White Paper

Beyond CO_2: Sensing VOCs in Indoor Air Protects Health, Saves Energy

Adults typically spend more than 80 percent of their day indoors, consuming about 15 kilograms of air per day. If the quality of the air they breathe is poor, it can cause health problems that can occur within minutes and can last for years. According to the United States Environmental Protection Agency (EPA), immediate symptoms of exposure to polluted air can include throat irritation, dizziness and headaches. Long-term health risks may include respiratory disease, heart disease and even cancer.

From the classroom to the cubicle, the benefits of maintaining good indoor air quality extend beyond protecting the occupant's health. According to a White House Summit on Sustainable Buildings, students in schools with healthy air are more proficient at retaining information and teachers have fewer sick days. For employers, improving indoor air quality directly correlates with higher productivity and a more satisfied workforce. Professor David Wyon of the Technical University of Denmark's International Centre for Indoor Environment and Energy, said, "It has now been shown beyond reasonable doubt that poor indoor air quality in buildings can decrease productivity as high as six to nine percent."

Indoor Air Quality Defined by Temperature AND Odor

The climate control industry defines the quality of indoor air as a measure of temperature, humidity and carbon dioxide (CO_2). For decades, the primary method for improving indoor air quality has been to dilute the amount of CO_2 and other contaminants through HVAC (heating, ventilation and air conditioning) systems or air filtration systems.

As the air quality monitoring technology has become more sophisticated, it is now possible to detect the presence of volatile organic compounds (VOCs) such as acetone, heptane and many other metabolic products in human breath in addition to formaldehyde, cooking odors, human bio-effluents, outdoor pollutants, paints and lacquers, cleaning supplies, and toxins. Figure 1 shows the sources of the most common chemical groups of mixed gases found in indoor air. These gases are often released into a facility's air from building materials, furnishings, office equipment and adhesives. According to the EPA, VOCs are two to five times more likely to be found inside the home than outside.

Figure 1 – Examples of VOCs and Sources

Substance Group	Example	Sources
Alcohols	alcohol, mineral spirits	cleaning supplies
Aldehydes	formaldehyde	building materials
Ketones	butanone	Paints
Esters	methyl acetate	Glues
Terpenes	pinene	Glues
Aromatics	xylol	paints and glues
Alkanes	heptane	human breath

The importance of detecting the presence of VOCs in indoor air goes beyond health concerns. A room's occupants judge the quality of the air not just by how it feels (temperature and humidity), but also by how it smells. Unfortunately, odors in offices, kitchens, gymnasiums and restrooms, for example, do not alter CO_2 levels measured by most indoor air quality monitors.

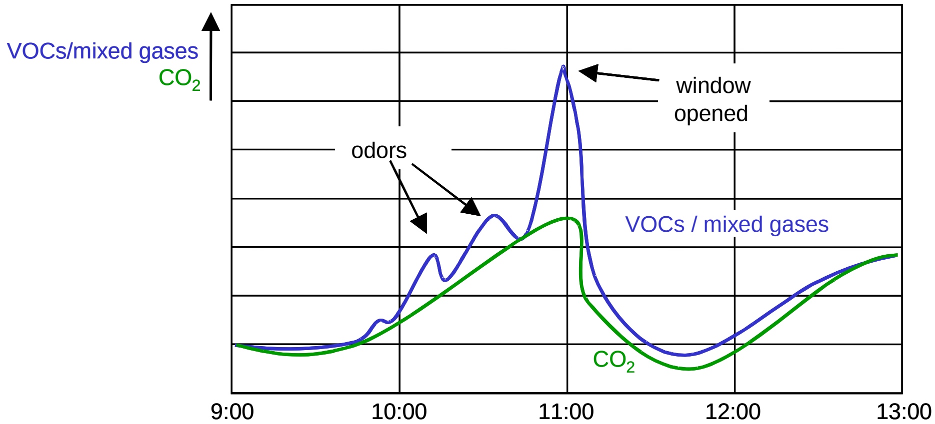
Some indoor air monitors use motion, light and heat detectors to signal the operation of ventilation systems. While those monitors may help maintain optimum temperatures, they cannot detect the odor of a tuna sandwich left in a desk drawer over the weekend, or cigarette smoke in someone's clothes, etc. By detecting odors and other pollutants, VOC sensors optimize proper ventilation to ensure the highest air quality for occupants and reduce utility costs for building owners.

Advances in Metal Oxide Gas Sensor Technology Enable VOC Measurement

Many air quality monitors work by measuring the sum signal of chemical compounds of a mixed gas and display the measurements as an arbitrary unit, which is not very useful. As the concentration of CO_2 is the most widely used measure for indoor air quality, AppliedSensor's VOC sensors measure of overall air quality is indicated in CO_2-equivalent units, thus making it possible to compare apples with apples. An appropriate function was calculated from real life data and is integrated into the air quality module's firmware.

Figure 2 illustrates the correlation of true CO_2 and concentration of mixed gases measured in a typical conference room. The signal of the air quality sensor follows the increasing CO_2 level and contains information about additional odorous events, while the CO_2 sensor detects just the exhaled CO_2 from the conference room's occupants.

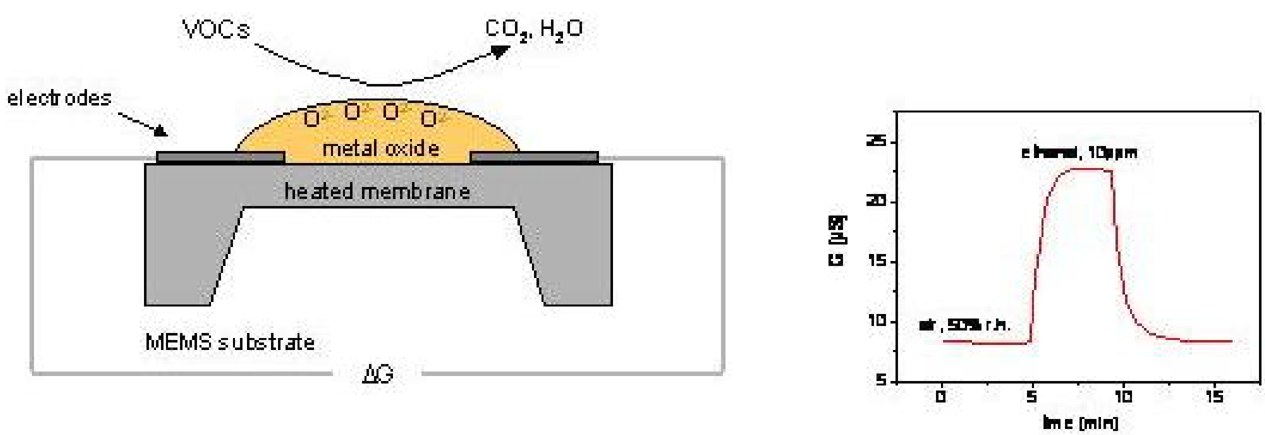
Figure 2 – Correlation of true CO_2 and Concentration of Mixed Gases as Measured in a Typical Conference Room



While sensors that can reliably measure temperature, humidity, and detect CO_2 (IR absorption) are commonplace, metal oxide gas sensors that detect VOCs are now also available. VOC sensors are produced by placing a semiconducting, nanocrystalline metal oxide on a substrate heated to between 300° to 400°C and measuring the conductivity. By adding dopants of noble metals, the sensitivity towards combustible gases (VOCs, carbon monoxide, natural gas) is influenced and allows a tuning of sensor performance for specific applications.

The operating principle of a metal oxide sensor is illustrated in Figure 3. VOCs from ambient air are combusted at the sensor surface, reacting with oxygen atoms/molecules from the crystal lattice. Electrons, which are released by this chemical reaction, lead to a higher conductivity of the semiconducting material. As soon as the induced lattice vacancies are filled again with oxygen from ambient air, conductivity returns to its initial value.

Figure 3 – Operating Principle of a Metal Oxide Sensor

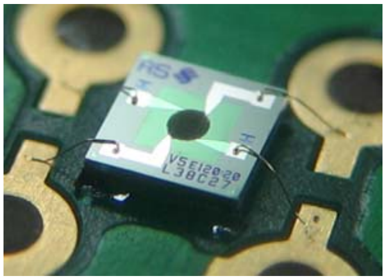


Operating Principal

1. Combustion of VOCs by oxygen from crystal lattice releases electrons.
2. Conductivity increases.
3. Oxygen vacancies are filled by oxygen from ambient air.
4. Electrons are consumed and conductivity decreases to initial value.

The gas sensor substrate is a Micro Electro Mechanical System (MEMS) with an undercut that provides thermal isolation. Requiring only 20-40 mW of power and generating very little heat, the sensor can be placed directly on a printed circuit board using chip-on-board technology. In addition, by eliminating the sensor housing, electronic components can be packed at very high densities.

Figure 4 – MEMS Gas Sensor on 2 x 2 mm^2 Chip



The best air quality monitors also feature low power consumption, are designed to withstand harsh environmental conditions, provide long-term stability and incorporate a maintenance-free sensing element. One example, the iAQ-2000 from AppliedSensor (Warren, New Jersey) illustrated in Figure 5, alerts a climate control system to increase air flow by initiating a ventilating action when the threshold air quality levels for target gases is exceeded.

Specifically, VOCs from ambient air are combusted at the sensor surface, reacting with oxygen atom/molecules from the crystal lattice. Electrons, which are released by this chemical reaction, lead to a higher conductivity of the semiconducting material. As soon as the induced lattice vacancies refill with oxygen from the ambient air, conductivity returns to its initial value. In addition, AppliedSensor's iAQ-2000 uses a proprietary algorithm to correct the baseline in certain intervals so that no recalibration or compensation for humidity is necessary.

Figure 5 – AppliedSensor iAQ-2000

Reduce Energy Cost While Improving Air

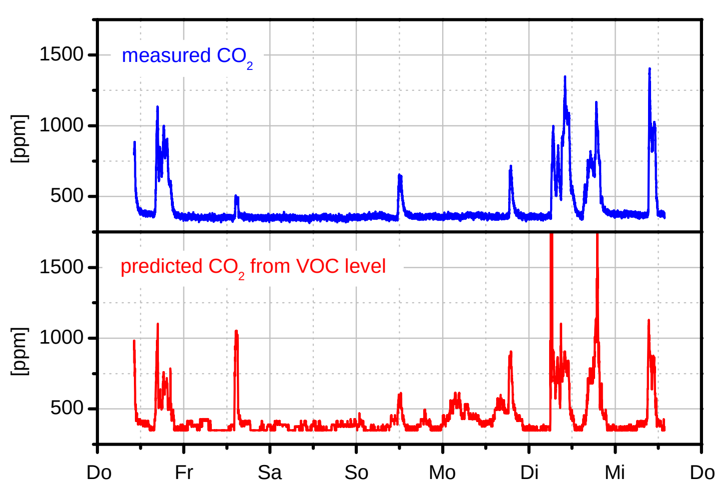
Over a period of several years, AppliedSensor monitored the performance of indoor air quality sensors installed in various locations including offices, cafeterias, schools, production facilities, apartments and homes. Figure 6 below illustrates data from an iAQ module incorporated into an air handling unit manufactured by Swegon AB, a Latour group company based in Sweden that manufactures and sells products and solutions for ventilation and indoor climate systems.

In this installation, the iAQ module is integrated in the air handling unit in a gymnasium to monitor the quality of the facility's air and control the speed of the air handling unit's fan. An infrared-absorption CO_2 sensor logs the concentration of CO_2 for comparison. Figure 6 illustrates the data collected from the facility, confirming that the predicted concentration of CO2 equivalents based on VOC detection from the iAQ module and measured true CO_2 concentrations are consistent.

Before the iAQ module was installed, the air handling unit was time-controlled, so the gymnasium was ventilated even when it was unoccupied. By switching to demand-controlled ventilation, energy consumption was reduced by approximately 60 percent. This reduction was produced by a combination of many factors, for example, flow rates at high and low speed when running on the time-controlled system compared to the VOC system. The percent of occupancy during the day was also important factor.

"We compared switching the speed of the air handling unit's flow rate using an occupancy sensor and a VOC (air quality) sensor. The VOC sensor reduced operating time by 24 percent," said Erik Edvardsson, an electrical engineer with Swegon. "In addition to the cost savings, in post-installation surveys, visitors to the gym gave the air quality good ratings."

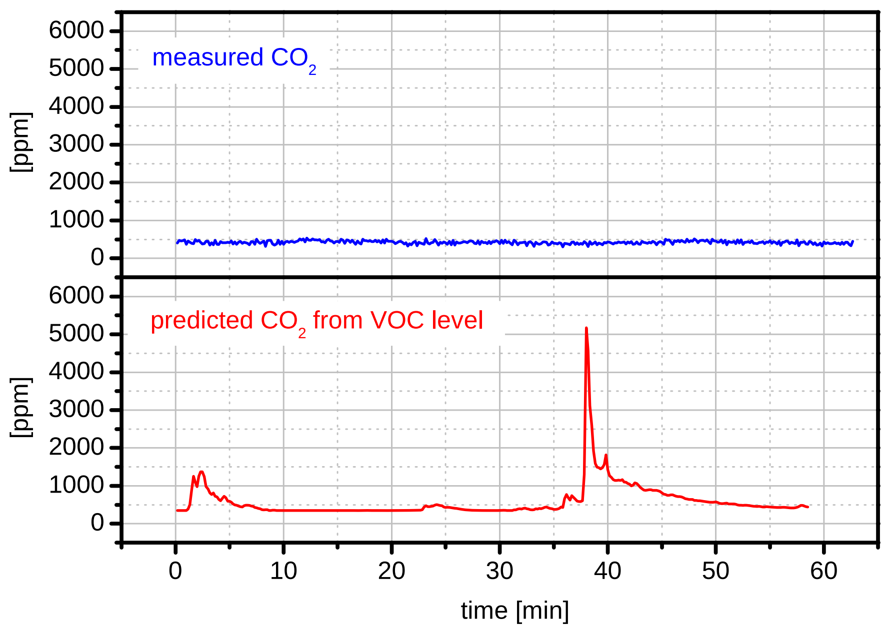
Figure 6 – Gymnasium: Measured CO_2 Compared to Predicted CO_2 from VOC Levels



Improve Restroom Air Quality by Detecting Human Bio-effluents

One room notorious for unpleasant odors is the commercial restroom. The cause of most restroom odors is the presence of a large amount of human bio-effluents (mainly methane and hydrogen) and other VOCs. At peak concentrations, these compounds correspond to more than 5,000 parts per million (ppm) of CO_2 equivalents. When VOCs are used as a measure, this would indicate highly contaminated air. Figure 7 below compares the measured CO_2 to the predicted CO_2 from VOC levels in restroom. This measurement demonstrates the advantage of VOC sensors in environments where CO_2 sensors fail to serve as indicators for bad air.

Figure 7 – Restroom: Measured CO_2 Compared to Predicted CO_2 from VOC Levels



Enhancing Building's Sustainability

While today's building owners and managers are diligent about reducing energy costs and utilizing sustainable materials, they often overlook the quality of the facility's indoor air. Considering that contaminated air not only poses health risks to occupants, but also lowers productivity and comfort, indoor air monitors capable of detecting the presence of harmful VOCs are becoming more prevalent.

AppliedSensor provides chemical sensor solutions for air quality, safety and control. Relying on its 25 years of research and development, the company designs and manufacturers chemical sensor systems for a broad range of applications, including the AS-MLV VOC Sensor Component for integration by OEMs into indoor air quality (IAQ) monitoring systems and the iAQ-2000 Sensor Module for integration into indoor air quality and HVAC systems in hotel guest rooms, bathrooms, schools, offices, gyms, and other indoor commercial facilities. Both products detect in seconds the presence of volatile organic compounds (VOCs) such as alcohols, aldehydes, ketones, organic acids, amines, and aliphatic and aromatic hydrocarbons.

AppliedSensor also manufactures in-cabin air quality monitors that are installed in BMW Sport Utility Vehicles and in other high-end luxury autos, and Hydrogen Gas Safety Sensor Modules that are integrated in fuel cell vehicles manufactured by BMW and General Motors.

AppliedSensor operates three facilities worldwide: AppliedSensor, Inc. in Warren, New Jersey; AppliedSensor Sweden AB in Linköping, Sweden; and AppliedSensor GmbH, in Reutlingen, Germany. Additional information is available by visiting www.appliedsensor.com or by calling 1-908-222-1477.