Measure VOCs to maintain high indoor air quality

By Ahmed Elbadry, Field Applications Engineer, ScioSense, www.sciosense.com

Building automation and demand-controlled ventilation (DCV) systems have traditionally used carbon dioxide (CO_2) sensors to control ventilation rates. They are used to monitor CO_2 in occupied indoor spaces, where concentration is typically dominated by human respiration. The more people in a given space, the higher the CO_2 concentration. More crowded spaces require a higher rate of ventilation to keep the air clean, odor-free and comfortable. Since CO_2 sensors can match occupancy with the required ventilation flow rate, many organizations have been installing CO_2 monitors in occupied indoor areas to improve ventilation and reduce the risk of spreading COVID-19 infections.

However, even though CO_2 concentration gives a measure of occupancy it does not give a complete measure of air quality.

For householders and building operators who are concerned about the quality of indoor air, volatile organic compounds (VOCs) are actually the key indicator. Some VOCs present serious health risks, while others are a common source of discomfort.

VOCs include both human-generated gases – including ‘bioeffluents’ such as smelly breath – and artificial sources such as readily evaporated chemicals in furnishings, cleaning materials, cosmetics, polishes, office equipment and consumer devices. Table 1 shows the World Health Organization’s (WHO) analysis of the health risks associated with VOCs commonly found in indoor air.

Indoor pollutant	Risk
Benzene	Acute myeloid leukemia, genotoxicity
Carbon monoxide	Acute reduction of exercise tolerance, increase in symptoms of ischemic heart disease
Formaldehyde	Sensory irritation, impact on lung function, nasopharyngeal cancer, myeloid leukemia
Naphthalene	Respiratory tract lesions, inflammation and cancer of airways
Nitrogen dioxide	Respiratory symptoms, bronchoconstriction, airway inflammation and decreases in immune defense
Polycyclic aromatic hydrocarbons	Lung cancer
Radon	Lung cancer, associated to leukemia and cancers of the extra thoracic airways
Trichloroethylene	Liver, kidney, bile duct cancer and non-Hodgkin’s lymphoma
Tetrachloroethylene	Early renal disease and impaired kidney performance

Table 1: Indoor VOC pollutants and their associated risks. (Source: WHO, 2009)

In the 19th century, the scientist Max von Pettenkofer discovered a correlation between CO_2 and VOC concentration levels in typical living environments. This correlation makes CO_2 measurements a potential alternative to VOC measurements when monitoring indoor air quality.

In practical indoor air quality management, however, a CO_2 sensor fails to track VOC contaminants in real time. A more responsive and accurate way to detect bad odors and VOC pollutants is to measure VOCs directly. Intelligent VOC sensors can in addition give an accurate estimation of CO_2 in indoor air in accordance with von Pettenkofer's research. For this reason, VOC sensors can be used alongside CO_2 sensors to confirm their readings. They can also detect occupation levels directly using hydrogen (H2) levels.

The NDIR CO_2 sensor's blind spot

The problem with using NDIR (non-disperse infrared) CO_2 sensors to measure VOCs is that the correlation breaks down in specific environments and conditions, at exactly the point at which the user would most want a ventilation system to be automatically triggered.

In a domestic setting such as a bathroom or kitchen, or in gyms and other public spaces, human activities generate large amounts of VOCs even when few people are present, and so when CO_2 levels are low. The odors from bio effluents in a bathroom or from cooking fumes in a kitchen are completely undetected by a CO_2 sensor – they are, to use a motoring analogy, in the sensor's blind spot.

On the other hand, a high-quality VOC sensor will detect bad odors or harmful chemicals within a few seconds, regardless of the density of occupation. That will enable a DCV system or air purifier to start up and clear the air immediately.

Understanding the techniques for VOC measurement

Indoor air quality can be impaired by any of a large number of VOCs. For any given installation of a DCV system, it is impossible for the system specifier to know which VOCs are or are not going to be present in the air over the lifetime of the system. For this reason, indoor air quality monitoring requires a sensor with broad sensitivity to multiple types of VOCs. A useful measurement output is derived from a combination of:

- Hardware which is sensitive to a broad array of VOCs
- Software which interprets the raw gas measurements to produce a measurement output which a DCV system or air purifier can use to trigger operation.

The ENS160, an indoor air quality sensor from ScioSense, for example, processes raw measurements from multiple gas sensing elements through advanced sensor fusion algorithms. The basic output from the sensor software measures Total VOC (TVOC) concentration. In the ENS160, this TVOC output is further processed to produce a series of air quality indicators adhering to various international and industry standards (Table 2).

Air Quality output signal	**Description**
TVOC	Total Volatile Organic Compound concentration, measured in parts per billion (ppb).
	Returns the total concentration of VOCs in the air. ScioSense follows international classification criteria and mixture references (e.g. ISO16000-29) for design and calibration of its products.
	Our TVOC signal ranges from 0 to 65,000 ppb
eCO_2	Equivalent CO_2, measured in parts per million (ppm).
	Returns the estimated CO_2 concentration based on VOC levels ("Reverse Metabolic Rule")
AQI	Air Quality Index, measured in levels 1 to 5.
	Returns a configurable air quality index as defined by national or international regulatory bodies.

Table 2: The types of measurement output produced by the ENS160 indoor air quality sensor

The TVOC measure is a standard unit governed by industry specifications like ISO16000, and is used by several countries as an indoor air quality indicator. Limits and recommendations are based on many studies correlating health problems with prolonged exposure to high TVOC levels. The German Environment Agency (Umweltbundesamt, or UBA), for example, sets the maximum acceptable TVOC concentration compatible with a healthy living environment at 1mg/m3.

The standards-compliant ScioSense ENS160 detects a broad set of VOCs commonly present indoors, including but not limited to those indicated by the WHO as important pollutants (aside from radon in Table 1, although this is only relevant in some geographical areas). It also enables a DCV or air purification system to act quickly to clear unhealthy or unpleasant air: it provides a response within seconds.

The ENS160 TVOC output provides a highly representative measure of the effect of VOCs on human occupants.

Measurement accuracy

'Accuracy' of measurement can be a somewhat misleading term. The accuracy of single-gas measurements is not relevant since an air quality sensor must be sensitive to a broad range of gases, the mix of which varies randomly over time and place.

The best measure of an air quality sensor is in a sample application. Air quality sensors like the ENS160 are for example tested exhaustively in applications like bathrooms, bedrooms, kitchens, gyms and offices/meeting rooms. The performance is rated on real-world parameters such as the users' feelings of comfort, perceived absence of bad odors and so on.

ENS160 AQI measurements provide an easy-to-understand measure of air quality derived from the UBA standard. Moreover, the AQI can be derived directly from the ENS160 without using external software libraries. You can simply extract direct recommendations from the AQI signal without additional processing.

Making VOC measurement compatible with legacy DCV designs

So, TVOC as a measure of indoor air quality is superior to CO_2 : it responds quickly to bad odors and to harmful airborne chemicals, even when a space is sparsely occupied.

Nevertheless, many types of DCV equipment operate on the basis of CO_2 and not TVOC measurements. To avoid a complicated transition to TVOC measurement for these legacy designs, ScioSense includes an additional measurement output in the ENS160: a proxy measurement of CO_2 called Equivalent CO_2, or eCO_2. It is calculated by reference to Pettenkofer's 'Reverse Metabolic Rule', while also considering the proportional correlation of VOCs and CO_2.

ScioSense gas sensors accurately estimate CO_2 concentrations following this rule, providing a very close match with the response of dedicated CO_2 sensors (Figure 1). The ENS160 closely tracks CO_2 levels when occupants are the dominant contributor of CO_2, but in addition accurately reports VOC events which an NDIR CO_2 sensor would not detect.

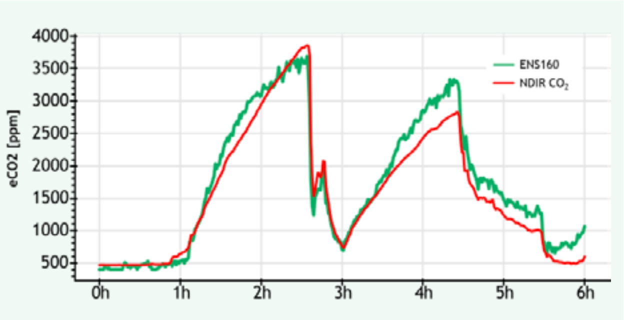

Fig. 1: comparison of measurement output of a typical NDIR CO_2 sensor with the eCO_2 readings from the ENS160

How to specify an air quality sensor

Modern ventilation and air purification systems are expected to monitor and guarantee good air quality. It is not only CO_2 levels that need to be diluted to prevent loss of attention and dizziness: air pollutants also need to be removed through filtering and ventilation to prevent health problems.

DCV systems use the key parameters of CO_2, TVOCs, temperature, and humidity to control air quality in an energy-efficient way. We performed experiments on a DCV system using a TVOC sensor in a gym operated for 24% less time than a system based on an NDIR CO_2 sensor. The TVOC sensor produced a 60% saving in total costs, while gaining good air quality ratings from users.

The ScioSense ENS160 VOC sensor, combined with its ENS210 temperature and humidity sensor, provides a reliable, complete, and compact solution for air quality monitoring. Together, they enable development of effective, energy-optimized systems tuned to the characteristics of indoor spaces.

The ENS160 provides on-chip heater drive control and data processing with no need for external libraries and no motherboard-CPU performance impacts. It also offers design flexibility through various types of interface – standard, fast, fast-mode-plus-I2C, and SPI – with separate VDDIO up to 3.6V (please see datasheet).