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 the "internet of things", a number of companies worldwide (most of them start-ups) are offering various wall-mount or table-top 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 sent to a smartphone or 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? Research citing laboratory method comparisons to low cost IAQ sensor boxes is rare, given how new they are. However, many papers are being published on the limitations of the low cost PM 2.5 sensors that are often included in those boxes. One exception is the progressing, albeit currently limited scope, work being conducted by California's South Coast Air Management District[1] that covers both ambient (outdoor) air sensors and some IAQ multi-sensor devices.

Ongoing validation of the accuracy of low end IAQ sensors with high quality instrumentation is key to verifying confidence in these 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 lab 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 Pro 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, nephelometric, photometric, absorptiometric/ photoelectric 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, minimal drift and rapid response time. GrayWolf includes calibration and compensation for various environmental factors to optimize them for IAQ use.

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

[1] http://www.aqmd.gov/docs/default-source/aq-spec/laboratory-evaluations/sensors-lab-testing-protocol.pdf?sfvrsn=2

complimentary MOS (CMOS) sensors and can be utilized to create microelectromechanical systems (MEMS) designed to report on the physical properties of the environment they are placed in. CMOS sensors are a low cost solution for monitoring various gases due to their simple nature of operation. In the presence of oxygen (O_2), the electrons in the MOS material are attracted, preventing an electric current to flow. 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 the performance. Because the sensor element is heated, the resistance of the sensing layer is affected by ambient temperature changes[3]. 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 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.

A dual-wave, rapid response NDIR sensor (optimized for the IAQ range) is employed for CO_2. NDIR is the IAQ industry standard technology for CO_2. The 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 CO_2. NDIR sensors offer high accuracy with very little cross-sensitivity and exhibit minimal drift over time. This makes them extremely capable of validating other modes of CO_2 monitoring, including single wave or non-compensated NDIR and especially devices that are merely deriving CO_2 from a CMOS sensor.

For the broader "soup" of TVOCs, GrayWolf utilizes a low range 10.6eV PID for IAQ with detection <5 parts per billion (ppb) and resolution of 1ppb. The PID sensor is comprised of a filter membrane, a 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[4] 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[5], 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[6], Hong Kong 50ppb[7], LEED 27ppb[8]). CMOS, and certain PID sensors for TVOC will detect formaldehyde as any other VOC lumped into the TVOC value. Electrochemical sensors for monitoring

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

[3] SGX Metal Oxide Gas Sensors (How to Use Them and How They Perform). https://sgx.cdistore.com/datasheets/e2v/AN172_Useandperform.pdf

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

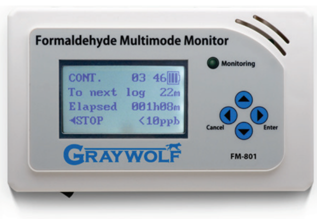
[5] www.epa.gov/iaq/co.html USEPA "An Introduction to IAQ"

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

[7] 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.

[8] US Green Building Council (USGBC) LEED 3.2 IEQ Credit, Option 2 (2013)

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



GrayWolf FM-801 Formaldehyde Meter

GrayWolf employs a colorimetric technique for monitoring HCHO. Sensor cartridges impregnated with β-diketone will yellow over the course of 30 minutes in the presence of HCHO. The GrayWolf FM-801 meter measures the change in color of the cartridge and determines the HCHO concentration. This allows for very low LOD (readings starting at 10 ppb), with 1 ppb resolution.

Another important measured parameter is particulate. GrayWolf offers 2 different technologies. GrayWolf's nephelometric (i.e. photometric) PM-205 scatters light from a laser diode at 90° within a sample chamber. The index of refraction, size, and density all effect the amount of scattered light. A lens focuses the scattered light to a photo-detector which converts the light into a voltage which will be proportional to the mass concentration of the aerosol (assuming that the aerosol is the same mass as the calibration material that was used). The range for the PM-205 is very precise and repeatable from 0.1 to 10 µm, and will detect particles up to ~25 µm.

GrayWolf PC-3016 Particulate Meter

The more popular GrayWolf particulate technique also measures particulates via light scattering, but sorts them into 6 "bins" based on size. These particle counters 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 a specific size, and determines the quantity of particles present. Based on the flow of the pump and with the assumption that all particles are 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 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 often not included, which greatly reduces accuracy). These devices will typically only measure PM 2.5 and generally will have a LOD of 0.5µ or larger, missing the very important 0.3µ to 0.5µ range. Many detect only >0.7µ, some only >1.0µ, which is truly unacceptable for IAQ applications.

Parameter	Range	Accuracy
Carbon Dioxide (CO_2)	0-10,000 ppm (calibration optimized for 350-1500ppm)	+/-3%rdg +/-50ppm
Carbon Monoxide (CO)	0-500 ppm (calibration optimized for 0-100ppm)	+/-2ppm <50ppm +/-3%rdg >50ppm
Total Volatile Organic Compounds (TVOCs)	0-50,000 ppb (calibration optimized for 0-10,000ppb)	N/A
Formaldehyde (HCHO)	10-1000ppb	+/-4ppb <40ppb, +/-10%rdg ≥40ppb
Temperature	-25 to 70 °C	+/-0.3 °C
Relative Humidity	0 to 100%RH	+/-2%RH <80%RH (+/-3%RH >80%RH)

GrayWolf specifications for select parameters

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.

U.S.A. (WORLDWIDE HEADQUARTERS)
GrayWolf Sensing Solutions, LLC
6 Research Drive, Shelton, CT 06484 USA

IRELAND
GrayWolf Sensing Solutions, LTD
Annacotty Industrial Park, Unit 1C
Annacotty, County Limerick
V94 PR2Y Ireland

For More Information Call:
Tel: 1-203-402-0477 or 800-218-7997
E-Mail: SalesTeam@GrayWolfSensing.com
Web: http://www.GrayWolfSensing.com