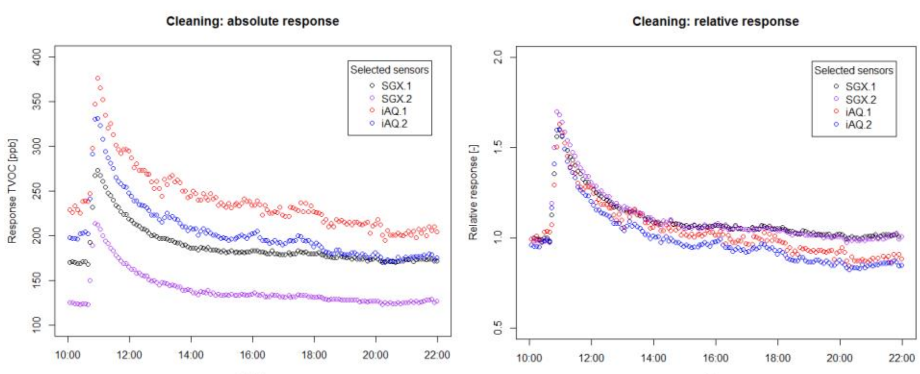


Figure 3: Response of SGX and iAQ sensors to cleaning with detergent: Left-absolute signal, Right-relative signal normalized by background concentration before activity

- 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)

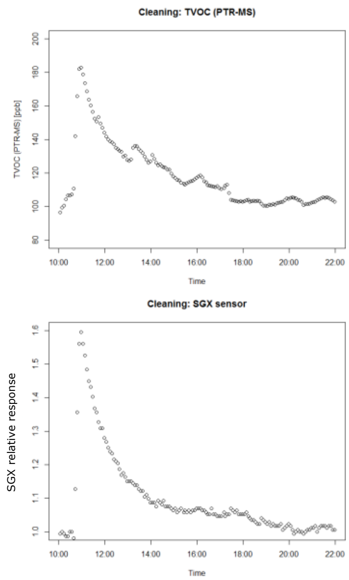


Figure 4: Cleaning with detergent: Top-TVOC signal determined by PTR-MS, Bottom-response of SGX sensor

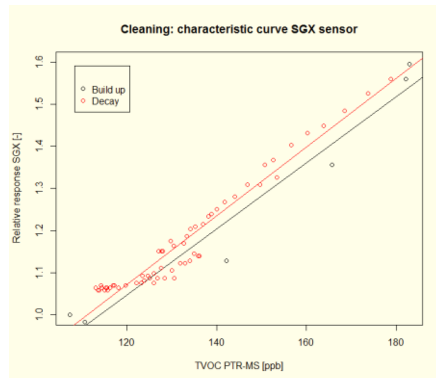


Figure 5: Characteristic curves (build-up and decay) for SGX sensor during cleaning with detergent

Results – Analysis of linear regression fit

Sensitivity – the aggregated picture

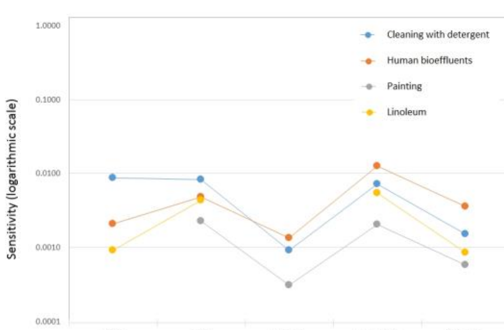


Figure 6: Sensitivity for tested sensor types during exposure to cleaning with detergent, bioeffluents, painting and linoleum

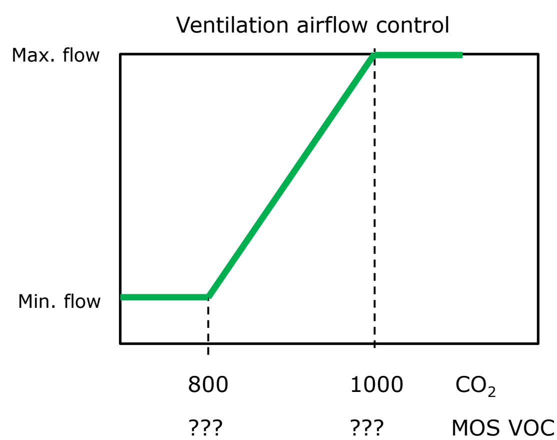
- Sensitivity of a particular sensor differs among activities
- iAQ sensor had most consistent sensitivity
- Sensitivity of SGX, iAQ and QPA1000 to cleaning was comparable
- Lowest sensitivity values were observed for painting

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

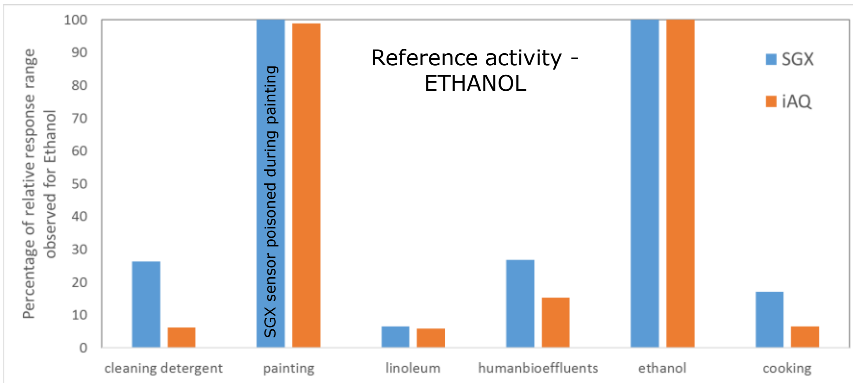


Figure 7: Percentage of relative response calculated based on exposure to Ethanol utilized during other tested activities

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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DEPARTMENT OF ARCHITECTURE AND URBAN PLANNING
BUILDING PHYSICS, CONSTRUCTION AND SERVICES RESEARCH GROUP

VOC VS. CO2 CONTROLLED DCV:

A CASE STUDY

AIVC 2018 Webinar

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The Context: Belgian DCV

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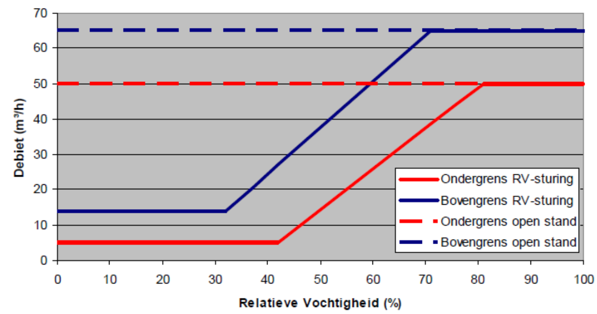
A BIT OF HISTORY OF 'DCV' IN BELGIUM



1st Generation: mechanical exhaust control imported from France
+- 2007

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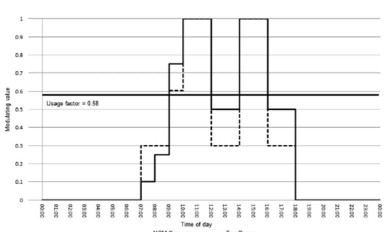
A BIT OF HISTORY OF 'DCV' IN BELGIUM



2nd Generation: RH/presence detection triggering exhaust fan
+- 2009

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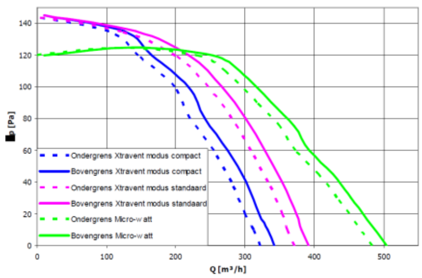
A BIT OF HISTORY OF 'DCV' IN BELGIUM



Figuur 3: 90-90 interval van de ventilatorkarakteristiek

3rd Generation: electronic dampers per exhaust space
+- 2010

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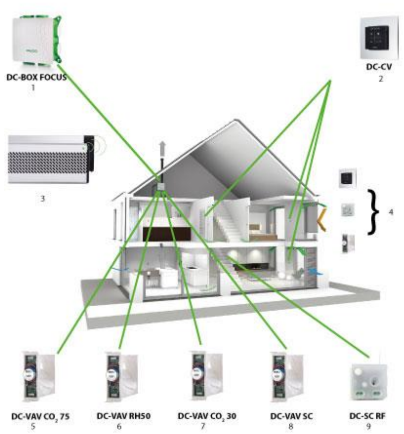
A BIT OF HISTORY OF 'DCV' IN EUROPE



4th Generation: Electronic supply grids and additional exhausts
+- 2012

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The Research Objective

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RESEARCH OBJECTIVE

Demonstrate the behaviour of DCV controlled by
‘cheap’ HVAC grade metal oxide sensors
in modern low-energy dwellings

Bonus: can they be ‘all-in one’ replacements for CO_2?

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The Case Study

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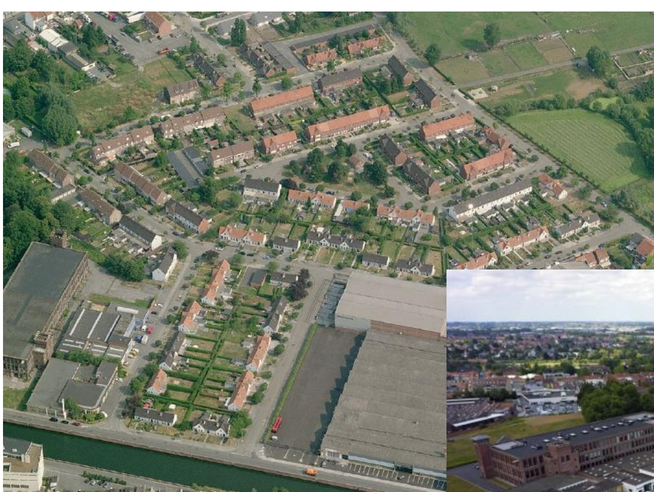
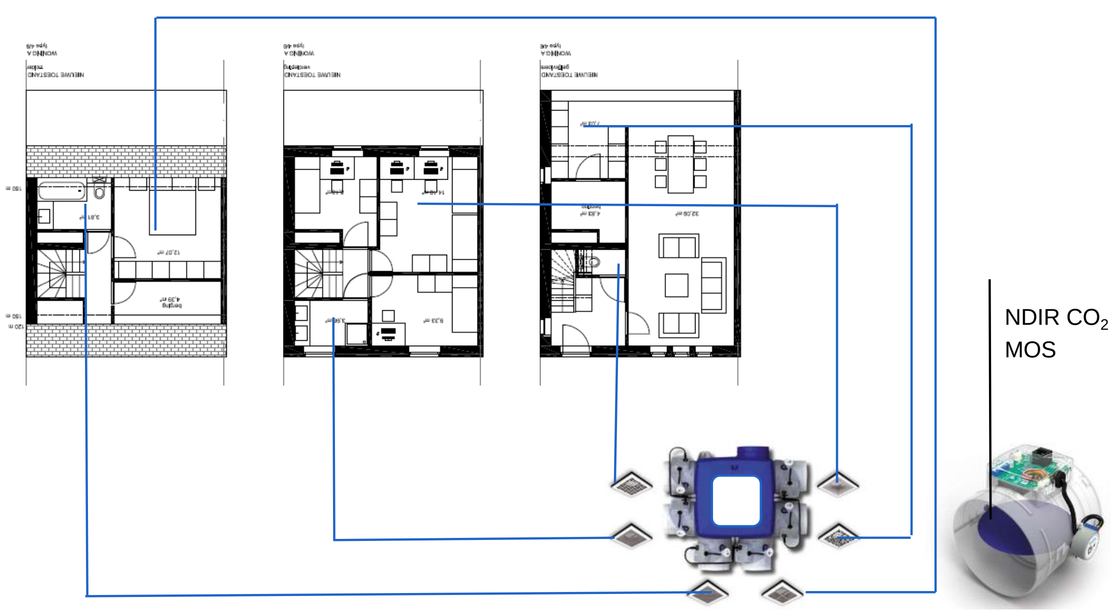


Social housing estate ‘Venning’
Kortrijk, Belgium

Renovation part of concerto ‘Eco-Life’

Focus on the individual dwellings



EXPERIMENTAL SETUP

In every test house:

- Mode 1: system controlled by NDIR (2 weeks)
- Mode 2: system controlled by MOS (2 weeks)

MOS output = factory calibrated to ‘CO_2 equivalents’
Same setpoints in both modes

Campagne	1	2	3
Fase 2			
W2.1	X	X	X
W2.2	X	X	X
W2.3	X	X	X
W2.4	X	X	X
W2.5	X	X	X
W2.6	X	X	X
W2.7	X	X	X
W2.8	X	X	X
W2.9	X	X	X
W2.10	X	X	X
W2.11	X	X	-
W2.12	X	-	-
W2.13	-	X	-
W2.14	-	X	X
W2.15	-	X	X

Campagne	1	2	3
W2.16	-	X	X
W2.17	-	X	X
W2.18	-	X	X
W2.19	-	-	X
W2.20	-	-	X
Fase 3			
W3.1	X	X	X
W3.2	X	X	X
W3.3	X	X	X
W3.4	X	X	X
W3.5	X	X	-
W3.6	X	X	-
W3.7	X	-	-
W3.8	-	X	X
W3.9	-	-	X

Table 1: Monitoring campaigns

	Campaign 1	Campaign 2	Campaign 3
DCV_{CO2}	November 14, 2015	December 11, 2015	January 09, 2016
	November 24, 2015	December 23, 2015	January 20, 2016
DCV_{VOC}	November 29, 2015	December 25, 2015	January 22, 2016
	December 09, 2015	January 06, 2016	February 02, 2016

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The Results

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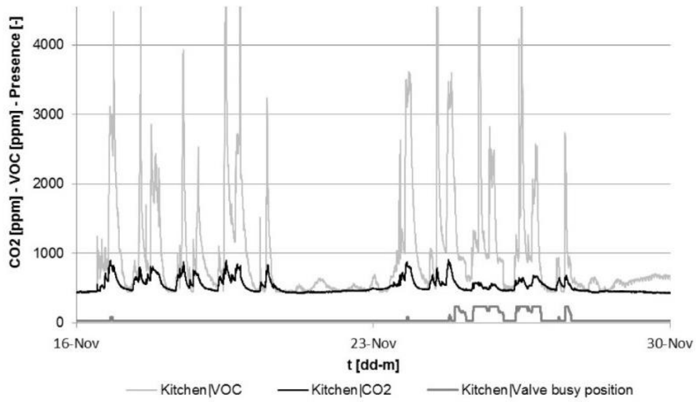
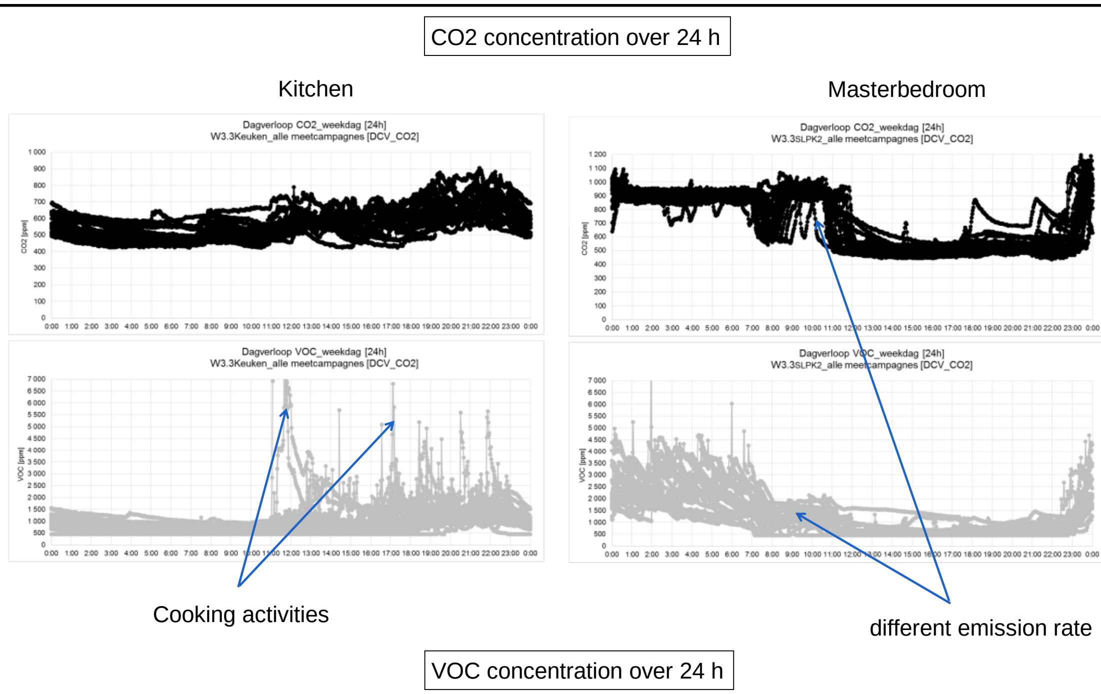
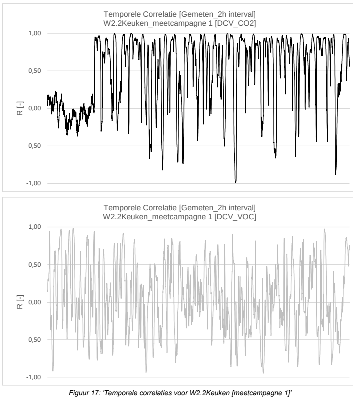
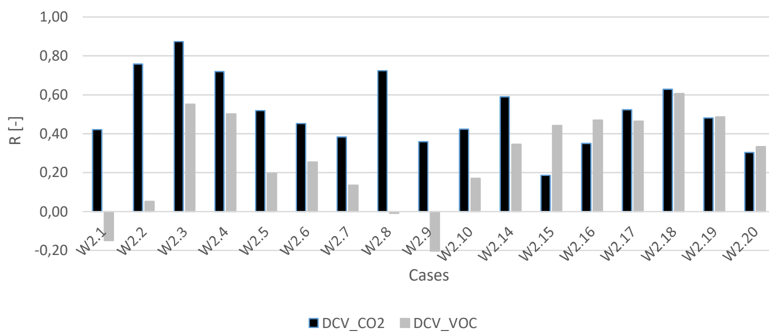


Figure 1: CO_2 and VOC concentrations over 2 weeks [week 1: DCV_{CO2} ; week 2: DCV_{VOC}]

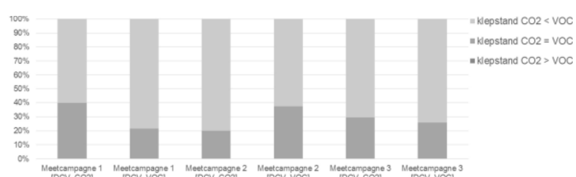


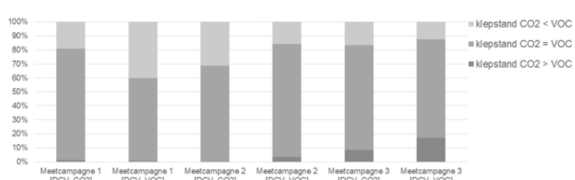




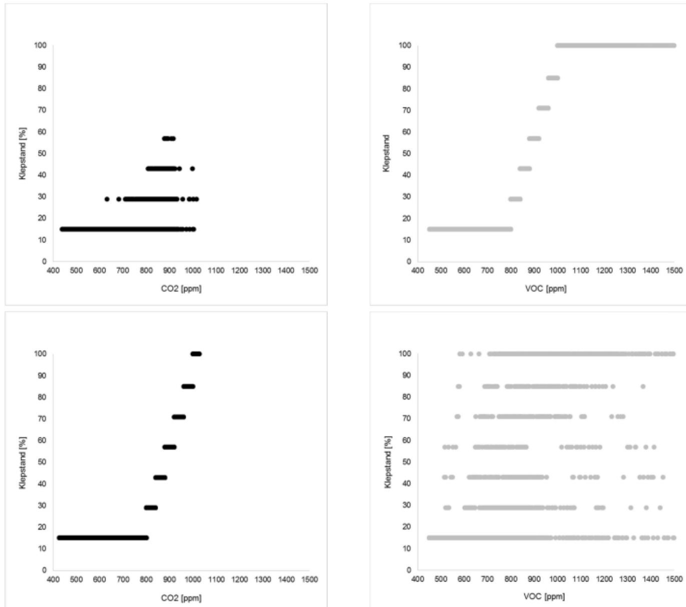
Pearson Correlation between CO2 and VOC concentration

Differences between individual houses, based on number of people, type of sources…

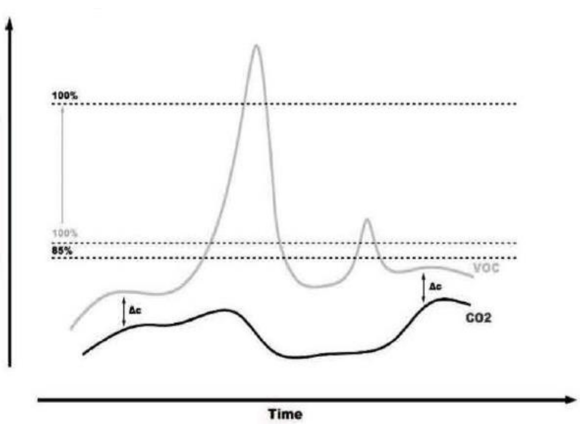




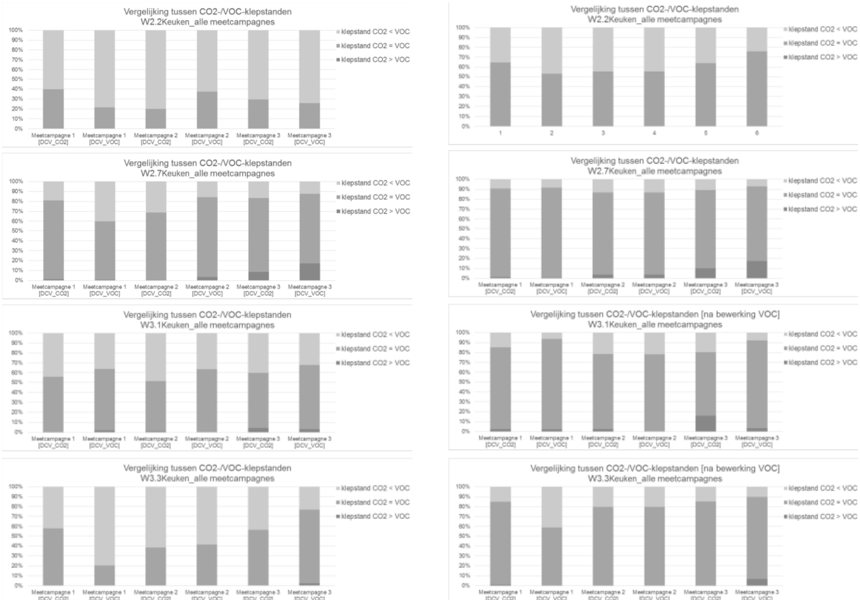
valveposition
as a function of
CO_2/VOC
concentration



How to handle this type of signal for better ventilation?



Differences between individual houses, based on number of people, type of sources…



Lessons learned

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Lessons learned

- ‘equivalent’ TVOC concentration was more than 50% higher than the CO_2 concentration
- TVOC much more peaked with occupant behaviour
- TVOC control significantly increases total ventilation (+69% in bedrooms, +176% in kitchens)
- ‘transforming’ the TVOC signal looks promising but requires some more work
- ‘raw’ TVOC signal suitable for event detection

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