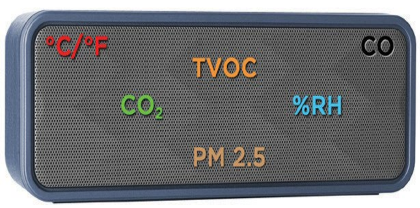
Validating Low Cost IAQ Sensors with High Quality Instrumentation

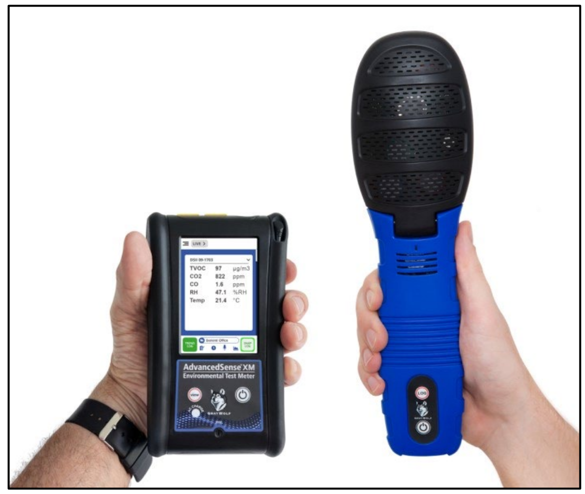
A variety of technologies are available for real-time measurement of indoor air quality (IAQ), and there are many parameters of concern. In this age of IoT, many companies worldwide (most of them start-ups) are offering various wall-mount or tabletop boxes full of low-cost sensors for monitoring IAQ. Some are marketing fixed sensors for demand control ventilation (DCV) designed to control ventilation rates, typically based on carbon dioxide (CO_2) concentrations. While most are attractively priced, are these devices reliable?



Multi-Sensor IAQ Box

People tend to accept the numbers shown on a built-in display, but will these low-end monitors lead to a false sense of security? Will they create problems due to false alarms or underreporting? Will sensors that have drifted, that have cross-sensitivities to other gases, or that just aren't accurate enough for the application, create more problems than they solve? If low-cost sensors report elevated levels in a specific area, is there a quick way to verify a likely problem before acting on the results from the low-cost sensors? Reliable research citing laboratory method comparisons to low-cost IAQ sensor boxes is relatively rare, given how widespread they are, except for the many papers that are being published on the limitations of the low-cost PM 2.5 sensors that are often included in those boxes. The USEPA lists some studies on their website that have been performed specific to IAQ multi-sensor devices, as opposed to ambient (outdoor) air sensors.[1]

Ongoing validation of the accuracy of low-end IAQ sensors with high quality instrumentation is key to verifying confidence in these increasingly ubiquitous devices and avoiding the negative consequences of inaccurate readings. Alternatively, there are many different types of expensive, time-consuming (albeit time-tested) methods requiring an air sample to be sent to a laboratory for analysis. Samples might be collected into various containers or onto various media. Lab tests on the samples include gas chromatography identified by mass spectroscopy (GCMS), high performance liquid chromatography (HPLC) and others. **For instantaneous results, a portable, high-quality instrument may be a more practical approach.**



GrayWolf AdvancedSense XM IAQ Meter

Established in 1998, GrayWolf Sensing Solutions is the leading worldwide manufacturer of real-time, portable IAQ measurement instrumentation. GrayWolf utilizes non-dispersive infrared (NDIR), photo-ionization detector (PID), electrochemical, photometric, and other sensor technologies, specifically for the IAQ application. These sensors are chosen based on their appropriate range, low limit of detection (LOD), high accuracy and precision, minimal drift, and rapid response time. GrayWolf's calibration optimizes the range of interest for IAQ and provides compensation for various environmental factors.

Several of the alternative real-time monitors utilize very low-cost metal oxide semiconductor (MOS) sensors to determine IAQ parameters. MOS sensors, when combined with a circuit board, are also known as complementary

[1] https://www.epa.gov/indoor-air-quality-iaq/low-cost-air-pollution-monitors-and-indoor-air-quality

MOS (CMOS) sensors and can be utilized to create microelectrochemical systems (MEMS) designed to report on the physical properties of the environment they are placed in. CMOS sensors are a very low-cost solution for monitoring various gases due to their simple nature of operation. In the presence of the target compound, which is a reducing gas, the density of the absorbed O_2 decreases. Current then flows through the sensor as electrons are released in the MOS material. The resulting current can then be converted into a known concentration. CMOS sensors are considered to be robust, lightweight and long lasting[2].

For general IAQ, some manufacturers employ CMOS sensors for monitoring total volatile organic compounds (TVOCs), carbon monoxide (CO), and in some cases to derive carbon dioxide (CO_2) concentrations. CMOS sensors are not overly specific to gases and also react to many non-target gases. This leads to many false positive readings, and in some cases underreporting. CMOS sensors are sensitive to relative humidity, which can impact performance. Also, as the sensor element is heated, the resistance of the sensing layer is affected by ambient temperature changes. This leads to a change in the sensor response in air and in measurements of the target gas.

GrayWolf offers IAQ-range specific electrochemical sensors for monitoring carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO_2) and many other specific gases of concern for IAQ. Electrochemical sensors measure the concentration of a target gas by oxidizing or reducing the gas at an electrode and then measuring the resulting current, which is linearly proportional to the fractional volume of the target gas. This type of sensor is much more specific than a CMOS sensor.

Non-Dispersive Infrared (NDIR) is the IAQ industry standard technology for Carbon Dioxide (CO_2). GrayWolf utilizes a dual-wave, rapid response NDIR sensor for CO_2 (with a 4-point factory calibration optimized for the IAQ range). It has industry leading accuracy for a portable instrument. The NDIR sensor works by having an infrared (IR) lamp directed towards a detector. The detector has a filter on it that only allows certain wavelengths to pass through it that correspond to the desired gas. The amount of IR light that penetrates the filter is inversely proportional to the concentration of CO2. Dual-wave NDIR sensors offer high accuracy with very little cross-sensitivity and exhibit minimal drift over time. This makes GrayWolf's NDIR sensors extremely applicable for validating fixed CO2 sensors, including those with less targeted calibration, single wave or non-compensated NDIR sensors, and devices that are merely deriving CO2 from a CMOS sensor.

For the broader "soup" of TVOCs, GrayWolf utilizes a low range 10.6eV PID for IAQ with detection <2 parts per billion (ppb) and resolution of 1ppb. The PID sensor is comprised of a filter membrane, an ultra-violet (UV) lamp and a detector electrode. Gas passes through the filter membrane to exclude particles and liquids and is exposed to high energy ultra-violet (UV) radiation which ionizes a proportion of the molecules present. Some of the molecules are converted into either positively or negatively charged ions. These ions are measured by a collection electrode and converted into a current corresponding to the concentration. The PID will not detect common gases such as methane (CH_4), NO_2, or CO, however most CMOS sensors for VOCs are cross-sensitive to CH_4 and CO. With high (~1.84ppm and variable) CH_4 background levels [3] and typical CO levels in homes without gas stoves of 0.5 to 5 ppm and levels near properly adjusted gas stoves often 5 to 15 ppm[4], this can have a significant impact on VOC results from CMOS sensors.

Formaldehyde (HCHO) is a VOC that is worth speciating, as it is a known carcinogen, even at low levels. IAQ specific HCHO regulations are typically <100ppb (e.g., Japan 80ppb[5], Hong Kong 50ppb[6], WELL 40ppb, 50μg/m3[7]). CMOS, and certain PID sensors for TVOC will detect formaldehyde, non-speciated, as just another VOC lumped into the TVOC value.

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[2] Fine, G.; Cavanagh, L.; Afonja, A; Binions, R. Metal Oxide Semi---Conductor Gas Sensors in Environmental Monitoring. Sensors. 2010, 10, 5469---5502.

[3] http://www.esrl.noaa.gov/gmd/ccgg/trends_ch4/

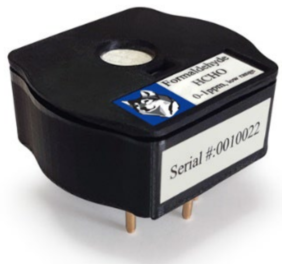
[4] www.epa.gov/iaq/co.html USEPA "An Introduction to IAQ"

[5] Ministry of Health, Labour and Welfare, Japan.

[6] The Government of the Hong Kong Special Administrative Region. Indoor Air Quality Management Group, Guidance Notes for the Management of Indoor Air Quality in Offices and Public Places, 2003.

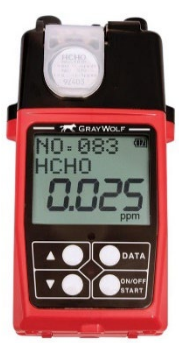
[7] https://v2.wellcertified.com/en/wellv2/air/feature/1

Electrochemical sensors for monitoring HCHO, occasionally used in low-cost monitors, typically have high cross-sensitivity to CO, and are heavily influenced by relative humidity. Sometimes the LOD of an electrochemical sensor will even be well above the concentration of interest for IAQ.



SEN-SMT-HCHO-L Formaldehyde Sensor

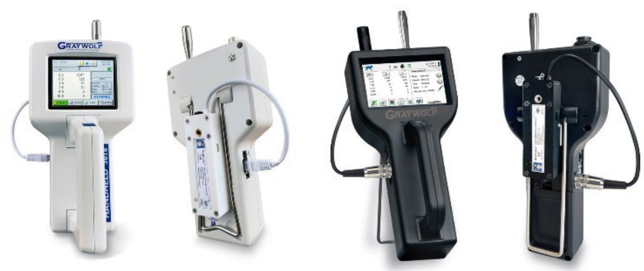
GrayWolf recently introduced a smart electrochemical sensor, for use in DirectSense II probes. The SEN-SMT-HCHO-L sensor is ideal for the low (0 to 1000ppb) IAQ range, with an excellent L.O.D. (<10ppb). Unlike most EC HCHO sensors, this sensor exhibits negligible CO cross-sensitivity <10ppm CO (GrayWolf meters alert when >10ppm CO might influence readings whenever a CO sensor is also installed in the DSII probe). 20%-90%RH operating range (some moisture is critical to achieve low-range HCHO performance).



GrayWolf FP-31G Formaldehyde Meter

GrayWolf also employs a colorimetric technique for monitoring which utilizes colorimetric tablets for HCHO detection. A tablet is placed into the instrument, and then a test area air sample is pumped onto the tablet for either a 15-minute or a 30-minute period. If formaldehyde is present, it will cause the chemically impregnated tablet surface to darken or stain. The magnitude of the stain directly correlates to the level of formaldehyde in the air. The stain darkness is read by an optical sensor in the FP-31G, and then the instrument calculates and displays the HCHO concentration. This allows for very low LOD (readings starting at 10 ppb), with 1 ppb resolution.

Another very important measured parameter is particulate. The most popular GrayWolf particulate technique measures particulates via light scattering and sorts them into 6 “bins” based on size. These particle meters have a laser light source which the particle will pass through, and the redirected light will be measured by a detector. The amplitude of the light redirected or obscured has a unique signature that relates to

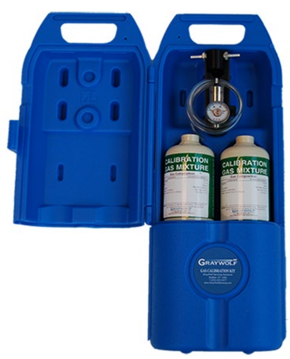


GrayWolf PC-3016/ 3500 Particulate Meters

a specific size and determines the quantity of particles present. Based on the flow of the built-in precision pump and with the assumption that all particles are the density of carbon, mass concentration can be estimated. GrayWolf’s laser particle counters have an optimal range from 0.3 - 10 µm, although also detect up to ~25 µm.

An alternative, lower cost technique for measuring particulate utilizes an LED, instead of a laser. Based on the angle and flow rate the PM values can be calculated (but to save cost, air pumps are rarely included, which greatly reduces accuracy). These devices will typically only measure PM2.5 and often will have a LOD of 0.5µ or larger, missing the very important 0.3µ to 0.5µ range. Many detect only >0.7µ, which is truly unacceptable for IAQ applications. Those that do display PM10 have generally been demonstrated to under-report that concentration which includes larger particles.

The GrayWolf equipment has the ability to be verified and, if appropriate, adjusted by the end user with traceable reference gases at any time. This allows for even more confidence in any subsequent testing of the GrayWolf meters against other devices. Any user calibration adjustments are recorded for inclusion in reporting.



User gas calibration kits are available from GrayWolf

GrayWolf meters are able to "snap" data log the current reading (also to trend log over time at customer defined intervals) to easily and reliably document any comparative readings. In addition, detailed file names with text notes (defining monitor location, condition, serial number, etc.), photos/videos with captions and audio notes, are all auto-attached to data files. This allows for efficient, reliable documentation of any of the sensors that have had readings compared to. GrayWolf's on-board sensor tips also provide access to government and industry guidelines, typical background levels, potential cross-interferences and more for every parameter being tested, assisting with instantaneous analysis and interpretation of readings.

Parameter	Range	Accuracy
Carbon Dioxide (CO_2)	0-10,000 ppm (calibration optimized for 350-2000ppm)	± 35ppm over IAQ range (350-2000 ppm) ± 3%rdg ± 35ppm> 2000ppm
Carbon Monoxide (CO)	0-500.0 ppm (calibration optimized for 0-100ppm)	± 2%rdg +/-1ppm
Total Volatile Organic Compounds (TVOCs)	0-40,000ppb (calibration optimized for 0-10,000ppb)	N/A
Formaldehyde (HCHO) electrochemical	0-1000ppb, 0-1ppb/digit	± 20ppb <200ppb, ± 10% Rdg 200-1000ppb
Formaldehyde (HCHO) colorimetric	(30-minute test): 0 -400ppb, 5ppb/digit (15-minute test): 0-1000ppb, 10ppb/digit	± 20% Rdg or ± 5% FS (whichever is greater)
Temperature	-25.0 to 70.0 °C	± 0.3 °C
Relative Humidity	0.0-100.0%RH	± 2%RH <80%RH (± 3%RH >80%RH)

GrayWolf specifications for select parameter

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