Making the numbers add up:

Understanding specifications and performance of indoor air quality test instruments

Application Note

Air quality test instruments must deliver accurate and verifiable performance, both to ensure precise and reliable air quality diagnosis, and to provide credible answers if results or procedures are challenged. The air quality professional's reputation depends on the quality and performance of the test tools in use, as well as on the user's understanding of instrument specifications, technologies, applications and maintenance. In this paper we examine:

- **Measurement issues and air quality standards.** Though firm standards for indoor air quality outside the industrial setting are limited, accurate measurement is important nonetheless.
- **Instrument specifications.** Not all specs are created equal. Definitions of instrument performance and accuracy may vary from one manufacturer to another, making it a challenge to determine which instrument delivers the required performance.
- **Instrument drift and calibration.** Over time, test instruments can and will drift out of spec. Instrument testing and calibration, following the schedule and methods recommended by the manufacturer, are vital to ensuring the accuracy of air quality measurement. Calibration should be documented for verification.
- **The characteristics of test technologies.** The sensor technologies used to measure some air quality parameters have limited stability. Instrument performance may be affected by such factors as altitude, ambient temperature and barometric pressure unless the user takes steps to compensate.

Issues in air quality measurement

The measurement of indoor air quality is influenced by a variety of factors, including the characteristics air exhibits as a fluid and gas, the standards of accuracy we must meet when making measurements, the performance characteristics of air quality test instruments and the way we use and maintain those instruments.

The fluid nature of air. The subtleties of air quality measurement begin with the very nature of air. Measuring air quality is not like measuring a two by four.

Because it is a gas, air is compressible. Its density varies with changes in altitude, temperature and barometric pressure. Unless compensation is dialed in when instruments are set up, or compensation circuits are built into the instruments, changes in air density can affect the accuracy of some air quality measurements. Unless it carries large quantities of pollutants, air is invisible. Instruments are needed to determine the levels of chemicals or particles borne along by the air.

The principal indoor air quality characteristics we measure include:

- Air temperature
- Humidity
- Airborne particle sizes and numbers. In sensitive environments such as medical facilities, the type of particles (such as the species of mold or bacteria) is important.
- Gases, such as carbon dioxide (CO_2), a byproduct of respiration that can indicate the rate of fresh air exchange into an indoor space, and carbon monoxide, a poison.

Limited and imprecise standards. Outside the industrial workplace, absolute standards for most indoor air conditions and air pollutants do not exist. Guidelines, not specific limits, are the rule. Government has been slow to establish specific standards to control levels of indoor air pollutants.

With few exceptions, science has yet to convince lawmakers that indoor air contaminants cause specific health problems that demand legislation. In 1994, the U.S. Occupational Safety and Health Administration (OSHA) filed a notice of proposed rulemaking for indoor air quality in non-industrial workplaces, but withdrew the proposal in 2001. The management of indoor air quality remains primarily a private, not public, concern.

Test instrument performance. Another important consideration is the accuracy of test instruments over time and in varying environmental conditions. Instrument standards and performance specifications, together with appropriate testing and calibration, are the keys to making accurate, repeatable and defensible measurements.

Accurate performance over time is essential for valid, repeatable results and effective remediation. Yet the technology used to measure some air quality parameters, such as CO_2 and CO, is inherently subject to drift and change as days and weeks go by. It's important for the practitioner to understand these characteristics and know what they can expect from their instruments—and what steps to take to achieve high quality results.

Calibration and traceability. Without documented proof that a test instrument has been calibrated against a known standard, called traceability, test results may be difficult to defend against a challenge. In a court case, failure to prove valid measurement, made by instruments that were calibrated and employed as specified by the manufacturer, could result in liability for the organization and the air quality professional.

Instrument usage and operator error. Measuring the characteristics of an invisible, changeable gas, using instruments that may perform within spec for a limited time, or in a narrow range of conditions, puts the responsibility on the operator to understand each test tool's limitations and to maintain and use those instruments correctly.

What is avoidable operator error? Consider what could happen if a technician drove to a job site to assess indoor air quality. In the middle of winter, this tech left his instruments in his unheated garage over night. Carrying the chilled instruments into the job site, he ran a quick temperature check.

The results are way off. The temperature tester's electronic circuits are accurate only within a specified temperature range, and the instrument is still very cold. Only by letting the tool warm up to room temperature will this tech get the accurate result he's after.

Specifications and the spec sheet

Every measurement is based on our belief that the instrument is going to give us the "real" reading. Specifications quantify both the likelihood of getting accurate readings and the risk of seeing inaccurate readings.

A specifications document is a clearly written description of an instrument's performance. It should quantify the instrument's capabilities objectively, under well-defined operating conditions.

Good specifications will be complete, identifying all factors that affect the instrument's ability to deliver accurate measurements. For air quality instruments, such factors could include humidity, temperature, altitude and air pressure. Specifications should also be clear and objective. You should expect that the information is both accurate and complete.

The spec sheet should identify measurement uncertainty specs and modifiers that affect the uncertainty, as well as operating limits (such as temperature) that constrain the environment in which the uncertainty specifications will hold true.

Drift and test tool calibration

Time and temperature are crucial for determining uncertainty. Electronic components experience small changes (or "drift") over time. The electrochemical nature of some air quality sensors makes their readings even more likely to drift over time. Because of drift, test instrument uncertainties are valid only for a specified period of time, which usually coincides with the recommended calibration cycle. At calibration, the clock starts over again and the uncertainties are valid for another period.

Temperature affects the performance of every component in an instrument. Instrument designers make every effort to build circuits that compensate for temperature variation. The ability to operate at various temperatures is captured in a specified operating range and is often accompanied by a temperature coefficient.

Instruments are designed to deliver measurements within a specific temperature range, generally around room temperature. Outside that range, results will deviate. It may be possible to calculate an adjustment factor or temperature modifier for use in adjusting results obtained in these conditions. The user should review instrument documentation or consult the manufacturer to determine how changing environmental conditions affect instrument performance, and how to compensate.

Other environmental factors, such as storage temperature, humidity, air density, and electromagnetic radiation, can also affect uncertainty.

There are a number of steps air quality professionals can take to prevent these performance characteristics from adversely affecting their results.

First, they should seek out, evaluate and compare manufacturers' claims regarding instrument accuracy and stability. As mentioned above, not all specs are equal. This review should also include an evaluation of each manufacturer's reputation for quality and performance.

After the user has chosen an instrument, it is important to keep that tool properly calibrated in accordance with manufacturer's instructions. Unlike a yardstick, an air quality test instrument's performance will change over time. Calibration and, when necessary, replacement of out-of-date or worn-out sensors will bring the tool back to peak performance. If renting, ask to see up-to-date proof of calibration for the instruments you will use.

Performance characteristics of indoor air quality test technologies

Each characteristic of indoor air quality is measured using a specific type of sensor. In some instances, instrument engineers can choose from several alternative sensor technologies. In every case, their decisions about which sensor technology to use, and how to employ it, must take into account a number of performance parameters:

- Accuracy
- Response time
- Stability over time, and in varying environmental conditions
- Strength, durability and longevity
- Portability and ease of use
- Ease of adjustment and calibration
- And always, cost

In most cases, product designers must make tradeoffs to deliver an affordable end product that meets user needs and expectations. A 'perfect' instrument is something few would be willing to pay for.

In the following section we review the technologies used to measure the various air quality parameters, the nature and limitations of those technologies and what users need to know to get the best results.

Air temperature

Sensor technologies. Though household thermometers may employ expanding liquid (alcohol or mercury) or a bimetallic strip attached to a pointer, professional instruments generally use one of two sensor technologies: the thermocouple or the bead thermistor.

Most common in the service industry is the thermocouple, which looks like a bead on the end of two wires. The sensor is a combination of two metals that when joined together and presented with a temperature, creates a voltage differential across the connected wires. Thermocouples have little mass and therefore respond quickly to temperature changes. This is significant when measuring air, a gas with relatively low density and limited ability to quickly heat or cool a material.

The thermistor uses a different technology. A small resistor in the device receives a voltage or current. Resistance in the device varies as temperature changes, causing output current or voltage to change as well.

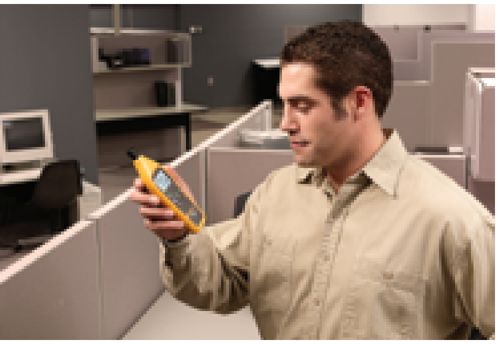
A third electronic technology is infrared, used in non-contact thermometers. Infrared thermometers do not measure air temperature, but measure the infrared radiation emitted from surfaces. Infrared thermometers provide greatest accuracy at short distances, and provide at best an indirect indication of air temperature.

Technology characteristics. Comparing thermistor and thermocouple technologies reveals several performance differences. Because simpler circuitry is needed to convert thermistor signals into temperature readings, instruments using thermistors are likely to cost less than those using thermocouples. Thermocouples can perform from near absolute zero to thousands of degrees. Thermistors operate over a limited temperature range (approximately -30 °F to 180 °F). This range is likely adequate for indoor air quality applications.

In terms of response time, both technologies perform well. But response time is also affected by the overall design of the test instrument. If the temperature sensor is enclosed in a massive housing, the surrounding material is liable to affect the speed with which air heats or cools the sensor, thus slowing response time. Minimal response time requires minimizing mass, and that means shrinking components. If carried too far, this could affect instrument durability.

Stability and drift. The thermistor temperature sensor is very stable and does not drift like some other sensors. However, the temperature sensing *function* can drift over time due to other components used and the layout of the circuit design. In design and manufacture, care must be taken in the layout of the printed circuit board that connects with the thermistor. Ionic contamination from soldering flux residues can cause performance degradation. This increases as the impedance of the circuit increases. Good analog design is essential to achieving optimal temperature performance.

User guidance. Allow for instrument 'settling time' when measuring temperature. The mass of a temperature tester may slow response time in rapidly changing conditions. In simple terms, it takes a while for the instrument to reach ambient temperature. In addition, the instrument's electronic circuitry will perform differently as temperatures vary, so the circuitry too must settle and stabilize.



Humidity

Sensor technologies. The device traditionally used to measure humidity is the sling psychrometer. This instrument consists of two bulb thermometers, one of which is surrounded by a wet cloth. When the device is slung through the air, moisture evaporates from the wet bulb and cools the thermometer. The dryer the air, the greater the temperature difference between the wet and dry thermometers.

A more convenient alternative is a hand-held humidity meter that uses a capacitance sensor technology. A semi-permeable membrane in the sensor becomes more conductive as humidity increases and moisture penetrates the membrane. The meter interprets this change in terms of humidity level.

Technology characteristics. The sling psychrometer is highly accurate when used correctly. It is also relatively slow and cumbersome to use.

The hand-held meter is much faster and easier to use, but over time the sensor membrane will be affected by airborne contaminants that reduce its ability to absorb moisture. The sensors cannot be cleaned, so if they are accidentally contaminated or simply 'get old,' they must be replaced.

Stability and drift. Users should be aware that the performance of humidity meters will decline over time. The rate of change will depend on how and where they are used.

User guidance. Testing to determine accuracy and calibrate the instrument requires sophisticated and expensive test equipment beyond the means of the individual user. Instruments can be returned to the manufacturer or sent to an independent testing laboratory to verify their performance. If out of spec, the sensor of an expensive instrument may be replaced. In the case of a less costly instrument, the user will probably choose to replace the entire tool.

Airborne particles

Sensor technologies. The particle counter uses a pump to pull a sample of air into a space called the view volume, where particles intersect with a laser beam. The particles reflect differing amounts of light based upon their size. Photo detectors "see" these light flashes and convert each one to a millivolt signal. Larger particles reflect more light and create a stronger signal. Signals within a certain millivolt range are counted in one size "bin," particles in another range are put into another bin, and so on.

Technology characteristics. Accuracy can be affected when the counter is used where extremely high levels of particles are present. Particles may collect within the intake passage and measurement chamber. If these particles are dislodged during a subsequent test, they can cause a misleading spike in the particle count.

Stability and drift. Laser particle counter technology is generally stable over time, but the manufacturer's recommended calibration interval should be observed to maintain optimal performance.

User guidance. Operating the air pump for a period of time before taking a reading will help to flush particles out of the instrument. Users can calibrate the instrument for a zero particle count by applying a HEPA (high efficiency particle air) filter over the air intake port.

Carbon dioxide

Sensor technologies. CO_2 sensors use a non-dispersive infrared technology. Incandescent light is projected through a small sample cell called the "bench link". The CO_2 present in the test sample will absorb a specific wavelength of the projected light. A filtered infrared detector at the other end of the chamber measures the amount of light at that wavelength that passes through the chamber. As CO_2 levels increase the gas absorbs more light, which reduces the strength of the electric signal emitted by the detector.

Technology characteristics. Design affects both the performance and accuracy of a CO_2 tester. The length of the test chamber or "bench" is important, because a longer chamber enables the light to pass through a larger air sample and more CO_2 molecules before reaching the detector, making greater accuracy possible. A test instrument that pumps air through the test chamber will respond faster than a dispersion unit that does not pump the air.

Changes in air temperature, pressure and density all will affect the accuracy of CO_2 test results, so CO_2 meters must be adjusted before use to compensate for changes in air pressure and temperature. Some instruments are built to compensate automatically for these changing conditions.

Stability and drift. The CO_2 sensor will degrade and drift over time due to loss of sensitivity and declining bulb performance. Airborne containments will pass through the sensor filter (assuming there is one) and accumulate on the interior walls, emitter and detector of the sensor. This contamination will affect the intensity of the light source, as well as the signal strength of the optical filter/detector. The more contaminants (smoke, dust, etc.) the sensor sees, the faster the degradation of the signal strength.

Another factor affecting long-term stability of the sensor is degradation of the light source. Like any bulb, it will burn out.

User guidance. A CO_2 sensor should be calibrated about once a year to compensate for the reduced output of the bulb and collection of contaminants. CO_2 meters can be tested and user-calibrated using a standard span gas that contains a known percentage of CO_2. A rough calibration can be achieved using outdoor air, which should contain 350 to 450 parts per million of CO_2. Dry nitrogen, which contains no CO_2, may be used as a zeroing gas.

Carbon monoxide

Sensor technologies. Carbon monoxide testers use an electrochemical gel sensor technology.

Technology characteristics. The gel sensor has a limited life span (two years) and its accuracy can be affected by changes in both temperature and ambient humidity levels.

Stability and drift. Prolonged exposure to humidity levels below the ideal 50 percent RH level can dry the gel sensor and cause the readings the instrument delivers to drift out of spec. The changeable nature of CO sensor technology means that users must calibrate their CO meters frequently (monthly) to ensure accuracy. Most CO meters can be user-calibrated using a span gas containing a known percentage of CO. They can be zero calibrated (zeroed) in free air.

User guidance. Calibrate the instrument when you receive it, to ensure that it is set for your environment. Then, if your environment changes (for instance, if humidity increases during the summer), recalibrate. Simply transporting the instrument from a humid outdoor environment into a dryer air-conditioned space should not cause problems. Environmental changes over a longer period are the issue.

Conclusion

Accuracy is fundamental for those who measure, monitor and control air quality in workspaces. By choosing instruments carefully based on an in-depth understanding of their specifications and performance characteristics, using them properly, and maintaining and calibrating them as recommended, HVAC and IAQ professionals can ensure themselves and their clients of accurate measurements and effective guidance to improve indoor air quality and comfort.

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