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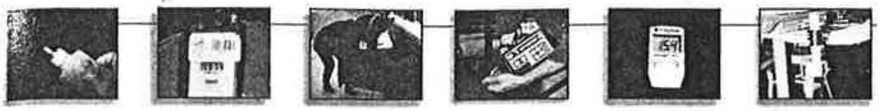

# Measurements to Solve Indoor Air Problems:

## PART 1—*Tools of the Trade*

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**Solving IAQ problems requires strategies and tools for making observations and measurements. This article covers the tools — a future article will impart strategies for using them.**

Every building trade has tools. Masons have their trowels, strings, and floats. Plumbers—wrenches, cutters, and torches. Carpenters—hammers, saws, and drills. Every tool in the box doesn't get used on every job. The wise tradesman uses only the right tools for the job at hand (unless of course they're in the other truck, in which case, a screwdriver might become a chisel). So it is with those of us who solve indoor air quality (IAQ) problems. For the record, I treat thermal comfort and moisture problems as IAQ problems because often they are related or will be.

There are two parts to using a tool: selecting the proper tool and using it effectively. This article describes tools that can be useful for IAQ investigations. Part 2, which will appear in a future issue of HPAC Engineering, will provide strategies for using them on investigations and examples from field experiences that demonstrate how equipment, procedures, and investigative creativity work together. You'll notice that my narrative is first person—like any problem-solving technique, investigative procedures and tool selection are subjective. How I investigate buildings may be entirely different from methods used by other professionals.

As you read this article, there are some important points about IAQ investigations that you should keep in mind:

✔ The investigator's senses, knowledge, experience, and personal communication skills are the most important investigative tools.

✔ Many indoor air quality problems can be solved without making airborne contaminant measurements. Too often during an investigation, emphasis is placed on taking samples and collecting test data. An important contaminant may be missed by the sampling method for a number of reasons, and the presence of a contaminant may not be related to the problem being investigated. Sometimes, a problem can be fixed for costs that are comparable to sampling.

### THE IAQ TRIANGLE

Although I'll cover testing strategies in a separate article, you should know that the basic structure of an investigation is related to the basic structure of an IAQ problem, which I call the IAQ Triangle. The IAQ Triangle consists of occupants, contaminant sources, and transport mechanisms that cause occupants to be exposed to contaminants. Investigation tools and techniques are divided into these three categories.

Another thing to keep in mind is that when talking about the tools of any trade, people often leave out the practitioner. My most valuable investigation tools are my eyes, ears, and nose. Using my senses for observation, inspection, and interviewing often provides me with enough information to identify the likely source and important dynamics of an IAQ problem. For example, consider the complaints from occupants with known mold allergies experiencing typical mold allergy symptoms in a building that smells musty. My experience is that there's probably a patch of mold big enough to sample with a spatula somewhere in the building or the building's systems. Test equipment is not required to find the patch or identify it as mold.

### OCCUPANT-RELATED TECHNIQUES

Interviewing and other processes for gathering information from people are important tools to every investigation. Before making any measurements, the first thing I do is collect as much information about the occupants and their complaints as I can, including symptoms, the potential sources, and the methods used to control the potential sources in the building. The information comes from talking to people, collecting copies of floor plans, drawings, control sequences, Material Safety Data

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Sheets (MSDS)[1] buildings and grounds practices, and observing occupant activities (if they're melting lead, that's a lot different than running a computer).

I then resort to processes and information that include event logs, work order records, results of medical examinations and tests, surveys, formal interviews, and informal chats. If I have a problem with a large number of occupants who are complaining, I suggest that a survey be carefully administered. If the occupants are worried about a cancer cluster, I suggest they contact the state health department where specialists are available for this concern. I leave formal surveys and questionnaires to those who are experienced at designing, using, and interpreting them. Over the years, I have been amazed at what an experienced epidemiologist can tell me about a building through surveys. I myself am likely to ask leading questions and misinterpret the answers, so I seek professional help for surveys.

When I talk to the buildings and grounds folks, I want to know about products and practices for cleaning products, walk-off mats, pest control, painting, and varnishing. I then get the MSDS for the products they use.

**Interviewing**

I generally chat with occupants to try and figure out what they need but are not getting. Sometimes, it turns out they're too hot or cold. Sometimes, they've got eye, nose, throat, or skin irritation. Other times, they're getting headaches or stomach aches. Occasionally, they have fevers, congestion, and other symptoms of a disease caused by a bacteria or virus. Sometimes, they've seen a doctor, and other times, they haven't. If the complaint is a health-based complaint, they should see a physician. Sometimes, there are aggravating factors like no pay hikes in five years or the job is a high-stress job.

The kind of questions I ask occupants about their symptoms include:

- ✔ How they feel
- ✔ When they feel that way
- ✔ What's going on when they feel it
- ✔ Where are they when they feel it

Plotting complaints on a floor plan sometimes turn up a pattern that helps solve a problem. If all the complaints are in the same air handler zone, that's one thing. If there are many kinds of complaints, scattered all over the building, I suspect an under-ventilated condition that allows a number of low-level sources to build up and cause problems. If the symptoms are all the same and clustered together, I suspect a single, strong source.

While talking to the occupants, I may take air temperature and relative humidity measurements to get a handle on thermal comfort and the performance of the mechanical equipment and thermal envelope. Depending on what I hear from the occupants, I may measure the temperature of the wall, ceilings, or floors using a non-contact infrared thermometer to get a quick indication of the thermal comfort zone. These two instruments provide useful data immediately and are easy to use in the presence of the people I'm interviewing.

I also talk to occupants when creating an inventory of contaminant sources. For example, if there's a photocopier right next to their desks, I'd like to know about what's in the toner, how many pages a day are printed, if there are special filters in it, how often it's serviced, and where are the MSDS that came with the product. If the copier is ventilated with an exhaust system, I want to know how frequently the exhaust system is cleaned and serviced. I may need to talk to several people to get the answers to these questions.

[1] *To learn more about material safety data sheets and to obtain leads for obtaining the MSDS you need, visit ILPI's Web site at http://www.ilpi.com/msds/index.chtml*

## Types of Test Equipment

Measuring contaminants requires specialized equipment and training for making and interpreting the measurements. Some of the more common types of test equipment include:

◆ **Electronic gas detectors**—These instruments have sensors and display units that provide instantaneous results. Some have logging capabilities allowing you to store a series of measurements. Use electronic gas detectors when surveying common gases such as carbon dioxide and carbon monoxide and when investigating large buildings.

◆ **Calibrated pumps and sample tubes**—These devices are useful for point-sampling gases that are not tested regularly. These instruments use a calibrated pump to draw a slug of air through a glass tube that has been opened on both ends and inserted into the pump. You can buy tubes for a wide variety of contaminants at different concentrations, and there are two types of tubes that can be used:

- Tubes that change color so you can read the concentration directly off the tube. The typical concentration range is parts per million (ppm).
- Tubes that collect a sample and are sent to a lab for Gas Chromatograph/Mass Spectrometry analysis. Typical ranges are parts per billion (ppb) and parts per trillion (ppt).

◆ **Passive monitors/detectors**—These are relatively inexpensive, one-time use devices left in place for a period of time and mailed to a lab for analysis. These are commonly used for radon, formaldehyde, and nitrogen dioxide. In some cases, you can leave instructions and postage-paid envelopes for occupants to mail to the lab for you, but it is best to make a return trip to retrieve samples and mail them in yourself. This will ensure that the sample is recovered at the appropriate time and will enable you to see if the sample or the test location was disturbed during the test.

◆ **Particle sample collectors**—Particles can be collected on filters using calibrated pumps left in place for a period of time (which is recorded) for subsequent gravimetric, elemental, or microscopic analysis. Bioaerosols are collected on coated glass slides or on nutrient media and are examined microscopically or cultured.

Once this body of information is in place, I'll know if measurements are needed or not. If they are, it's time to open the toolbox.

## MEASUREMENTS AND EQUIPMENT

Measurements taken using test equipment or resulting from laboratory analysis of samples are most useful when I have a particular question to answer. Sometimes, I'm testing a guess about what's happening. Other times, I'm collecting information I need toward the design of an intervention strategy meant to correct the problem. Lastly, I may take measurements during a mitigation effort to document containment or occupant exposures.

Some questions that testing helps answer are:

- ■ Is this space receiving ventilation appropriate for its activities?
- ■ Is a particular space within the thermal comfort zone?
- ■ Are contaminants from an observed source at higher levels in the complaint areas than in non-complaint areas?
- ■ How much air has to be exhausted from the crawlspace to prevent crawlspace air from entering the occupied space, and what size fan will meet that requirement?
- ■ How tight does the crawlspace have to be sealed so a fan half that size can be used?
- ■ Are fungal spores and hyphae escaping from the work area into the rest of the building?

Test equipment exists for the other two legs of the IAQ Triangle: contaminants and transport mechanisms.

### Contaminant Tools

Contaminant-related tools fall into three categories:

- Inventory of potential contaminant sources
- Measurement of airborne contaminant concentrations
- Measurement of contaminant release rates from materials

If I make airborne contaminant measurements it's generally because:

✔ I have a hypothesis I want to test.

✔ I want to test for a specific contaminant for which public health agencies suggest I test.

✔ A test may have value in a legal case.

✔ I can't figure out what's going on, and I'm hoping that comparing the results of airborne measurements with industrial standards or data aggregated by the U.S. EPA will tell me something.[2]

The most common reason I test for an airborne contaminant is because a pattern among the complaints, potential sources, and transport mechanisms leads me to guess that a specific source is involved. If people are complaining of eye irritation and headaches, and I suspect that there are times when combustion fumes are spilling into a building, I'll test for carbon monoxide or other combustion products while conducting spillage tests. The hypothesis I'm testing is that the combustion equipment is producing and spilling carbon monoxide into the space, resulting in physical symptoms.

Often times, the buildings and grounds personnel already know what's wrong, but they need more evidence so that administrators will feel like they can defend the expense of fixing it.

I routinely test for carbon dioxide and carbon monoxide. I use the carbon dioxide as part of my assessment of ventilation rates; the measurement and analysis procedures will be described in Part 2.

I measure carbon monoxide regularly for the following reasons:

- There are potential sources of carbon monoxide in most buildings.
- Carbon monoxide in buildings may vary by a couple of orders of magnitude over time, depending on complex building dynamics.
- Carbon monoxide exposure can result in serious injury or death.
- I've found previously undetected carbon monoxide sources in buildings often enough that I believe it's worth checking.

Public health agencies sometimes recommend testing for specific contaminants such as radon in air; asbestos in suspect materials; or lead in paint, soil, or dust. Testing for these contaminants requires equipment, supplies, and procedures that are beyond the scope of this article. Contact your local public health agency or your regional U.S. EPA office for more information on these contaminants.

Sometimes, a measurement is made because it is important to identify the source of a contaminant for liability and litigation purposes. Such tests must be performed using the most defensible procedures. There have been a few cases where it was important to identify the source of glass or mineral fibers that were causing eye irritations and skin rash on occupants' forearms. In cases like these, samples are taken from dust on horizontal surfaces and from materials in the space or air handling equipment containing glass or mineral fibers. The samples are sent to a specialty lab to determine which material was the source of the symptoms. An airborne sample would probably not find the fiber present because the size of glass and mineral fibers are large enough to cause the particles to settle onto horizontal surfaces quickly.

If the evidence I've collected using my usual methods leaves me baffled, I may sample for specific contaminants for which there's guidance. For some contaminants, the airborne concentration can be compared to industrial standards or occupational regulation. In commercial, institutional, and residential settings, it's uncommon to find contaminant levels that exceed industrial standards. The U.S. EPA has compiled a large database of contaminant levels in non-complaint buildings. If I have concentrations of a specific contaminant that are far greater than the average or maximum levels found in the EPA studies, this gives me a new lead to pursue.

### Transport Mechanisms

To understand and solve indoor air quality problems, I have found that it is crucial to understand how air moves through both the mechanical equipment and the building itself. Some of the air flows are intentional, and some are unintentional. Unintentional or unanticipated consequences of intentional air flows are at the heart of many IAQ, thermal comfort, excessive energy use, and moisture-related problems.

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[2]*The U.S. EPA's Building Assessment Survey and Evaluation (BASE) study is a cross-sectional study of at least 100 buildings. For more information about BASE, visit the EPA Website at: http://www.epa.gov/iedweb00/base/*

Here are some of the methods I use to assess the planned and unplanned air flows in buildings.

• Smoke bottles—A smoke bottle (or smoke pencil) is a small Teflon or glass bottle that contains a glass fiber filler and titanium tetrachloride (a liquid). When titanium tetrachloride is exposed to air, it reacts and forms small, white particles of titanium dioxide, which just hang in the air, and a little hydrochloric acid fume. The acid impartially irritates your lungs, eyes, or skin and eats any metal or fabric it comes in contact with. Safety tip—don't breath this stuff (or leave it in your pocket or toolbox with your electronic gear). Carefully read the manufacturer's instructions for handling and storage. I keep mine in double zip-lock baggies, which works pretty well.

I use smoke bottles to identify the direction of air flow at openings between rooms, wall and ceiling cavities, utility chases, attics, staircases, and ductwork. Although this is actually pretty simple, it becomes complex when the stack effect, wind pressures, and a number of air handlers operating with different control modes are interacting. Adding to the complexity is the effect that window and door positions can have on air flows and pressure relationships. Some problems happen only when one door is open and another is shut.

FIGURE 1. A Teflon bottle containing a few cotton balls and liquid titanium tetrachloride makes a great "smoke bottle."

• Eyes—A trick I use to determine air flow direction between rooms is to examine particle deposits. Particle deposits on door jams or on porous materials like carpet or glass fiber insulation are useful, time-integrated indicators of pressure-driven air flow between adjacent spaces. Wall or ceiling insulation that has been in place for awhile is a good way to find thermal bypasses and leaks in the building shell. Corrosion rings around nails penetrating attic walls and ceilings, moisture stains on framing and sheathing, and mineral deposits on foundation walls are visual indications of moisture flow and condensation formation.

• Micromanometer—A micromanometer measures the pressure difference between two ports to which tubing can be connected. This allows pressure measurements to be made between locations that are hundreds of feet apart.

I use micromanometers to measure the pressure differences that are driving the air flow. A micromanometer is a portable electronic gauge or a hydraulic gauge (Hooke gauge) that can measure down to one thousandth of an in. WC. At these low pressures, I often use the SI units of Pascals (Pa), and differentials in the 1 to 5 Pa range are often significant.

Micromanometers are also used in conjunction with devices such as Pitot tubes and cross-sectional vanes to measure air velocities in ducts, pipes, and cavities.

FIGURE 2. Carbon monoxide detector showing a high reading (1374 ppm) during a radon investigation at an unoccupied school. This incident is exemplary of the need to measure carbon monoxide levels routinely during IAQ investigations.

## MY TOOL BOX

Perhaps, the best way to summarize the types of IAQ test equipment that can be useful for investigations is to simply tell you what's inside my tool box. I use a variety of tools during an investigation. Some of them are fairly simple to use, but many require special training. Here's a list of tools that I require on a regular basis categorized by their frequency of use.

### Nearly Every Case

• Smoke bottle to track air flows between rooms and into and out of walls, ceilings, and grilles. If I could have only one tool to solve air quality, moisture, thermal comfort, and energy use problems, I'd want a smoke bottle (Figure 1).

• Micromanometer to measure air pressure differences. It can help me to determine how much competing pressure I'll need to intervene in a transport mechanism; the location of the neutral pressure level, or – in combination with the sharp-edged orifice equation how much air is moving through an odd-shaped hole. In combination with a calibrated, variable speed fan, I can calculate the air tightness of a room, chase, crawlspace, attic, or building; estimate inter-zonal leakage areas; and estimate the air flow of air handlers that would otherwise be difficult to measure (e.g., kitchen range hoods).

• Carbon dioxide monitor to screen for under-ventilated rooms and as an indicator of outdoor air in supply air flows. Elevated levels of carbon dioxide in occupied rooms indicate under-ventilation or combustion gases. Low levels of carbon dioxide do not necessarily mean that the room is adequately ventilated. If the carbon dioxide level in the supply air is between the carbon dioxide levels in outdoor air and the return air, there is outdoor air mixed in the supply air. Detailed measurement and analysis procedures will be described in Part 2.

FIGURE 3. Non-contact infrared thermometer taking a surface reading of the roof surface below an outdoor air intake. Note the high temperature (154 F) for energy efficiency implications of such conditions. See the related article on economizer optimization on page 35 of this issue.

• **Temperature/relative humidity monitor** —temperature and relative humidity are key variables in thermal comfort and mold growth.

• **Moisture-content meter** to measure the amount of moisture in porous materials such as wood, concrete, composite materials, or gypsum. Very useful in understanding moisture dynamics.

• **Carbon monoxide monitor**—I routinely test for elevated carbon monoxide levels because carbon monoxide may be released into buildings by a variety of complex mechanisms, and the consequences can be deadly. I've found previously undetected carbon monoxide sources in buildings often enough that I believe it's worth checking. Carbon monoxide levels above outdoor concentrations trigger an inspection for proper operation of all combustion devices (Figure 2).

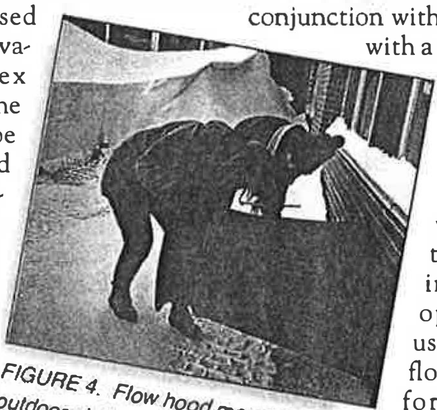
*FIGURE 4. Flow hood measuring outdoor air flow through the intake of a classroom's unit ventilator.*

## Frequently, but not on every case

• **Non-contact infrared thermometer** (IR)—aim it toward a surface, press the button, and read the surface temperature directly. Surface temperatures are important in thermal comfort, moisture, and energy problems. If the people in the corner room complain they're too hot or cold, even though the air temperature is the same as everyone else's, check the wall temperatures. Corner rooms have twice as much outside wall as other rooms, so the radiant exchange is different for them. I can find defects in the thermal envelope with an IR thermometer. I can check the temperature at the outdoor air intake to see if there's a solar pre-heat on the air conditioner. With room air relative humidity measurements and surface temperatures, I can tell whether condensation is the result of high indoor moisture sources or surface temperatures that are too cool. The temperature of a supply diffuser quickly tells me whether it is operating or not...without climbing a ladder to check (Figure 3).

• **Flow hood** for measuring air flow through vents, diffusers, and a variety of holes (Figure 4).

• **Pitot tube or hot wire anemometer** for measuring the speed of air. The Pitot tube is a primary measurement method for air speed. Air flow in ducts can be measured using Pitot tubes (in conjunction with a micromanometer) with a great deal of accuracy (Figure 5).

• **Fan pressurization door**, also called a "blower door," is a calibrated, variable speed fan that can be sealed into door or window openings. It can be used to generate an air flow pressure drop curve for rooms, cavities, crawlspaces, or any enclosed space you can depressurize. It is extremely valuable for designing interventions. It can also be used to estimate inter-zonal leakage areas and air flows through hard-to-measure air handlers. In buildings with large leaks, multiple fans can be used to make these measurements. As an alternative, building air handlers can be cycled so that a pressurization-air flow curve can be generated without a fan door.


*FIGURE 5. Building manager making duct traverses with a Pitot tube connected to a micromanometer.*

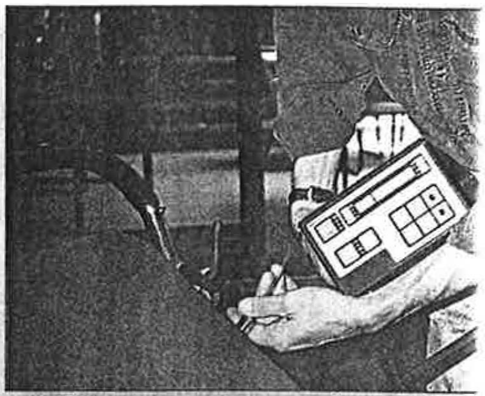
*FIGURE 6. Laser particle counter being used to measure particle concentrations and sizes bypassing a vacuum cleaner's filters. It will also be used to characterize particulate matter being raised (but not entrained) by the vacuum cleaner through disturbance.*

*FIGURE 7. Laser particle counter making baseline particle measurements in a school. The measurement will be expressed as total mass of particles less than 10 microns, which can be converted to micrograms per cu m because the device uses a calibrated pump to draw in the sample air.*

• **Microscope**—I examine particles under 200x to 800x to distinguish between major types of particles (e.g., fungal spores, pollen, soot, fabric-paper-mineral fibers, insect parts, soils, skin flakes). By examining things while out in the field, I can narrow my focus on the spot. Otherwise, I'd need to wait for a lab report and perhaps have to make another visit.

• **Binoculars** are very useful for examining things from a distance that you would rather not examine close-up while 40 ft in the air, near electric shock, moving equipment, or burn hazards.

• **Canning jars** are handy for tracking down sources of odors. Collect a sample of suspect material, seal it in the jar, and try a tentative whiff several minutes later. If the material is a source, you'll know (as long as you can detect the complaint odor ... I've encountered people who can't smell a skunk). This technique came in handy when investigating a problem that eventually led to a vole nest.

**Specific Cases**

• Laser particle counter reads in the number of particles per cu ft in specific size ranges. Mine has cuts for greater than 0.5 microns and greater than 5 microns. This allows me to calculate the range between 0.5 and 5 microns—pretty useful for the fine particles that someone might breathe (Figure 6). Another type of laser particle exists for making total mass measurements of particles less than 10 microns (Figure 7).

• Theatrical fog generator makes a couple thousand cfm of glycol fog. Nothing beats a visual tracer for demonstrating transport or control mechanisms. I've used it for chimney fume, exhaust hood effectiveness; inter-zonal, containment, and displacement ventilation; and duct-leakage studies.

• Sulfur hexafluouride (SF6) monitor —I use SF6 to make ventilation, infiltration, air flow, and inter-zonal measurements using a variety of tracer analysis methods. A compressed air tank of SF6 and a datalogger are also needed.

• Data logger—when a case is complex with events that only occur at unknown times, it is hard to beat the power of continuously monitoring a number of important variables at several locations. Powerful, but expensive, I only do this when simpler methods cannot clearly establish the dynamics.

• Lab samples—I sometimes collect bulk, surface dust, and air samples so a lab can identify biological particles, total particles, allergens, and chemical compounds. Samples of this type should be made by qualified personnel, using accepted standard practices, and following the direction provided by the analysis lab you're using. **HPAC**



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