Tools for the Indoor Environmental Quality Investigator

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Introduction

Researchers estimate that we spend 22 of the 24 hours in a day, more than 90% of the day, in an indoor environment. (Wu 2007, 953) As such, it is not surprising that the indoor environmental quality (IEQ) can have a significant impact on our health, and it has been known for centuries that contaminants in the indoor environment can reach levels that are dangerous to health and even to life. (Morawska 2008, 5)

The relationship between the built environment and health effects is very complex (Wu 2007, 954), but our understanding of the relationship is evolving. Acceptable indoor air quality was once defined as “air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction.” (ASHRAE, 1989) When that definition was in vogue, investigators were primarily concerned with indoor air constituents and comfort factors. However, today’s IEQ investigators understand that there is a complex interplay between a building’s occupants (who they are and what they do) and a wide array of physical, chemical, biological, and design factors. (Mitchell 2007, 958)

It is the IEQ investigator’s job to determine what hazards exist in the built environment and the sources of those hazards. The potential hazards in the built environment include particulates; chemical, biological and physical agents; and psychological factors. The sources of hazards can include the building’s design, envelop, mechanical systems, and furnishings; products used; occupant activities; and even external sources. (Wu 2007, 954)

When one steps out to conduct an IEQ investigation, one is never sure what all the investigation will entail. The process of the investigation is well known and is flow charted in Exhibit 1, but the actual tools that will be required “to collect additional information” are always uncertain at first. In my 20+ years of investigating IEQ complaints, I’ve seen sources and hazards that have run the gambit from simple and obvious to complex and elusive. But every investigation has required the use of IEQ tools to validate my hypotheses. Some investigations have required just a few simple tools and others have required every IEQ tool in my arsenal, and then some. This paper will examine the tools commonly used to conduct an IEQ investigation.

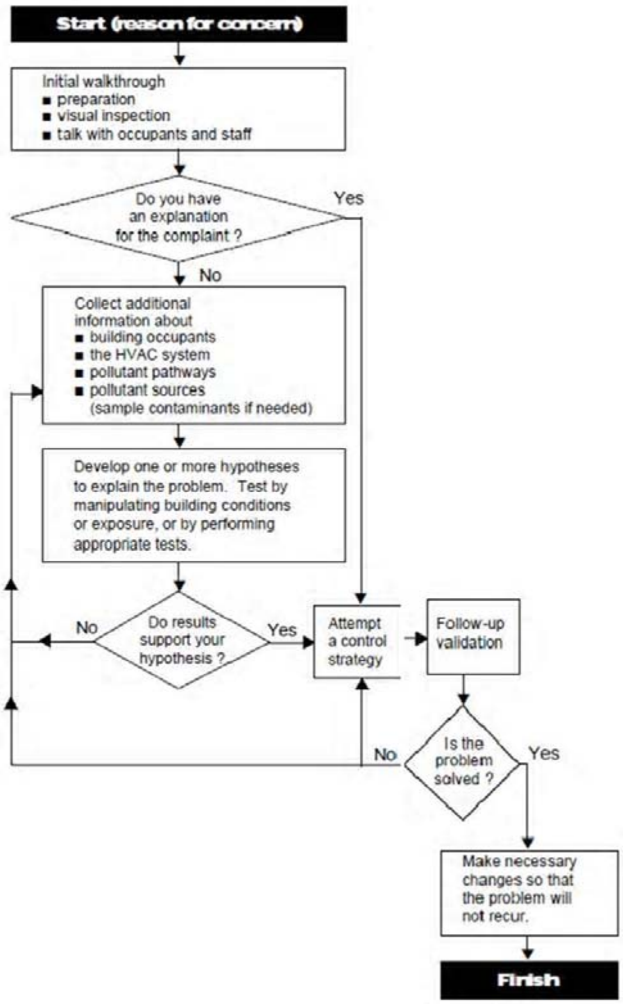

Exhibit 1. This flow chart depicts how to diagnose IEQ problems and is adapted from *Building Air Quality: A Guide for Building Owners and Facilities Managers (page 45).*

Making "Sense" of the Tools

One of the very first tools used to measure IEQ contaminants was the canary. Carbon monoxide is an inherent threat in underground mines, but in the early days of the mining industry there were no instruments to warn of dangerous levels of this odorless, colorless, and tasteless gas. So, cages of canaries were hung throughout the mine to act as "indicators". The birds were particularly susceptible to carbon monoxide and, if one died, it was a warning to leave the mine. (Morawska 2008, 5) Thankfully, today we have much better tools and methods for evaluating the indoor environment and for measuring contaminants.

Any discussion of IEQ tools would be remiss if it didn't start off with what are arguably the three most important IEQ tools – the eyes, nose and ears. Granted these aren't exactly tools in the traditional sense, but they are truly the foundational tools of every good IEQ investigation.

Early on in every investigation, there is a walkthrough inspection of the area. This walkthrough is typically a feast for the senses. The eyes take in the building's conditions and layout, maintenance and upkeep issues, the types of operations that take place in the immediate and surrounding areas, the quality and quantity of the lighting, ergonomic postures of the workers, signs of thermal discomfort, and many other factors.

The odors present in a workplace can be a quick clue to problems that may not be immediately visible. Chemical odors in areas where there are no chemical processes or tobacco smoke in areas where there is no smoking suggest that odors are entrained from other areas of the building or from outside. Musty odors in an area where there are no visible signs of mold or water damage suggest the possibility of hidden mold.

The ears listen to the building's occupants to hear and understand their complaints. In my experience, these folks are great sources of information. They often know the building's history and its problems and offer valuable clues as to the source of the building's problems.

The insight gained by the senses during the walkthrough inspection give the investigator valuable direction. To use these tools to their fullest potential the walkthrough should not be hurried or rushed.

The Basic Tools

Every investigator needs a set of basic tools. These are the tools that will be used on almost every investigation and are kept readily at hand all the time. All of these tools are inexpensive, easy to operate, and most are readily available at the local hardware store. The basics set of tools includes:

- A flashlight
- A thermo-hygrometer
- A tape measure
- A digital camera

Every investigator needs a good sturdy flashlight because he will inevitably find himself working in low light situations. There is always something to look under or inside or behind. Overheads and closets are notoriously dark places, and attics and crawl spaces can be even worse. There are many types and sizes of flashlights and power supplies available. You can get them with traditional incandescent bulbs or with the newer light emitting diodes. You can get them with disposable batteries, rechargeable batteries, or even hand cranked dynamos. You can get them with single position or adjustable beams. You can get handheld models or head-mounted models; you can even get caps with the lights built in.

The next must-have basic tool is a digital thermo-hygrometer. This small hand-held, battery powered device measures temperature and relative humidity. This is a not data-logging device or a device with which to conduct a fully spectrum heating ventilation and air conditioning system check, but a few screening measurements taken during the walkthrough inspection will serve the investigator well. It does require a few minutes to equilibrate to the environment in which it is to measure and it requires periodic calibration. Most manufacturers recommend quarterly calibration and have simple kits you can buy to do so.

Next is a tape measure. Whether its ventilation openings, distance to potential sources of contamination, or room dimensions, there is always something to measure. There are almost as many kinds of tape measures to choose from as there are flashlights, including some tape measures that are battery-operated like the power tapes and the newer point and read models.

Every investigator's basic kit should also include a digital camera. These little cameras are an easy way to record facility layout, to document conditions, and to identify testing locations and equipment setup. Plus, the photos serve as memory aids when the investigator is back in the office drafting the report. Whether you're documenting overloaded HVAC filters, poorly located fresh air intakes, water damage, microbial growth, or signs of rodent infestation, a picture really is worth a thousand words.

The Specialized Tools

Okay, so now we've got a basic kit; let's look at some of the more specialized tools of the trade. According to the National Institute of Occupational Safety and Health (NIOSH), more than half of the all their IEQ investigations have found inadequate ventilation to be the source of hazard and most IEQ investigations start with an evaluation of the ventilation system. (OSHA 1999) So too will we continue our discussion of IEQ tools.

While most IEQ investigators don't need the tools or skills to test and balance a ventilation system, having the tools to verify that the air flow at a register meets the design criteria is often needed. Balometers make easy work of this task. A balometer is a tool for measuring air volume; it's essentially a velometer with an aluminum frame which is covered in nylon skirting. The frame and skirting can be adjusted to fit standard register sizes. When held flush against the outer edges of the register, the balometer measures the volumetric air flow in cubic feet per minute. The measured values compared to the design values give the investigator a clue as to how well the ventilation system is operating. Assembling the correct size frame and attaching the skirting can be a little tricky, especially if don't do it very often. But, with a little practice, the process becomes somewhat intuitive. The balometer requires an annual factory calibration.

Temperature, relative humidity, and carbon dioxide levels have long been recognized as important indicators of air quality. (Mitchell 2007, 958) Temperature and relative humidity are key comfort indicators and carbon dioxide levels are an indirect measure of an adequate supply of fresh air. These indicators are dynamic and fluctuate over a wide range throughout the day. As such, they are best measured with what the trade often calls "indoor air quality meters." These tools are actually data logging devices that record temperature, relative humidity, and carbon dioxide levels continuously and can be left in the workplace for several days to characterize the indicators and provide valuable clues about the ventilation system function. The data is stored and then downloaded to a computer where you can review the data either in table form or on line graphs. I've used several different models of indoor air quality meters over the years and have never found one I wouldn't recommend to a colleague. In addition to serving as a data logger, some can be used as a handheld screening tool and could replace the thermo-hygrometer in the basic kit. In the data logging mode, they all require a source of electricity, but have a battery backup so data is not lost if the unit is accidently unplugged. Pre- and post-calibration of the carbon dioxide sensor is required as is annual calibration of the temperature and humidity sensors.

There is no shortage of tools to measure particulate and chemical hazards because there is no shortage of types of particulate and chemical contaminates in the built environment. There are occupational exposure limits established by the Occupational Safety and Health Administration (OSHA) and by the American Conference of Governmental Industrial Hygienists (ACGIH) for many of these hazards, but, even though building occupants present with health effects, contaminates in non-industrial settings are seldom present in concentrations approaching occupational limits. (Burge 1997, 391)

Most particulate and chemical contaminants can be measured using traditional industrial hygiene active sampling methods. Active samplers collect contaminants by means of forced air movement from a sampling pump through an appropriate media. Personal sampling pumps are small, battery-powered, vacuum pumps which can be calibrated to a specified flow rate, typically between 0.05 and 4 liters per minute (LPM), and can either be worn at the waist of a worker or set in the general area around a worker. High volume sampling pumps are larger, electrically-powered, vacuum pumps that operate between 5 and 30 LPM and are designed for sampling in the general area around a worker. (Todd 1997, 213) All these pumps require pre- and post-sampling calibration and periodic maintenance. To use active sampling methods, the sampling medium, flow rate, and sample time specific for the contaminant must be used. This information can be found in the NIOSH Manual of Analytical Methods which is available on web at www.cdc.gov/niosh/nmam.

Some contaminants, such as formaldehyde, acetic acid, and a wide variety of organic vapors, can be measured using passive samplers. These samplers collect contaminants at a controlled flow rate by a physical process such as diffusion through a static layer or permeation through a membrane without the active movement of air through an air sampler. These samplers can be used to collect area samples or personal samples and attach easily by a built-in clip. (Todd 1997, 215) These samplers are easy to use and often more accepted by non-industrial workers than the active samplers.

Some contaminants, such as carbon monoxide, sulfur oxides, and nitrogen oxides, can be measured using electrochemical sensors. Remember the indoor air quality meters discussed earlier? They can be fitted with additional electrochemical sensors to measure a variety of gases. You will need span and zero calibration gases appropriate to each sensor for the pre- and post-sampling calibration. The sensors have a limited service life, and in my experience give little notice they've reached the end of that life.

There are a few tools available when the chemical hazards present are unknown that allow the investigator to scan the air. The first is a Summa canister. A Summa canister is a pre-evacuated stainless steel canister with a passivated interior surface that acts as collection vessel. The passivation prevents the gases in the sample from reacting with the canister. (Burge 1997, 224) These canisters allow the investigator to collect a sample of the air over a period ranging from a few minutes to 24 hours which is scanned for a variety of contaminants. Many labs analyze the canisters using the standard set of 63 compounds from the Environmental Protection Agency (EPA) method for toxic organics. The set may or may not be helpful in your investigation, but you can add or delete analytes as needed. The canisters come in several sizes ranging from 400 milliliters to 6 liters and can be equipped with different size regulators depending on your needs. The cans and regulators are expensive and require special preparation before sampling so most investigators do not purchase their own cans, but rely on their laboratory's loaner service. You'll have to know up front how long you plan to sample so the laboratory can send the appropriate size canister and regulator. There is no on-site calibration required, simply attached the regulator to the canister then open the regulator to begin the collection of gases.

Another tool for scanning the air is an infrared gas analyzer. This portable, but often bulky and cumbersome tool, scans the air in real-time. It has a built-in library of hundreds of gases, and it can be fitted with an optional gas identification package that compares a scan of the air with its library and then lists the gases in descending order of matching probability. (Todd 1997, 192) This tool requires annual calibration.

The tools for evaluating biological hazards must start with a look at the tools for evaluating the conditions that support biological growth; the tools for evaluating moisture. For many investigators, a moisture meter is a tool in their basic kit and goes with them on every investigation because moisture problems are so often a part of IEQ investigations whether or not there is reported water damage. These small hand-held meters are used to measure the moisture content in building materials. Most meters are calibrated by the manufacturer for use with wood at 77°F and have a working range of 0-30%. In addition, many have scales calibrated for other types of building materials like gypsum board and concrete. There are advantages and disadvantages of each type of meter. The pin meters are a little destructive leaving behind two 1 millimeter holes at each measurement location, but fitted with the proper length pins can test the moisture levels at different depths in building materials. The pinless meters are not destructive, but allow the testing of moisture at only the outermost surface, and they cannot be used on rough surfaces. (Prezant 2008, 71) To get the best of both worlds, meters are available that integrate the pin and pinless model into a single tool.

Another tool for evaluating moisture is a thermal imaging or infrared (IR) camera. Both of the moisture meters previous discussed require direct contact with the building material surface to work. In contrast, the IR camera detects moisture by imaging the different temperatures of wet versus dry building materials. These cameras are simple ‘point and shoot’ tools and, just like other cameras, can store photos for later printing. (InfraMation, 2003)

There are several tools for measuring biological contaminates but they fall basically into two categories: tools for culture-based sampling and tools for non-culture-based (spore trap) sampling. For culture-based sampling, a sample of the air is drawn by a high volume sampling pump through a multiple-hole inertial impaction device which accelerates the air along with any suspended particles (like mold spores) and then deposits it a nutrient agar. Once the sample is collected it is incubated at room temperature for 2-7 days and then the individual colonies are identified and counted. (Prezant 2008, 140) There are several brands of culture-based samplers, each with its own suggested flow rate and sampling time, several nutrient agars are available as well. Some samplers require pre- and post-sampling calibration and others have factory set flow rates and require quarterly calibration.

For spore trap sampling, the process is much the same as discussed earlier for active sampling methods, except in this case the collection medium is a glass slide coated with silicon-based grease or a sticky transparent membrane. The collected spores are then identified and counted. There are several brands of spore trap samplers, each with its own suggested flow rate and sampling time, and they require pre- and post-sampling calibration (Prezant 2008, 140)

There are advantages and disadvantages to both types of sampling. With culture-based sampling, one can identify fungi at the species level where spore trap sampling can only identify at the genus level. Culture-based sampling requires an incubation period of several days where spore trap samples can be analyzed immediately.

Microbial volatile organic compounds or MVOCs are organic compounds given off by all microorganisms; they are the source of the musty or decay smell associated with active fungal growth. Active sampling methods are used to measure MVOCs; a sample of air is drawn over an adsorbent tube by an air sampling pump. (Prezant 2008, 144) Again, the medium, sample time and flow rate are specific, and pre- and post-sampling calibration is required.

There is often much to be learned from surface sampling, as well as air sampling in cases of visible microbial growth. The tools for surface sampling are sterile swabs and/or glass slides and clear adhesive tape (tape lifts). In my practice we do lots of microbial investigations and I keep surface sampling tools in my basic tool kit. These tools are available from most microbial labs for free provided you use their services for the analysis of the samples. The swabs carry an expiration date so check your supplies periodically. For swab sampling, a moistened swab is wiped over a dry surface or a dry swab is wiped over a wet surface. The sample is them analyzed by cultivation (species) or by direct microscopic examination (genus). (Prezant 2008, 145) For tape lifts, a section of clear tape is gently pressed against an area of visible growth then lifted off and adhered to a glass slide. The sample can then be analyzed by direct microscopic examination (genus). (Prezant 2008, 148)

A Few Last Thoughts

We have discussed the tools commonly used by IEQ investigators. I have personally used every one of these tools; some I use all the time and others I just use occasionally. It is important that IEQ investigators understand the tools of the trade, what they are used for, and when they might be appropriate to an investigation. Every investigation will not need every one of these tools, but every investigation will need some of these tools.

Some of the equipment we've discussed costs tens of thousands of dollars, some cost a few hundred dollars. The decision as to which tools to purchase for your practice will depend on your own cost-benefit analysis. Many of these tools are available to investigators through loaner programs or from rental companies. The obvious disadvantage is that the equipment you need might not be available when you need it, but that has to weigh against the cost of some of these instruments.

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