

Webinar – Using MOS sensors to measure VOC for ventilation control

Peter Wouters – Operating Agent AIVC
Tuesday 4 September 2018



A screenshot of the AIVC (Air Infiltration and Ventilation Centre) website homepage. The header features the EBC (Energy in Buildings and Communities Programme) logo on the left and the AIVC logo with the text 'Air Infiltration and Ventilation Centre' on the right. A navigation bar includes links for Home, About, AIVC Countries, Events, Resources, Links, FAQ, and Contact us. The main content area is divided into several sections: 'Recent News' with a highlighted article about the AIVC 2018 conference; 'Highlighted News' with articles about the AIVC 2017 conference and the revised EPBD; 'AIRBASE' with a link to search a database of 22321 publications; 'Top events' listing the 4 September 2018 webinar and the 18-19 September 2018 conference; and 'Did you know?' and 'Key Publication' sections. A red-bordered box on the right side of the page contains the text: 'AIVC is the information centre of the International Energy Agency on energy efficient ventilation (= annex 5)'. The footer includes links to 'View All News', 'View All Events', and 'View All Publications'.

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The IEA-EBC Programme is a multi-disciplinary programme in the field of energy efficient buildings and communities. It enables:

- High quality scientific research
- Summary information

High Priority Research

1. Integrated planning and design
2. Building energy systems
3. Building envelope
4. Community scale methods
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ANNUAL REPORT 2017

The summary of the IEA EBC Programme's activities for the year 2017 is available as a PDF document.

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The latest news about EBC can be found in the twice-yearly newsletter [EBC News](#). Email alerts for new editions of [EBC News Signup](#)

The June 2018 edition features articles on:

CONTACT

EBC Secretariat (ESSU)

Mr. Malcolm Orme

+44 (0)121 262 1920

Email

LATEST NEWS

16th IBPSA International Conference

The 16th IBPSA International Conference will be taking place in Rome, Italy, between 2nd - 4th September 2019.

SSB 2018

The 10th International Conference on System Simulation in Buildings will be held in Liège, Belgium, between 10th - 12th December 2018.

National Energy Efficiency Conference 2018

The National Energy Efficiency Conference 2018 will take place in Sydney, Australia between 19th - 20th November 2018.

AIVC Annual Conference

The 39th AIVC Annual Conference will be held in Juan-les-Pins, France, between

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

AIVC is the information centre of the International Energy Agency on energy efficient ventilation (= annex 5)

www.iea-ebc.org



AIVC Member countries

- Australia
- Belgium
- China
- Denmark
- France
- Italy
- Japan
- Korea
- Netherlands
- New Zealand
- Norway
- Spain
- Sweden
- United Kingdom
- United States

→ Interest from several other countries



More focusing on knowledge generation aspects

Tight Vent
Europe

BUILDING AND DUCTWORK AIRTIGHTNESS PLATFORM



Ventilation related annexes
e.g. Annex 68

QUALICheck
Towards better quality and compliance

More focusing on
market implementation
venticool
the international platform for ventilative cooling

IEQ Global Alliance

For better indoor environment quality



Mission of the IEQ Global Alliance

The mission of IEQ-GA is to provide an acceptable indoor environmental quality (thermal environment-indoor air quality-lighting-acoustic) to occupants in buildings and places of work around the world and to make sure the knowledge from research on IEQ get to be implemented in practice. >> Read more...

Register now for AIVC 2018 Conference "Smart ventilation for buildings", 18-19 September 2018, Juan-les-Pins, France



Registration is still open for the 39th AIVC – 7th TightVent – 5th venticool joint conference "Smart ventilation for buildings" to be held on 18 and 19 September 2018 in Antibes Juan-Les-Pins, France. An overview of the draft programme is now available at: <http://aivc2018conference.org/#PROGRAMME>.
AT-A-GLANCE There will be a total of 17 topical sessions: Rationale behind ...
Continue reading →

New REHVA Dictionary App available!



The Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA) has developed a new Dictionary App available for tablets and smart phones. The REHVA Dictionary is a user-friendly tool for HVAC professionals, developed in the last 15 years to ...
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User's Manual for 2016 IAQ Standard Published by ASHRAE



ATLANTA – A manual to help users navigate the changes in ASHRAE's 2016 ventilation standard is now available. The User's Manual for ANSI/ASHRAE Standard 62.1-2016, Ventilation for Acceptable Indoor Air Quality, provides information on the requirements of the standard and ...
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www.ieq-ga.net

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Energy Efficiency and Indoor Climate in Buildings

... with specific information on AIVC, IEQ-GA and the platforms QUALICheck, Dynastee, venticool and TightVent


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HEADLINES AIVC VENTICOOL TIGHTVENT DYNASTEE

Tuesday, Jul. 03, 2018 | Archives | < | Q

Register now for the AIVC 2018 Conference "Smart ventilation for Buildings" - 18-19 September 2018, Antibes Juan-Les-Pins, France

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39th AIVC Conference
Smart ventilation for buildings

18 - 19 September 2018 | Antibes Juan-Les-Pins | France | 39th International Conference


buildup.eu - Registration is now open for the 39th AIVC - 7th TightVent - 5th venticool joint conference "Smart ventilation for buildings" to be held on 18 and 19 September 2018 in Antibes Juan-Les-Pins, France. ...

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Highlights of the AIVC 2017 Conference at the June 2018 issue of the REHVA journal!

New Energy Performance in Buildings Directive comes into force on 9 July 2018

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ec.europa.eu - The revised Energy Performance of Buildings Directive (EU) 2018/844 has today been published in the EU Official Journal (L156) and will enter into force as of 9 July 2018. EU countries will have to t...

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Editor's note

Dear Reader,

We wish you a healthy 2018!
With this monthly information paper on energy efficiency and indoor climate, we hope to keep you informed about our interactive information on the

Ventilation Information Paper n° 38

March 2018

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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



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



40th AIVC - 8th TightVent & 6th venticool Conference

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



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**

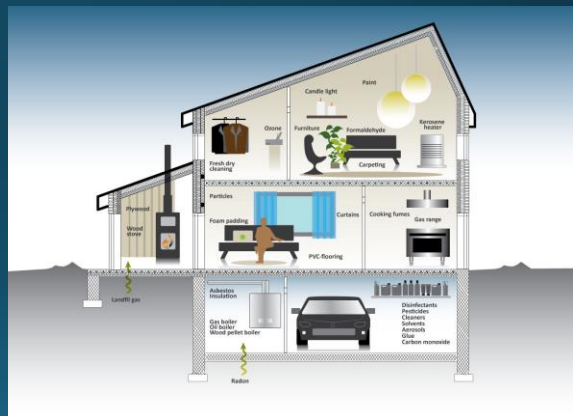
Project Motivation

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

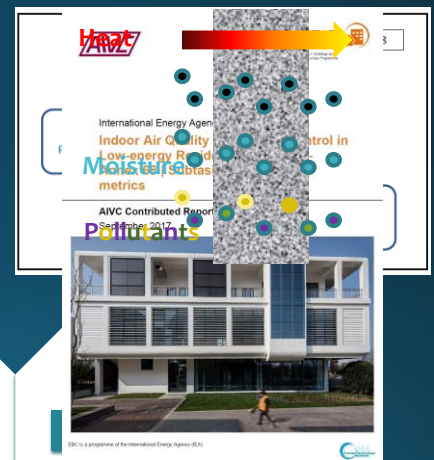
ST1 - Defining the metrics

ST2 - Pollutant loads in residential buildings

ST3 - Modelling

ST4 - Strategies for design and operation

ST5 - Field measurements and case studies



- Austria (UIBK)
- Belgium (UGent)
- Canada (BCIT, Health Canada)
- China (University of Shanghai for Science and Technology)
- Czech Republic (CVUT)
- Denmark (DTU, SBI/AAU, ITI)
- 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.)

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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. CO₂ controlled DCV: A case study

Jelle Låverge, Gent University, Belgium

16:30 End of the webinar

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

Information

Carsten Rode, Operating Agent

car@byg.dtu.dk

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

Can TVOC-sensors be used for ventilation control?



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

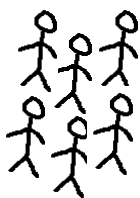
Demand controlled ventilation



Temperature,
Relative humidity,
CO₂

Comfort,
Mould risk

Air quality



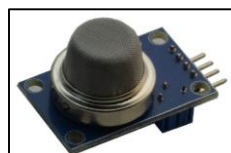
- Day Care Centers
 - Classrooms
 - Meeting rooms
 - Offices
 - Residential buildings
- Other Activities
such as cleaning, painting, cooking
(VOC's)

Methods for measuring indoor air quality (VOC's)



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



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

Selection of suitable sensors for indoor purposes:

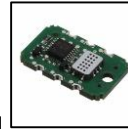
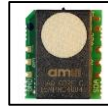


Producer	Model	Short name	Sensor/ integrated in a box	Price pr. Unit in €	No. of tested sensors	Output
SGX Sensortech	MICS-VZ-89TE	SGX	Sensor	18.5	2	TVOC (ppb)
AMS	iAQ-Core C	iAQ	Sensor	19.8	2	TVOC (ppb)
Omelix	MQ-135	MQ135	Sensor	5.5	5	Volt
Winsen	MQ503	MQ503	Sensor	2.4	2	Volt
Siemens	QPA1000	QPA1000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

Tested MOS sensors



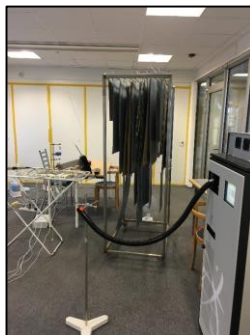
- AMS, iAQ-core C
- SGX, MiCS-VZ-89TE
- Olimex, MQ-135
- Winsen, MQ503
- S+S Regeltechnik, RLQ-W
- Siemens, QPA1000 (Figaro, TGS2600)

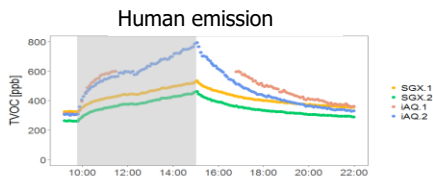


Method



- Full Scale Test Facility (EnergyFlexOffice) – Constant T, RH & ACH
- Activities;
Painting, Cooking, Cleaning, Candles burning, Human emissions, Humidity, Linoleum flooring, Ethanol, Background



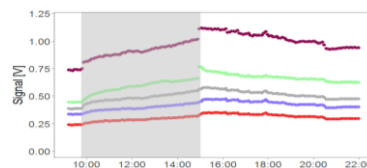


H_3O^+ ?

Conclusion



- 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



TVOC-sensors use in
evaluating air quality



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Test is performed by:



AARHUS UNIVERSITET

Rossana Bossi



Nadja Lynge Lyng, Thomas Witterseh



Jakub Kolarik, Kevin Smith, Pawel Wargocki

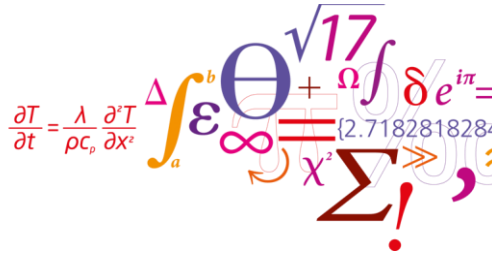
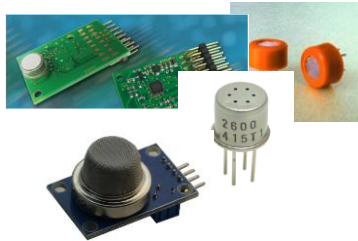
MOS VOC sensors' properties and suitability for DCV control



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



DTU Civil Engineering
Department of Civil Engineering

The team:

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

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 CO₂ 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) CO₂ 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 CO₂ equivalent; Herberger et al. (2010), Burdack-Freitag et al. (2009)
- They are cross-sensitive to water vapour/humidity

Basic idea

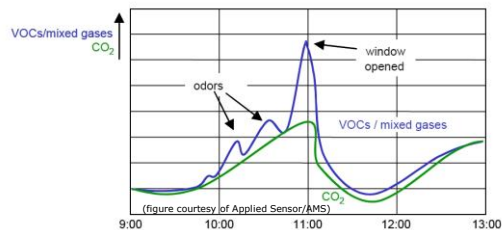


Figure 1: Illustrative development of VOC and CO₂ signals; marketing materials courtesy of Applied Sensor/AMS)

Introduction – MOS VOC vs. CO₂ 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 from compared VOC and CO₂ sensors were in agreement w 49% of occupied time
- VOC sensor would clearly trigger the mechanical ventilation in contradiction with CO₂ 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 CO₂ sensor with MOS VOC sensor even if its response is expressed in CO₂ 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



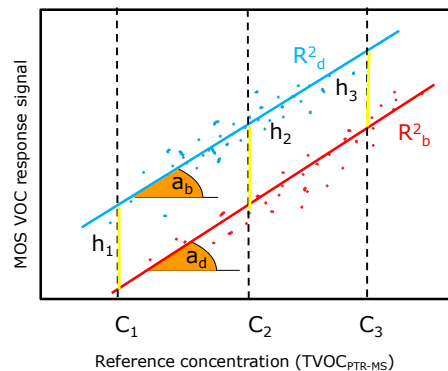
Figures: www.pixabay.com

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 m ²) placed in a steel rack
Painting	Paint 11.6 m ² 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]	400-2000 ppm	(yes)	2
		TVOC [ppb]	0-1000 ppb*		
AMS	IAQ-Core	CO ₂ eq. [ppm]	450-2000 ppm	yes	2
		TVOC [ppb]	125-600 ppb**		
Omelix	MQ-135	0 – 5 [V]	10-300 ppm NH ₃ 10-1000 ppm C ₆ H ₆ 10-300ppm Alcohol	no	5
Siemens	QPA1000	0-100 % air quality	0-10 V	yes	1
niv S+S Regel-technik	RLQ-W	0-100 % air quality	0-10 V	yes	1

Results – Absolute vs. relative response

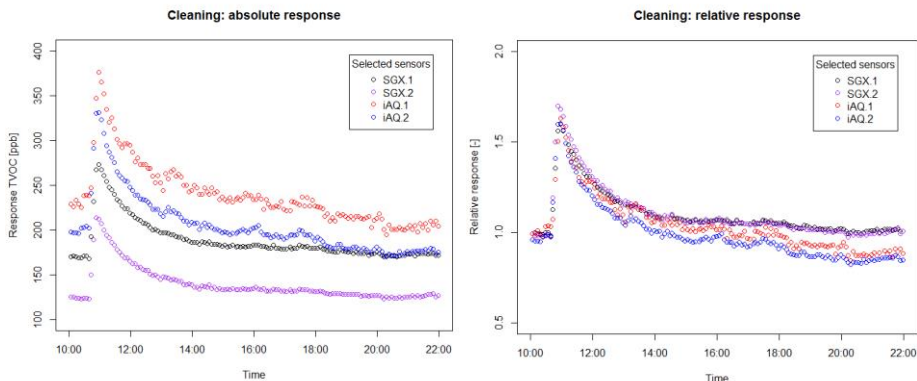


Figure 3: Response of SGX and iAQ sensors to cleaning with detergent: Left-absolute signal, Right-relative signal normalized by background concentration before activity

- 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)

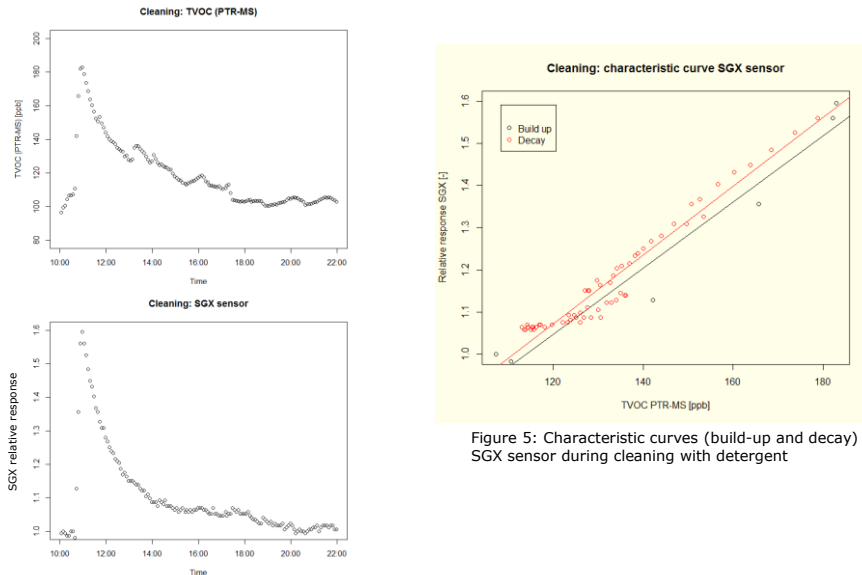


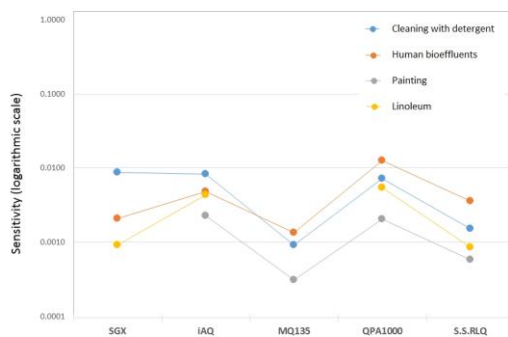
Figure 5: Characteristic curves (build-up and decay) for SGX sensor during cleaning with detergent

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

Results – Analysis of linear regression fit



Sensitivity – the aggregated picture



- 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

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

Issues regarding ventilation control

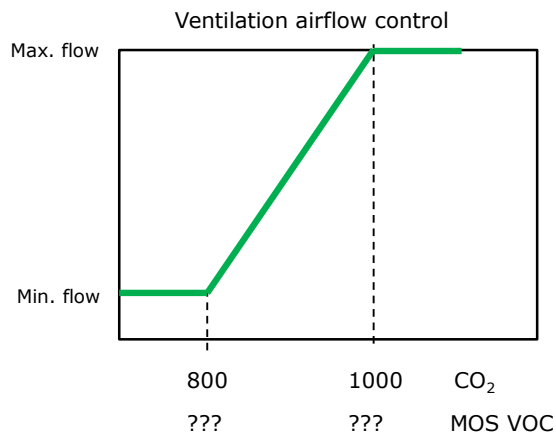


- Information regarding sensor properties are often missing
- Relative signal, even several sensors from one producer can present different response to the same conditions
- "Auto-calibration" may be a disadvantage
- Definition of set-point value is problematic due to
 - Broad range sensitivity
 - Relative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

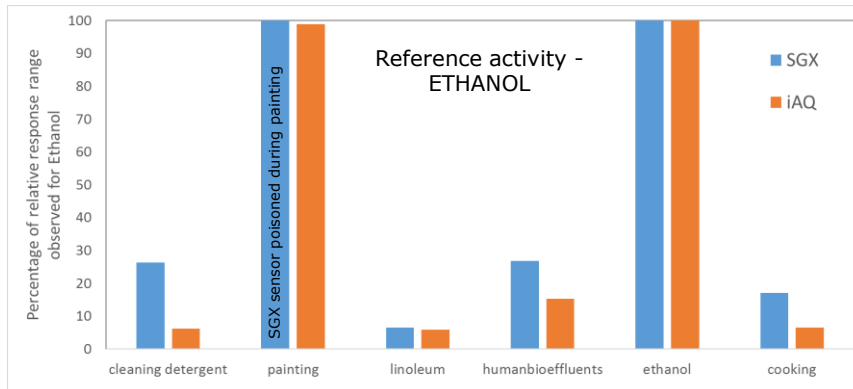


Figure 7: Percentage of relative response calculated based on exposure to Ethanol utilized during other tested activities

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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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VOC VS. CO₂ CONTROLLED DCV:

A CASE STUDY

AIVC 2018 Webinar

 GHENT
UNIVERSITY

Jelle Laverge

Assistant Professor

ARCHITECTURE & URBAN PLANNING

E jelle.laverge@ugent.be

T +32 9 264 37 49

architecture.ugent.be

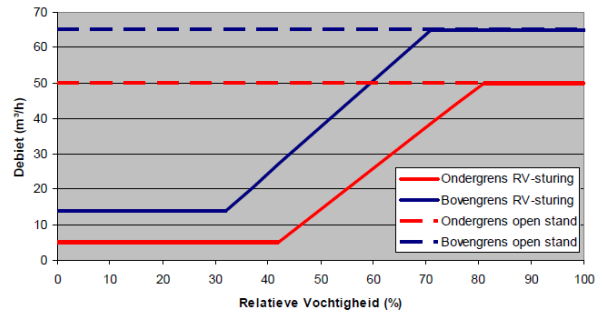
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 @Jlaverge

 Jelle Laverge

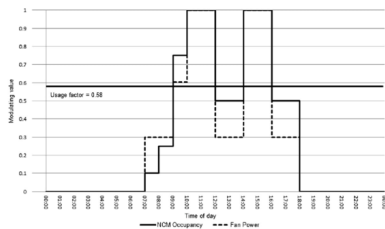
The Context: Belgian DCV

A BIT OF HISTORY OF 'DCV' IN BELGIUM



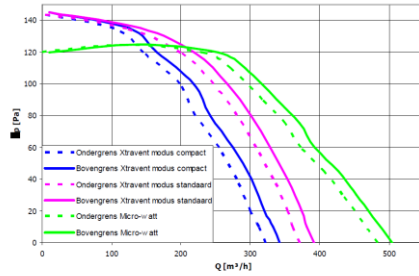
1st Generation: mechanical exhaust control imported from France
+- 2007

A BIT OF HISTORY OF 'DCV' IN BELGIUM



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

A BIT OF HISTORY OF 'DCV' IN BELGIUM

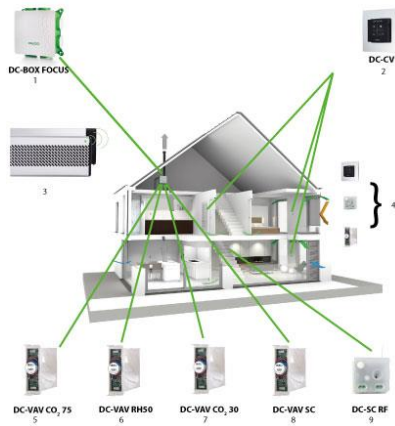


figuur 3: 90-90 interval van de ventilatorkarakteristiek



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

A BIT OF HISTORY OF 'DCV' IN EUROPE



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

The Research Objective

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 CO₂?

The Case Study



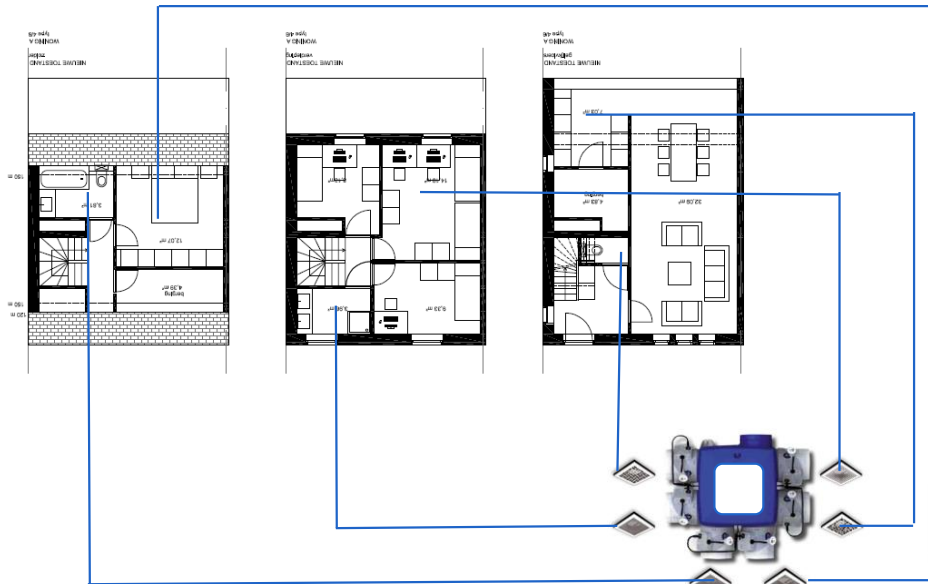
Social housing estate 'Venning'
Kortrijk, Belgium

Renovation part of concerto 'Eco-Life'





Focus on the individual dwellings



NDIR CO₂
MOS



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 'CO₂ equivalents'

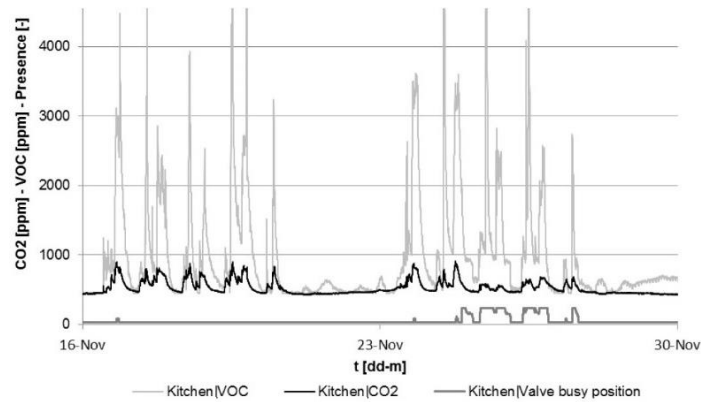
Same setpoints in both modes

Campaign	1	2	3	Campaign	1	2	3
Fase 2							
W2.1	X	X	X	W2.16	-	X	X
W2.2	X	X	X	W2.17	-	X	X
W2.3	X	X	X	W2.18	-	X	X
W2.4	X	X	X	W2.19	-	-	X
W2.5	X	X	X	W2.20	-	-	X
W2.6	X	X	X				
W2.7	X	X	X	Fase 3			
W2.8	X	X	X	W3.1	X	X	X
W2.9	X	X	X	W3.2	X	X	X
W2.10	X	X	X	W3.3	X	X	X
W2.11	X	X	-	W3.4	X	X	X
W2.12	X	-	-	W3.5	X	X	-
W2.13	-	X	-	W3.6	X	X	-
W2.14	-	X	X	W3.7	X	-	-
W2.15	-	X	X	W3.8	-	X	X
				W3.9	-	-	X

Table 1: Monitoring campaigns

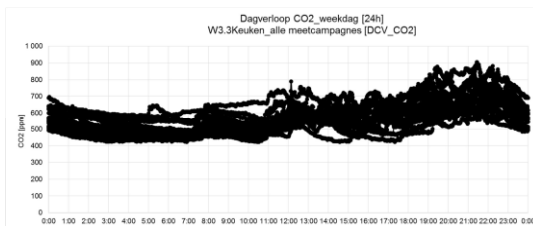
	Campaign 1	Campaign 2	Campaign 3
DCV _{CO2}	November 14, 2015	December 11, 2015	January 09, 2016
	November 24, 2015	December 23, 2015	January 20, 2016
DCV _{VOC}	November 29, 2015	December 25, 2015	January 22, 2016
	December 09, 2015	January 06, 2016	February 02, 2016

The Results

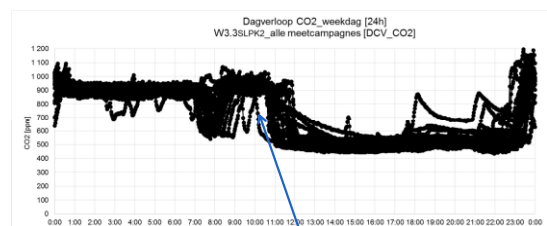


CO₂ concentration over 24 h

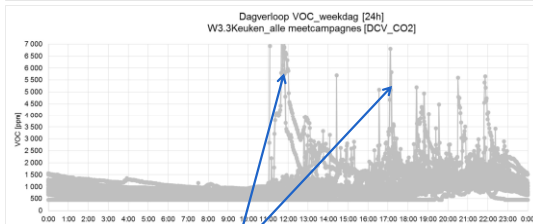
Kitchen



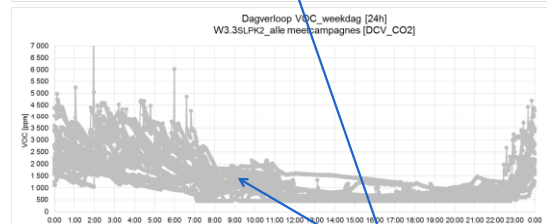
Masterbedroom



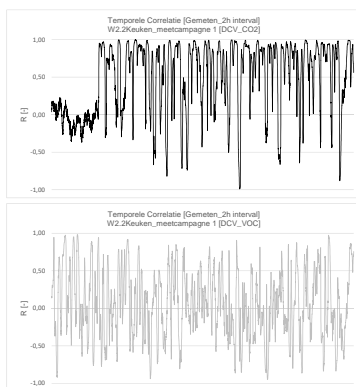
Cooking activities



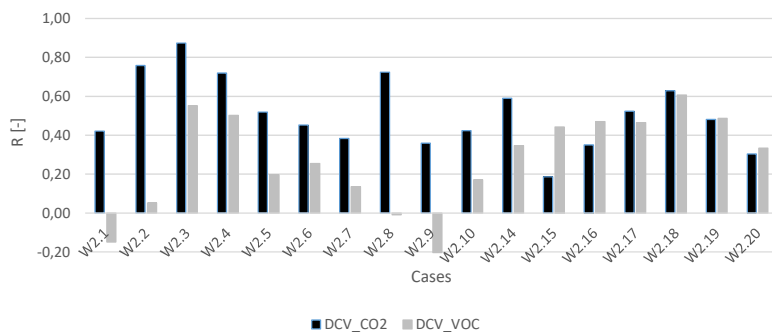
different emission rate



VOC concentration over 24 h



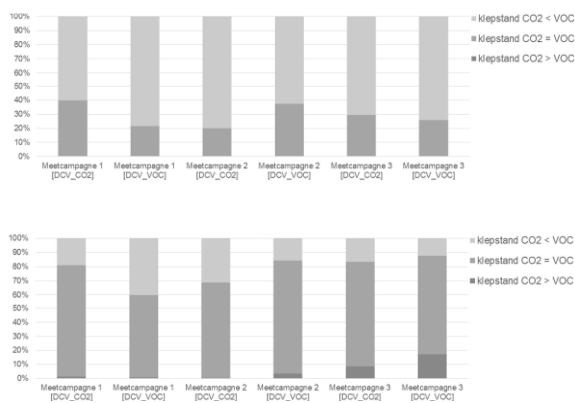
Figuur 17: Temporele correlaties voor W2.2Keuken [meetcampagne 1]



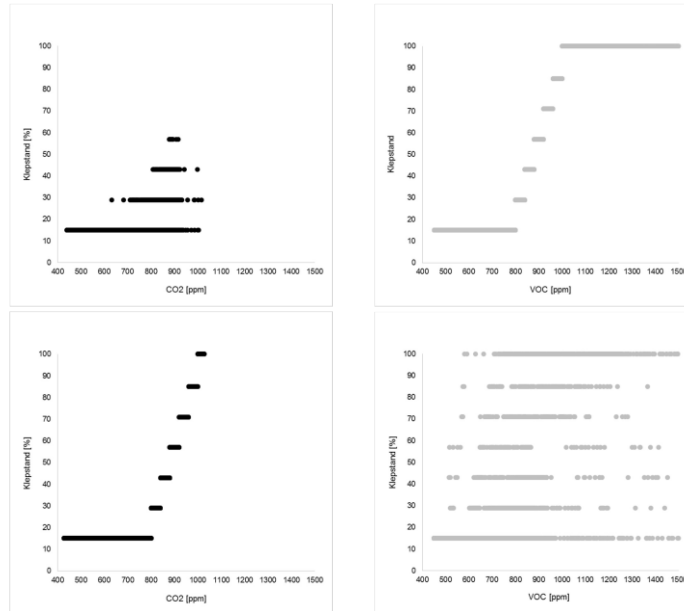
Pearson Correlation between CO2 and VOC concentration

By DenisBoigelot, original uploader was Imagecreator - Own work, original uploader was Imagecreator, CC0, <https://commons.wikimedia.org/w/index.php?curid=15165296>

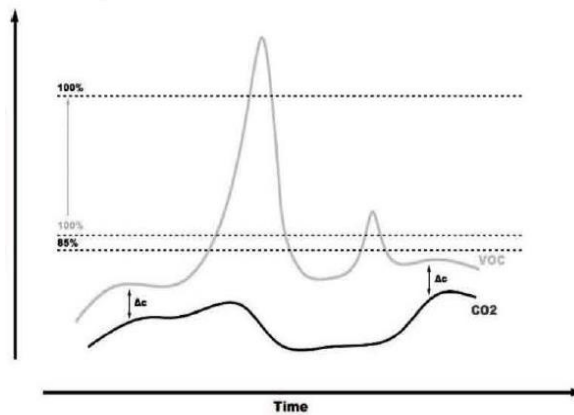
Differences between individual houses, based on number of people, type of sources...



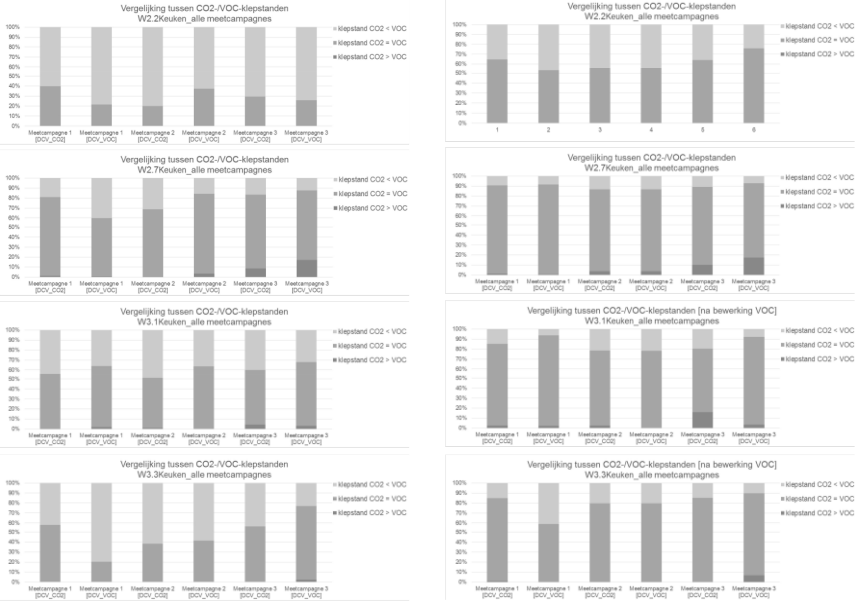
valveposition
as a function of
CO₂/VOC
concentration



How to handle this type of signal for better ventilation?



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



Lessons learned

Lessons learned

- ‘equivalent’ TVOC concentration was more than 50% higher than the CO₂ 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