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Technical Article

New small, low-power MOX VOC sensors: how might they be used for indoor air quality monitoring?

By Norwood Brown

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Alarming stories in the news media have served to heighten public concern over air quality. The Volkswagen emission tests scandal set off a storm of outrage over the effect of potentially harmful vehicle exhaust emissions on the health of city dwellers.

This has also heightened people's awareness of the quality of the air we breathe both indoors and outdoors. The average human inhales about 15kg of air a day, 80% of it indoors. And while the quality of outdoor air is routinely monitored by public agencies, Indoor Air Quality (IAQ) monitoring is the responsibility of the building's operator or occupier, if it is performed at all. Here, a new generation of small, surface-mount, low-power VOC (volatile organic compound) gas sensors has emerged, offering the potential for distributed, local IAQ monitoring by small and affordable devices, and therefore for more responsive operation of air-moving and air-filtering equipment in buildings.

This article explains the operation of these new VOC sensors and the differences between them and absolute single-gas sensors. It also shows how they can provide data which enables air management equipment to respond most efficiently and effectively to variations in indoor air quality.

How IAQ monitoring is performed today

Professional operators of commercial buildings today in general draw on one or two types of air quality data to control the operation of ventilation and air-filtering systems. Most commonly, they use absolute measurements of a single gas, usually carbon dioxide (CO_2). They might also use occupants' subjective judgements on the quality of the air.

Because humans exhale CO_2, it is normal for the concentration of CO_2 to increase over time in an occupied room, and the more people in the room, the more the CO_2 concentration rises in the absence of adequate ventilation.

An excessive concentration of CO_2 in indoor air is associated with feelings of drowsiness, loss of focus, impaired decision-making and a feeling of 'stuffiness'. Commercial building management systems fitted with CO_2 sensors today therefore regulate the operation of filtering and/or ventilation equipment in response to measured CO_2 levels. The aim is to keep the indoor air fresh and comfortable while minimizing the rate of thermal exchange, since the loss of artificially heated or cooled air wastes both money and energy.

In fact, the concentration of CO_2 is a reasonable proxy measure for the density of human occupation of a given space. And since people are responsible for the production of VOCs as well as of CO_2, through what are scientifically – and politely – termed 'bio-emissions', building operators today commonly assume that air-handling equipment configured to regulate the concentration of CO_2 will also adequately regulate the concentrations of the many types of VOCs found in indoor air.

Practical considerations underpin this assumption. The packaging, price and power-consumption characteristics of CO_2 sensor components have been attractive enough for many years now to warrant their integration into the circuit boards of mainstream building automation equipment.

The options for measurement of VOC concentrations were until recently much more limited. There are various methods for measuring and analyzing VOCs suspended in air: photo-ionization, flame ionization, colorimetric tubes, and wavelength absorption are reasonably portable methods. In the laboratory, gas chromatography coupled with mass spectrometry (known as GC-MS) is the favored method.

Unfortunately, these methods are unsuited to use in compact, localized, low-power air quality sensing equipment, either because they are too large or they consume too much power.

This is why the introduction of a new generation of metal oxide (MOX) VOC sensors, now available in surface-mount IC-type packages and using only milliwatts of power, is so exciting for the field of IAQ monitoring. These low-cost, compact and low-power VOC sensing devices may readily be integrated into everyday objects such as luminaires, thermostats, fans and remote controls for fans – even in mobile phones. The potential for providing distributed, local VOC sensing is real and current.

Contamination Source	Emission Source	Indoor Air Contaminants
Building Materials	Adhesives, Carpets, Cement, Flooring, Solvents,	Formaldehyde, Alkanes, Alcohols, Aldehydes, Ketones
Combustion	Engines, Appliances, Smoke	Hydrocarbons
Cleaning Products	Household cleaning supplies	Acetone, alcohol, spirits
Furniture	Wood, Poly Vinyl Chloride (PVC), Glues	Formaldehyde, Toluene, Xylene, Decane
Human Being	Breath	Acetone, Ethanol, Isoprene
	Flatulence	Methane, Hydrogen
	Cosmetics	Limonene, Eucalyptol, Alcohols
Office Equipment	Printers, Copies, PCs	Ozone, Benzene, Styrene, Phenol

Fig. 1: the types of VOCs typically found indoors and their sources

And this should enable the users of air-handling equipment to re-examine their reliance on CO_2 data alone. In fact, VOC concentrations do not rise and fall exactly in step with CO_2 concentrations for two main reasons:

- first, not all VOCs have a human source (see Figure 1)
- second, humans' rate of CO_2 production is continuous and normally fairly constant when not exercising. Human VOC production, however, fluctuates, rising for instance in the period after consuming a meal.

As a report by the Building and Fire Research Laboratory of the US National Institute of Standards and Technology stated, 'Many contaminant sources are not a function of occupancy, for example emissions from building materials and contaminants entering a building from outdoors. Carbon dioxide concentrations do not provide any information on the concentration of contaminants emitted by occupant-independent sources.' (A K Persily, 1996)

So for instance a CO_2 sensor would register a low level of CO_2 in the air in a room occupied by a single person but recently refitted with new furniture, carpets and fixtures attached to the room's walls and floor with glue. The room's air-handling equipment would typically be configured to provide minimal ventilation in this circumstance, leaving the sole occupant to breathe in high quantities of suspended VOCs.

An elevated concentration of VOCs in a room's air most obviously affects the comfort of the occupants. While CO_2 is odorless, a significant cross-section of VOCs smell, and the smell is (for a large segment of VOCs) unpleasant.

Discomfort is not the only effect of VOCs in the air, however. The US Environmental Protection Agency's (EPA) website lists short- and long-term health effects that, it says, 'may' be linked to exposure to VOCs in indoor air. The EPA says these effects can include:

- Eye, nose and throat irritation
- headaches, loss of co-ordination and nausea
- damage to liver, kidney and central nervous system
- Some organics can cause cancer in animals; some are suspected or known to cause cancer in humans.

(Source: https://www.epa.gov/indoor-air-quality-iaq)

Examples such as the one above, then, are prompting OEMs to investigate the use of surface-mount MOX VOC sensors in IAQ monitoring equipment.

The operating principle of a MOX gas sensor is pictured in Figure 2.

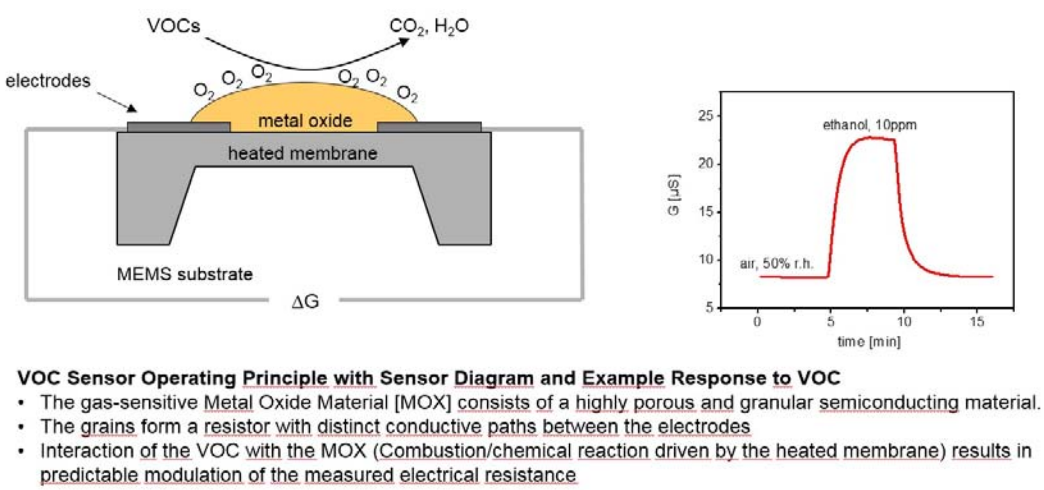

Fig. 2: how a chip-type MOX gas sensor operates

MOX VOC devices natively sense a broad spectrum of VOCs, and provide relative outputs in response to changes in VOC concentration. When equipped with an on-board processor, the sensor may also be able calculate equivalent relative values for a range of VOCs. These devices, since they operate as relative output devices, do not require calibration.

Separately, a class of absolute output gas sensors is available: they are ideal, and necessary, for safety-critical applications, in which an excessive concentration of a particular gas could pose an immediate risk to life or health. Such absolute output devices are normally:

- relatively expensive
- can only sense a single gas
- require regular calibration to provide accurate output data

These factors are distinctly unwelcome in IAQ monitoring applications. Complementary to this important, but limited, absolute measurement resource, is the VOC sensor: this can sense a wide spectrum of VOCs, and is therefore able to note variations in indoor air quality which might be caused by one or more compounds in a wide range of VOCs and which affect people inside a building.

In IAQ monitoring, broad-spectrum sensors such as the ams CCS811 (in a 2.7mm x 4mm x 1.1mm, LGA package) or the iAQ-CORE (an integrated sensor module with a footprint of 15mm x 18mm) do not report absolute ppm values specific to any particular gas for safety-critical applications, but instead provide an indication of the relative change in the concentration of a wide range of VOCs in the environment, including, but not limited to, all of those listed in Figure 1.

In an IAQ monitoring application, the MOX VOC sensor could be used alongside an absolute-output CO_2 sensor, which can provide a known baseline for CO_2 concentration at all times. The VOC sensor supplements the absolute CO_2 measurements, capturing additional information regarding VOC events which may, or may not, correlate directly with human occupancy (which is normally the primary cause of raised CO_2 concentrations), as Figure 3 shows.

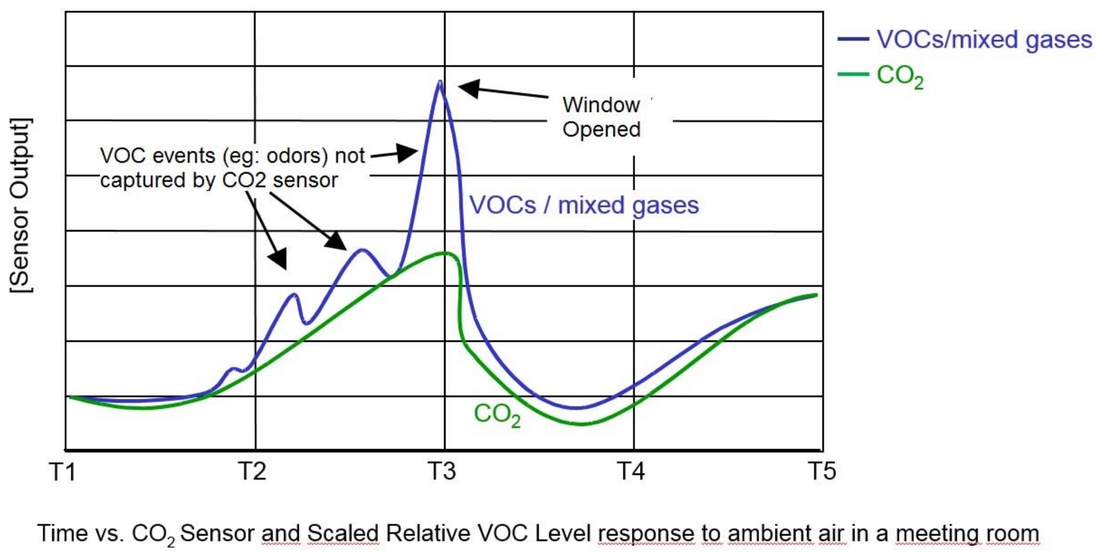

Fig. 3: comparison of measurements from a VOC sensor and a CO2 sensor operating simultaneously in a meeting room used by multiple people for several hours

In Figure 3, the CO_2 sensor has completely missed times during which the VOC sensor indicated degraded air quality, which might have been due for instance to the use of cleaning chemicals during a break in the meeting, or emissions from equipment such as a copier or printer. Better ventilation in response to the output from the VOC sensor, but not indicated by the CO_2 sensor, would in this case have have improved air quality for the occupants of the room during these VOC events.

Formatting measurement data for air-handling systems

A VOC sensor such as the CCS811 or iAQ-Core, then, has an excellent ability to detect changes in the concentration of VOCs in the air over time. But how can this information be used to manage the operation of air-filtering or air-moving equipment?

Today, air management systems are typically configured to respond to the measured absolute value of CO_2 concentration. For this reason, the iAQ-Core and CCS811 include a processor running supplied algorithms which calculate a relative eCO_2 (equivalent CO_2) value, as well as a relative TVOC (Total Volatile Organic Compound) value. This allows the designer of an air-quality management system to translate an input from the sensor into an appropriate instruction to, for instance, increase the fan speed of the ventilation equipment or to open vents wider – or in the case of a fall in VOC concentration, to reduce energy use by slowing filtration and/or air exchange.

Tests repeatedly demonstrate that the calculated relative values for eCO_2 when tied to a proper baseline, and driven primarily by human VOC emission, closely match the change in actual CO_2 concentrations measured by an absolute CO_2 sensor (see Figure 4).

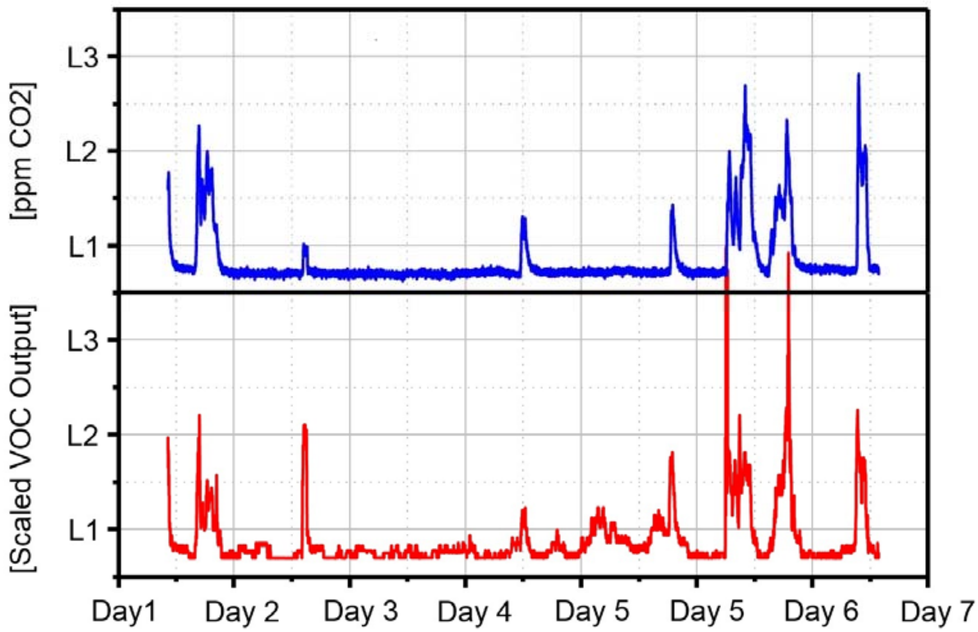

Fig. 4: comparison of calculated, scaled eCO_2 values from an ams MOX gas sensor with actual values measured by an absolute CO_2 sensor over a seven day period

New opportunities for integrating IAQ monitoring

Now that chip-type VOC sensors have developed to the point that their size, cost and power consumption allow them to become distributed sensing resources in areas managed by controlled-air systems, the integration of them into air quality management systems is only a matter of time – and will surely yield a healthier and more pleasant environment in which to work, live, and play.

It is also possible to see the value in integrating small, surface-mount VOC sensors in end products which have never previously included an air quality sensing function. For instance, a broad-spectrum VOC sensor in a cooker hood could automatically manage the air flow depending on the change in the concentration of VOCs it sensed in the air produced by raw and cooked food odors, smoke, cleaning agents and so on. This would free the cook of the need to operate the ventilator manually.

VOC sensors can also be extremely useful in almost any indoor space, including public transportation, private vehicles, and public buildings such as hospitals, offices and shops. And given that they are small enough to be mounted on a PCB alongside other electronic components, their integration in almost any kind of connected device for interfacing to air management systems is readily achievable.

Summary

Alarming stories in the news media have served to heighten public concern over air quality. The Volkswagen emission tests scandal set off a storm of outrage over the effect of potentially harmful vehicle exhaust emissions on the health of city dwellers.

This has heightened people's awareness of the quality of the air we breathe both indoors and outdoors. The average human inhales about 15kg of air a day, 80% of it indoors. And while the quality of outdoor air is routinely monitored by public agencies, Indoor Air Quality (IAQ) monitoring is the responsibility of the building's operator or occupier, if it is performed at all. And here, a new generation of small, surface-mount, low-power VOC (volatile organic compound) gas sensors appears to offer the potential for distributed, local IAQ monitoring by small and affordable devices, and therefore for more responsive operation of air-moving and air-filtering equipment in buildings.

This article explains the operation of these new VOC sensors and the differences between them and absolute single-gas sensors, and shows how they can provide data which enables air management equipment to provide more comfortable and healthier air indoors.

For more information

For more information about ams CCS811 gas sensor solution, please go to www.ams.com/CCS811

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