

NEW DEVELOPMENTS IN VOC SENSING FOR DCV

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ABSTRACT

The paper summarizes the activities undertaken by AppliedSensor within the European Clear-up project with respect to new developments in volatile organic compound sensing for demand controlled ventilation. State-of-the-art is to use non-dispersive infrared sensor technology for indoor carbon dioxide detection. Carbon dioxide so far serves as indicator for bad indoor air quality and required ventilation rates. Indoor events coming along with complex mixtures of gaseous compounds, mainly volatile organic compounds, released by human bio-effluents, cooking odours, outdoor pollutants, cleaning supplies as well as building material and furniture emissions, play a pronounced role for human air quality perception and health, but cannot be detected with carbon dioxide as indicator. Within the European Clear-up project, AppliedSensor worked on the development of metal oxide semiconductor based indoor air quality monitoring modules specialized for demand controlled ventilation, closing the gap between pure CO₂ and volatile organic compound only detection, their implementation in test facilities and enhancement for wireless application.

KEYWORDS

IAQ, VOCs, MOS gas sensor, DCV, Energy savings

INTRODUCTION

Buildings have to operate over a wide range of environmental and load conditions and contribute to a large part of the world's energy consumption and carbon emission. Almost continuous adjustment of many operating parameters in buildings is required in order to achieve minimum energy consumption while maintaining acceptable comfort levels. Intelligent sensors for safety, comfort and control appliances are considered as the keys to energy-efficiency and a high standard of living. Improvements in low power sensor systems and wireless communication continuously increase the application of wireless sensor networks for monitoring and control systems in the building sector, especially when there is no infrastructure available [1].

Energy efficient ventilation relating to good indoor air quality (IAQ) is a major task for building performance according to the requirements set by the European Energy Performance of Buildings Directive (EPBD) in 2010 [2]. Today's ventilation schemes are mainly based on time-scheduled ventilation, leading to a waste of energy and often do not account for the right ventilation demand. More advanced systems apply demand controlled ventilation (DCV) using sensors for IAQ control. DCV ensures that fresh air is supplied to interior spaces

whenever necessary, saving energy and lowering building operation costs. Sensors alter the climate control system to increase ventilation when defined indoor pollution threshold limits are exceeded. Decreasing pollution levels result in ventilation rate reduction. State-of-the-art is to use carbon dioxide (CO₂), whose production is proportional to the human metabolic rate, as indicator for bad IAQ [3]. Ventilation standards and guidelines in Europe specify ventilation rates for different IAQ categories based on CO₂ concentrations above outdoors, related to the percentage of dissatisfied people with the IAQ [4,5]. The leading sensor technology for IAQ monitoring based on CO₂ quantification is non-dispersive infrared adsorption (NDIR) [6].

Clear-up [7] focuses on sensor technologies and strategies for DCV taking into account events coming along with more complex mixtures of gaseous compounds, mainly volatile organic compounds (VOCs), released by human bio-effluents, cooking odours, outdoor pollutants, cleaning supplies as well as building material and furniture emissions, that cannot be detected with carbon dioxide as indicator, but play a pronounced role for human air quality perception and health [8].

AppliedSensor developed IAQ modules specialized for DCV, closing the gap between pure CO₂ and VOC only detection. The detection of VOCs and potentially harmful substances (e.g. CO) is facilitated by a micromachined metal oxide semiconductor (MOS) sensing element optimized for the detection of anthropogenic VOCs. Sensor data of various indoor spaces (meeting rooms, offices, kitchens etc.) has been correlated with analytical measurement data and user perception. The use of NDIR-CO₂ reference sensors led to the development of an empirical algorithm correlating proportionality of human CO₂ production rate and other bio-effluent (VOC) generation. This way, the sensors are able to give measures of both, human related CO₂ events as well as VOC related events at the same time. Based on VOC detection the sensor module provides a standardized output signal in CO₂ equivalents [ppm] that can be linked to specific IAQ levels requested by HVAC planners and established ventilation standards referring DCV settings to CO₂ concentrations above outdoors [9].

The sensor modules have been installed in different test buildings for long-term stability measurements and investigations on the energy saving potential using the sensor module for DCV. Further development led to power reduced IAQ sensors suitable for battery operated devices.

FIELD STUDIES - VOC vs. CO₂ APPROACH

Fig. 1 shows the developed IAQ-module used for the field studies within the European clear-up project.



Figure 1. Sensor module for IAQ monitoring - micromachined MOS gas sensor.

The benefit of VOC-based IAQ control compared to CO₂-based DCV becomes obvious in indoor spaces where changes of CO₂ are too small for ventilation control but indoor air is dominated by odorous events, affecting perceived air quality by a large extent (e.g. kitchens, restrooms, smoking areas).

The developed IAQ-module allows capture of CO₂ concentrations and odorous events at the same time. The main signals caused by cooking activities, that can be attributed to VOCs are only detected by the developed IAQ-module in the background of CO₂ (Fig. 2, right hand side: cooking event). The NDIR reference sensor however, is only able to measure the CO₂ production linked to the grade of occupancy. Implementation of the empirical algorithm for CO₂ prediction based on anthropogenic VOC detection allows reliable correlation of predicted and measured CO₂ concentrations in indoor spaces where no appreciable human activity takes place. The perfect correlation of predicted CO₂ equivalents calculated from the detected VOC level compared to the measured CO₂ concentration using NDIR technology is shown by means of a meeting room on the left hand side of Fig. 2.

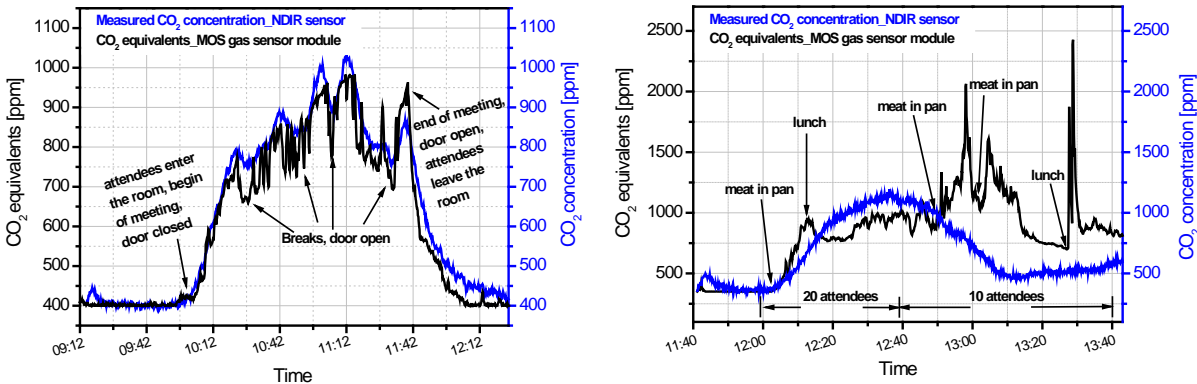


Figure 2. VOC vs. CO₂ approach: predicted and measured CO₂ concentrations (left: meeting room/right: kitchen).

DCV vs. TIME-SCHEDULED VENTILATION

DCV – office

The developed IAQ-module has been tested for DCV compared to natural and time-scheduled ventilation with the main focus on energy demand and resulting IAQ.

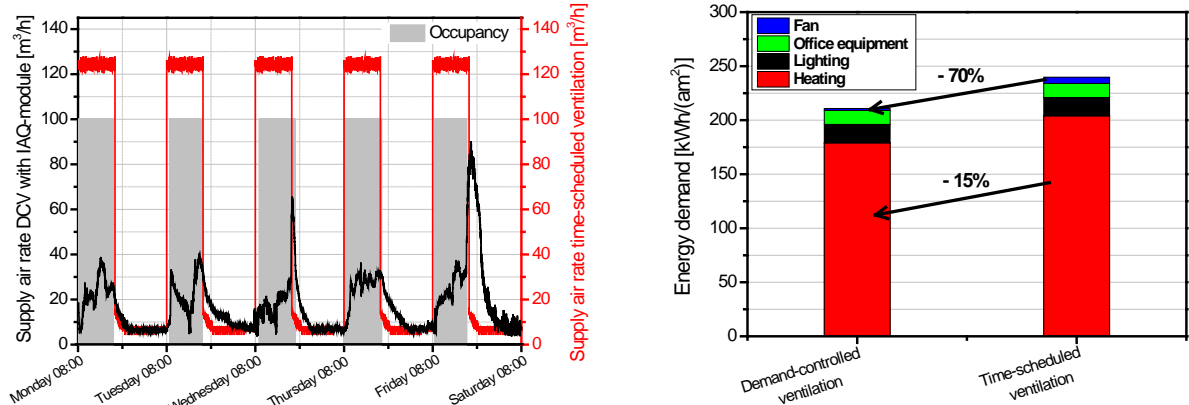


Figure 3. Left: Supply air rate [m³/h] - DCV compared to time-scheduled ventilation. Right: Energy demand during winter period 2009/2010 for DCV and time-scheduled ventilation.

The results when triggering the supply air rate with the IAQ-module instead of applying time-scheduled ventilation are very promising: In a 80m³ office with two employees, the supply air rate could be reduced by 60% compared to time-scheduled ventilation, set up according to DIN EN 15251 (Fig. 3, left hand side). Good air quality was maintained, measured CO₂ concentrations did not exceed 1000 ppm for the design value of 2 people in the office.

Natural, demand-controlled and time-controlled ventilation were carried out reiterating weekly for 4 months during winter time. The ventilation settings can be taken from Table 1.

Ventilation Strategy	Description
Natural ventilation	Window opening is up to people working in the office
Time-scheduled ventilation	Ventilation according to EN 15251 (assuming IAQ category II, low polluting building material and equipment, 2 attendees) <ul style="list-style-type: none"> Total air flow rate: 125 m³/h (Mo-Fr 08:00 a.m. to 06:00 p.m.) 6 m³/h otherwise
DCV using iAQ-module	Sensor output, 450-2000 ppm CO ₂ equivalents serves to trigger the ventilation rate in linear scale from 6 m ³ /h to 125 m ³ /h

Table 1. Ventilation settings - office.

60% less supply air resulted in 70% less power consumption for the fan and 15% less heating energy demand during heating period 2009/2010 (Fig.3, right hand side).

DCV – meeting room

In a highly frequented meeting room designed for 8 people and time-scheduled centralized ventilation of 70 l/s from 08:00 a.m. to 6 p.m., 50% supply air rate could be saved within one week applying a 3-step DCV scheme as shown in Fig. 4, left hand side. Step 1: 35 l/s, corresponding to sensor output > 700 ppm, step 2: 50 l/s, corresponding to sensor output > 900 ppm and step 3: 70 l/s, corresponding to sensor output > 1300 ppm.

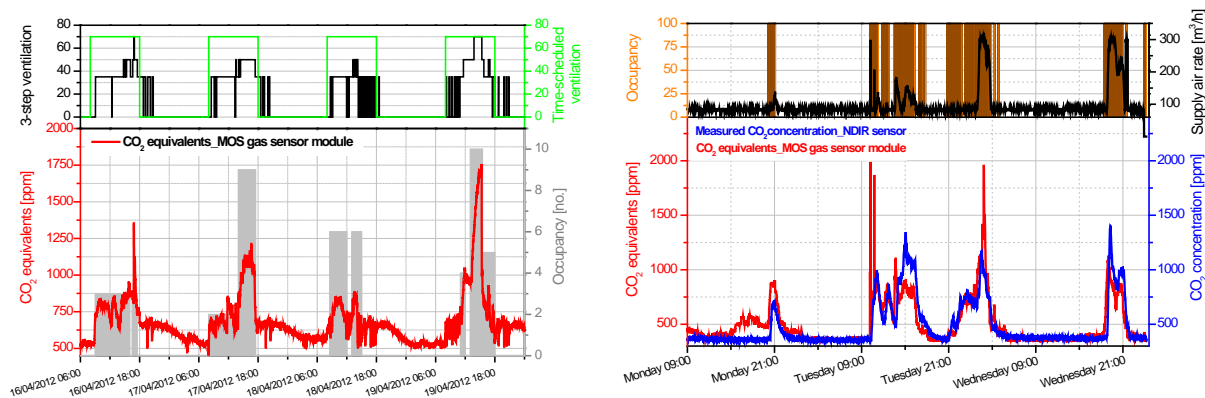


Figure 4. Left: DCV – meeting room. Right: DCV – fitness center.

DCV – fitness center

Installation in an air handling unit in a fitness center resulted in 24% less operating time, which translates to 60% energy cost saving with the overall IAQ rated "good" (Fig. 4, right hand side).

LONG-TERM STABILITY

Long-term stability of sensors in the building sector is essential because of maintenance reasons. Field-tests comparing permanently operated IAQ-modules with new modules showed, that perfect functionality in the field is guaranteed even for more than 50.000 operating hours (Fig. 5). As result of the standardized output signal, the IAQ-module is not affected by typical chemical sensor drift effects.

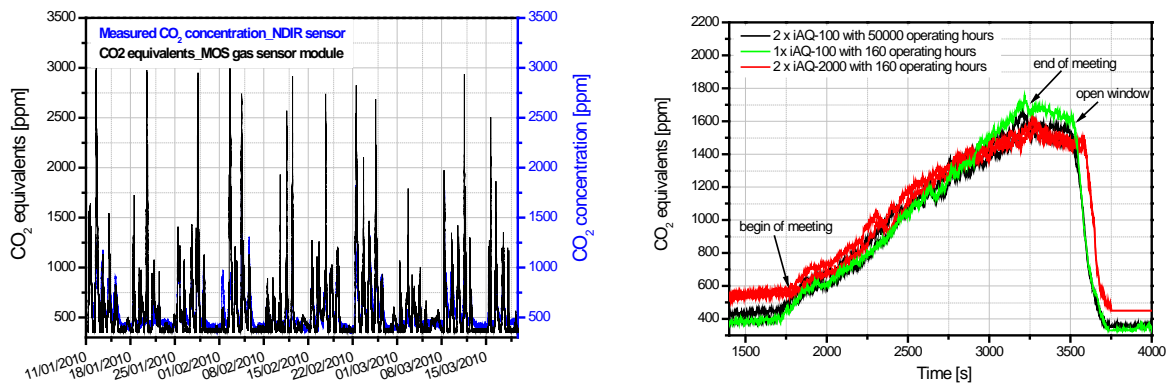


Figure 5. Long-term stability: Left: 10 weeks sensor data permanently operated IAQ-module. Right: Real-life test after 50.000 operating hours.

POWER REDUCED IAQ-MODULES

Wireless sensor networks require low power consuming sensors. Constant power operated IAQ-modules currently consume ~200 mW, too much for desired battery operation at an arguable maintenance level. Temperature modulation of the sensing element is seen as the way forward to reduce power consumption drastically whereat performance of the sensor has to remain unaffected.

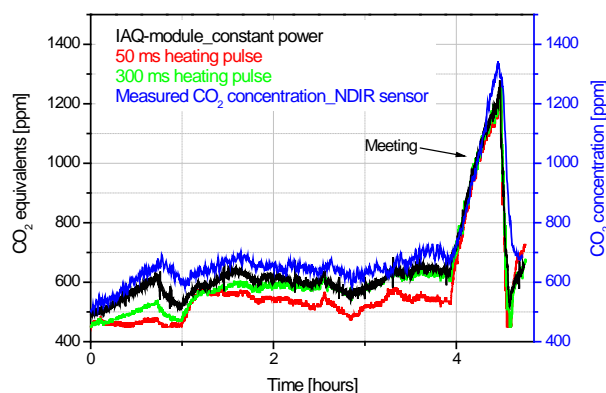


Figure 6. Predicted CO₂ concentrations for constant powered IAQ-module, temperature modulated modules in comparison to measured CO₂ concentration.

Different temperature profiles have been applied and tested in real-life in comparison to the constant power operated IAQ-module and NDIR-CO₂ reference sensor. 50 ms and 300 ms heating pulse of 3 V showed comparable performance to the constant powered IAQ-module while lowering the power consumption between ~50-90%. Fig. 6 shows output signals in CO₂ equivalents applying AppliedSensor's evaluation algorithm to the temperature modulated sensor raw data in comparison to the constant operated IAQ-module and measured CO₂ concentration, as obtained for an office scenario where a meeting of 6 people took place.

BUILDING MONITORING SYSTEM

Together with sensors for humidity, temperature, illuminance level and CO₂, the developed IAQ-modules build the core of environmental condition monitoring within the Clear-up project. In the test building in Prague and in the demonstrator building in Cadiz, the IAQ-modules serve to trigger ventilation. Monitoring and evaluation of data is supported by an installed web-based monitoring system that provides real-time web-access to the sensor data (Fig. 7).

The system enables the setup of thresholds for temperature, relative humidity and IAQ that provides the chance to immediately interfere upon sensor/system failures or significant events by text notification. Floor plans of the buildings can be used to display the information about each analyzed room on a monitor. A detailed view of time series for the last day up to the last month of the monitored parameters can be selected by the user.

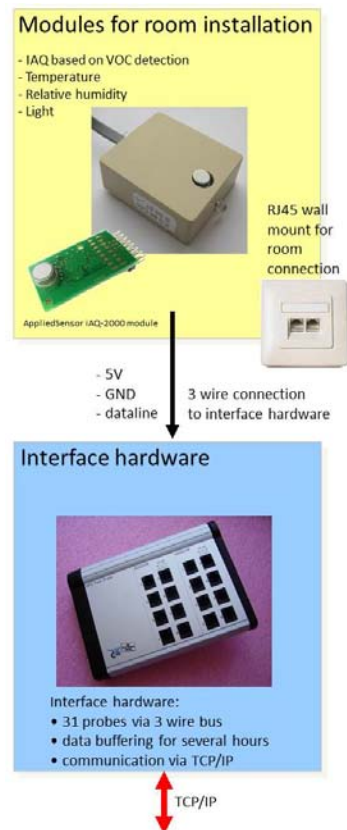


Figure 7. Left: Wall-mounted IAQ-modules for ventilation control and dimmable lighting at the test building in Prague. Right: Web-based monitoring system with room probes for IAQ, temperature, relative humidity and illuminance measurement using the normal UTP infrastructure of the building. The FlexProbe serves as interface hardware between room probes and software.

CONCLUSION

The energy findings accentuate the need for DCV regarding actual VOC load conditions in buildings using the developed IAQ-module. Human adaption often prevents air quality perception and results in high indoor pollution loads. Time-scheduled ventilation needs air flow rates to be adjusted before start-up depending on the average grade of occupancy or activity in the respective room which often results in a lack of overlap of operation time, ventilation demand, occupancy profiles and indoor pollution load. IAQ control with the developed IAQ-modules however ensures that fresh air is supplied to rooms whenever necessary minimizing the amount of supply air and hence the energy consumption compared to time-scheduled ventilation (Table 2).

Case study	Supply air rate reduction
Office	• 60%
Meeting room	• 50%
Fitness center	• 24%

Table 2. Case studies DCV - Supply air rate reduction.

Remote building monitoring and control systems are seen as a way forward for intelligent buildings, providing very meaningful information about the metabolism of the building, occupancy profiles, long-term data, comfort conditions and applied ventilation strategies. Implementation of low power consuming IAQ-modules in wireless monitoring and control systems will even lead to new applications in the building sector.

Clear-up test building measurements have just started and we are looking forward to gain new experiences with the developed IAQ-module.

REFERENCES

- [1] Gassmann, O., Meixner, H. (Editors) 2001. *Sensors in Intelligent Buildings, Sensors Applications*, Volume 2, Wiley-VCH Verlag GmbH.
- [2] EPBD, Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings, Official Journal of the European Union, L 153, Volume 53, 18 June 2010, 13-23.
- [3] Pettenkofer M. 1858. *Über den Luftwechsel in Wohngebäuden (Air change in residential housing)*, Munich: Cotta'sche Buchhandlung [German].
- [4] CR 1752 1998. *CEN Report Ventilation for Buildings: Design Criteria for the Indoor Environment, CEN/TC 156/WG 6*, European Committee for Standardization, Brussels, Belgium.
- [5] EN 15251 2007. *Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics*, European Committee for Standardization, Brussels, Belgium.
- [6] Won, D. and Yang, W. 2005. *The State-of-the-art in Sensor Technology for Demand-Controlled Ventilation*, National Research Council Canada, October 2005.
- [7] Clear-up 2012. www.clear-up.eu

- [8] Burdack-Freitag, A., Rampf, R., Mayer, F. and Breuer, K. 2009. *Identification of anthropogenic volatile organic compounds correlating with bad indoor air quality*, Proceedings of the 9th International Conference and Exhibition Healthy Buildings, 2009, Sept. 13-17, Syracuse, NY, paper 645.
- [9] Herberger, S., Herold, M., Ulmer, H., Burdack-Freitag, A. and Mayer, F. 2010. *Detection of human effluents by a MOS gas sensor in correlation to VOC quantification by GC/MS*, Building and Environment, 45 (11), 2430-2439.
- [10] Herberger, S. and Ulmer, H. 2012. *Indoor Air Quality Monitoring Improving Air Quality Perception*, CLEAN – Soil, Air, Water, 40 (6), 578-585.