Testing and Inspection Equipment for Indoor Environmental Quality

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Introduction

Designing and implementing an indoor environmental quality (IEQ) program is an important consideration for facility managers. Many such programs are now being implemented at the initial commissioning of buildings. Others are developed in facilities having later construction to improve real estate value and the perceptions of the occupants. Regardless, more and more, the contributive negative impact of poor productivity, absenteeism, bad press, potential litigation, rising costs of insurance, and other factors exist to help facility managers rationalize and implement appropriate IEQ pro-active programs. The cost of a single legal case taken to full litigation can often exceed the costs to completely purchase the necessary equipment and fund the staff to operate an in-house IEQ program over several years. While facility managers often see the need to implement an IEQ program, many simply have not implemented such a plan because they do not know what testing and inspection equipment is involved in the development of such a program. This article is written for the facilities manager who is interested in implementing an IEQ program, and seeks to provide the facilities manager with the basic "nuts and bolts" of such a program, in order to assist in its development.

Appropriate IEQ can be defined as a function of three different components: 1) appropriate thermal comfort, 2) appropriate ventilation, and 3) control of airborne contaminants. Obviously, an appropriate IEQ program must contain various aspects of these essential components. Additionally, IEQ programs can be pro-active or reactive. Pro-active approaches offer the best foundation to develop an ongoing and successful IEQ program; however, such programs must also include the ability to "react" when necessary. It is exceedingly difficult to develop a "pro-active" IEQ program in the midst of dealing with an "immediate" IEQ problem. That is why it is wise for the facility manager to begin and implement a pro-active program now and not wait until problems start to unfold. The presence of an appropriate and existing IEQ program can often serve as a deterrent to escalating indoor environmental related problems.

It is important for facility managers to be aware of the peculiar nature of IEQ-related problems. While thermal comfort is a component of IEQ, building occupants often perceived IEQ as a health-related issue and not just a comfort issue. This is an important concept for the facilities manager to grasp. People can elicit a wide variety of political, social, and/or personal reactions when they perceive that they or someone dear to them is being "hurt" by the IEQ in a building. Knowing how to react quickly when such problems occur is of extreme benefit to preventing escalation of an IEQ -related event. However, the basic approach to either pro-active or reactive IEQ events should encompass the three basic defining issues involving IEQ identified above. These three issues will be discussed individually in the following sections to provide the facilities manager some basic information on the performance of testing, the equipment required, and whether the type of testing should/can be performed “in-house” as opposed to seeking “ testing services”. However, before we go there, we need to make certain that some “basic” information is covered.

Basic Training, Education, and Equipment

Go blindly into an IEQ program and you will be likely to stump your toe. Given the realm of possible fallout, stumping your toe could be the best thing that could happen. Starting an IEQ program knowing nothing about personal protective equipment, confined spaces, chemical application, and a host of other regulations can result in a real nightmare for you and your facility. Not knowing how to inspect an air-conditioning system that is contaminated with mold can take a bad situation and make it much worse. The recommendation is “don’t do it”. Before you hastily set off in the development of an IEQ program, seek out basic training and education. The Indoor Air Quality Association (IAQA) offers a variety of programs in this area, as well as serves as a conduit of information and training with other organizations (www.IAQA.org). Additionally, a host of companies like Indoor Environmental Consultants, Inc. offer basic training and education in these areas. I strongly urge you to seek them out. Let these experts help you in establishing the basic educational and training foundation from which your facilities IEQ program will grow. It is the best, first step in the entire process.

Next, you might want to consider acquiring some basic inspection and documentation equipment. Nothing can replace a digital camera. These instruments are great for snapping shots as you perform general walk-through of your facilities. Scanning the photos later may assist in reminding you of projects that need to be attended to and /or scheduled. Some of the cameras these days even have built-in tape recorders that allow you to further document the picture with a verbal note. This or a standard portable tape recorder also provides some benefit to assist you in collecting and recovering field observations when you’re back in the office. Such devices produce pictures or voice captions that are easily loaded into your computer for archiving and/or the development of a photo-enhanced report.

More elaborate cameras are available and should at least be evaluated. I specifically find the infra-red (IR) camera to be an excellent tool in detecting various aspects of building performance. **Photograph 1** illustrates an infra-red photograph of over-heating electrical wires that are hidden in a wall cavity and causing a hidden fire potential. The owner of this building had no idea that this was occurring. The problem was easily diagnosed with the non-invasive use of an IR camera. The IR camera technology is also extremely helpful in the evaluation of appropriate air distribution, insulation deficiencies, water leaks, and numerous other aspects of the building, its envelope, and internal systems. Now on to the three main issues of IEQ.

Appropriate Thermal Comfort

Appropriate thermal comfort is, as the terms imply, how comfortable does one feel inside the facility. Thermal comfort is a function of both temperature and humidity. The American Society of Heating, Refrigeration and Air-Conditioning Engineers has defined appropriate indoor temperature and humidity in a document referred to as Standard 55 (aka ASHRAE-55). This standard cites appropriate ranges of both temperature and humidity for occupied buildings in winter and summer conditions. The evaluation of a building for appropriate thermal comfort is something that a facilities manager can undertake without a great deal of expense or complexity. A number of thermometers or temperature recording devices are available on the market to readily enable the facilities manager to evaluate building temperatures. Humidity can also be evaluated through a variety of low cost instruments, such as sling psychrometers and hygrometers. However, typically the “lower costs” instruments available provide for “spot” measurements. While these types of instruments do provide the ability to instantaneously collect important temperature and humidity data, they do not readily provide an ongoing, real-time evaluation of the dynamics of temperature and humidity of a building. Temperature and humidity within a building can fluctuate dramatically over a 24-hour period as a function of outdoor weather, occupancy loads, indoor activities, and a host of other factors. For this reason, it is highly recommended that the facility managers interested in performing in-house evaluations of appropriate thermal comfort purchase equipment that can provide an ongoing monitoring of temperature and humidity functions. Once in place, these devices can provide data by which the facility manager can make valid data-based decisions regarding the operation of air-conditioning systems, track any specific changes as a result of operational changes, maximize the energy conservation of the system, as well as provide data to support that the building is being operated within ASHRAE guidelines for thermal comfort.

The degree to which a facility can distribute these monitoring devices throughout the building is of course related to a budget. Some situations limit the purchase of such equipment and thus require the manager to relocate the collection device to various building locations in order to collect appropriate data. **Photograph 2** illustrates a typical hand-held, portable, multifunction instrument that can be re-located to various areas of a building to collect data. Note: this article is not intending to represent any one product and/or manufacturer over another. Information about such products, their costs, and individual benefits and/or drawbacks can be easily obtained on the Internet. Other facilities having generous budgets can create building-wide monitoring from a centralized location. These systems can be quite elaborate and costly; however, the net result basically remains the same. Ongoing monitoring of temperature and relative humidity can assist in the overall performance of the air-conditioning systems and provide critical data to assist the facility manager in the evaluation of air distribution and balance throughout the facility. Often the basic evaluation of temperature and humidity can provide initial data indicating that an air balance or distribution problem exists. Evaluating thermal comfort is the first aspect of IEQ that the facilities manager can readily implement into the management of the facility. While not comprehensive in itself relative to the total IEQ picture, the implementation of testing for thermal comfort does provide the first step in establishing a functioning IEQ program, and represents one that can be readily affordable and easy for the facility manager to integrate into existing facilities operations, especially those involving energy management. Over cooling, heating, or ventilating a facility wastes thousands of dollars. Operating this component of the IEQ program results in immediate savings that will assist in the development of other components of the IEQ program. The savings realized on reducing unnecessary cooling, heating, and ventilation could in itself fund the entire IEQ program.

One of the critical aspects of establishing an in-house IEQ program is appropriate documentation. While it is the data that provides us with the rationale to implement a specific IEQ action, it is the written documentation of the data and action that provides the occupants, management, or heaven forbid lawyers, with the knowledge of a functional and accountable IEQ program. Don't forget to document the times, dates, and data in a written format, along with any specific actions that were taken as a result of the findings. Put this information in a notebook and keep in a neat working order. Hopefully, you will never have to show the information to anyone; however, when and if you do, your goal of having an appropriate and ongoing IEQ program will be that much further served when you produce a neat and orderly file of data and actions. Some of the instruments available today use internal thermal printers. These systems are adequate for immediately evaluating data; however, over time, thermal imprints can fade and become illegible. There's nothing more disappointing than collecting and storing all of these records than returning to them 1-2 years from now and discovering that all of the thermal printing has faded and you have no actual history of these IEQ parameters despite the efforts. It is highly recommended that such data be copied on a regular carbon copier for long-term storage and legibility.

Appropriate Ventilation

It is important to know that "ventilation" in terms of IEQ is NOT simply the movement or distribution of air throughout the facility, but rather it is the introduction of outdoor air into the facility. Often termed "make-up air", ventilation is the appropriate volume of outdoor air that should be introduced and appropriately distributed within the building. Ventilation provides two basic functions in IEQ. One, the introduction of outdoor air, in theory, is intended to "dilute" concentrations of various substances that accumulate in buildings. While originally developed as a means to control "body odors", appropriate ventilation also serves to dilute various gaseous, chemical, particulate, and/or biological agents that are generated within the building or may enter the building through transient episodic events. Two, the introduction of outdoor air, in theory, enables the building to operate under a positive pressure with respect to the outdoors. This enables the air that is physically entering the building to be appropriately treated, filtered, tempered, etc, and thus provides an improved control of IEQ.

It has long been coined that "ventilation is the solution to pollution". Such an adage was a popular IEQ term in the 80's and early 90's when the predominant rationale was that most IEQ problems were the result of inadequate ventilation. However, before appropriate IEQ can be established with ventilation, the actual quality of the outdoor air utilized as the ventilation source must be considered. An office facility having outdoor make-up air vents located in a parking garage located below the office area can possibly suffer the introduction of carbon monoxide in to the facility when automobiles arrive in the morning and leave in the afternoon. I once investigated a facility in the Dallas/Fort Worth area located in the flight path of a nearby airport. The roof top ventilation systems of this building resulted in occupant complaints from the introduction of airline exhaust through the roof top ventilation systems of this building. In summary, while ventilation is a basic component of IEQ, the ability to readily ventilate a building depends largely on the quality of air outside of the facility. Initial consideration must be directed towards the overall condition and quality of the outdoor air. Under special circumstances, appropriate ventilation might require additional treatment of incoming air prior to being distributed throughout the building.

The American Society of Heating, Refrigeration and Air-Conditioning Engineers has defined appropriate ventilation for buildings in Standard 62 (aka ASHRAE-62) and it is highly recommended that the facility manager utilize this reference as a guide to appropriate building ventilation. Different ventilation rates are cited for differing building uses. For example, the standard cites that a classroom having occupants of age 9 or greater should have a ventilation rate of 10 cubic feet per minute (cfm) of outdoor air per occupant, while an office space only requires a ventilation rate of 5 cfm per person. The standard provides a reference for all types of indoor facilities including, correctional facilities, schools, offices, restaurants and bars, medical facilities, and more. Actually measuring specific ventilation rates based on the number of occupants at any given time can be difficult, if not impossible. To circumvent this difficulty, the standard cites the measurement of carbon dioxide (CO_2) as an indirect method to determine when appropriate amounts of outdoor air are being introduced. Carbon dioxide (CO_2) is a gas that is exhaled from building occupants and its cumulative levels have been utilized as a "surrogate" means to establish if appropriate ventilation is occurring. For example, ASHRAE-62 standard cites that CO_2 levels of 700 parts per million (ppm) above ambient (outdoor) levels are typically successful in providing occupant comfort from body odors (appropriate ventilation is occurring). Outdoor CO_2 levels typically range from 300 to 500 ppm; therefore, indoor CO_2 values between 1000 and 1200 ppm are fairly reliable indicators that appropriate ventilation is occurring. Rather than measuring specific ventilation rates per occupant at make-up air vents, facility owners often use the evaluation of CO_2 to determine if appropriate ventilation is occurring. As with temperature and humidity, there are several rather simple and inexpensive devices capable of measuring CO_2. One of the more common methods involves a "colormetric" tube that simply changes color as the air sample passes over the contents of the tube. The tube is metered so that the degree or length of color changes corresponds to specific levels of CO_2. However, like temperature and humidity, such measurements represent "spot" or "grab" samples that reflect the concentrations of CO_2 at that moment in time. Carbon dioxide within a building can fluctuate dramatically over a 24-hour period, primarily as a function of occupancy loads and indoor activities in non-industrial situations. For this reason, it is highly recommended that the facility managers interested in performing in-house evaluations of appropriate ventilation purchase equipment that can provide an ongoing monitoring of CO_2. A host of real-time CO_2 monitors are available on the market and recent competition in the development of this type of equipment has reduced the cost of this equipment when compared to years past. Today, it is very common to find CO_2 real-time monitoring devices that are also integrated with temperature and humidity functions. Thus, this single piece of equipment can provide the facility manager with the ability to monitor two of the three basic components of IEQ.

Findings of excessive CO_2 levels in accordance with ASHRAE-62 may require the need for additional ventilation; however, such IEQ inadequacies may also be solved through other personnel or management activities such as re-evaluating and re-distributing occupant densities within the building. Carbon dioxide (CO_2) levels below the ASHRAE-62 standard may be revealing an "over-ventilation" situation, thus providing data to support reducing ventilation rates and increasing the energy savings. Having a real-time CO_2 / temperature/ relative humidity monitoring device greatly enhances a facilities managers ability to establish two of the major components of an "in house" IEQ program; however, remember that these digital devices don't do it all. Just as before, data must be extracted from this equipment and appropriately maintained in a notebook or IEQ program facility reference.

As mentioned earlier, the second important component of building ventilation involves building pressure. Buildings should operate under a positive pressure (minimum 1 Pascal). A building that exhausts more, or the equivalent amount, of air than what is introduced will exist in a negative or neutral pressure status. This is undesirable as exterior and interstitial air can literally be "sucked" or "migrate" in an uncontrolled manner into the building. In this case, the building is being ventilated and it's possible that even the CO_2 in the building can reveal values that are consistent with ASHRAE-62 standards; however, the "source" of the air used to ventilate the building is undesirable and un-controlled. Hence, measuring CO_2 alone is not sufficient as a means to evaluate the overall appropriateness of building ventilation. The source of the ventilation air must be considered and this can generally be accomplished by evaluating building pressure. Building pressure can be readily monitored with a "smoke tube". Monitoring the direction of the smoke at doors, building vents, and other designed building openings can provide the facility manager with a quick and inexpensive means to evaluate building pressure. Smoke that remains still or that is drawn back into the building suggests neutral or negative building pressure that would warrant some attention. Micro-manometers are also rather simple devices that enable facility managers to evaluate building pressure. As before, more sophisticated real-time devices are available for the budget that can afford them; however, this is one area where such expensive equipment might not be necessary. Used in conjunction with real-time CO_2 devices and a quarterly evaluation of make-up air equipment and function, a qualitative "smoke test" or a "grab" sample from a micro-manometer are generally sufficient as a method to establish that buildings are operating under an appropriate positive pressure. Re-checking the building pressure on a monthly basis provides additional support that an appropriate ventilation pathway is being maintained and provides an initial indication as to when something may be going wrong. Again, don't forget to document in written form. These simple little hand held devices are great to provide us the information we need immediately; however, we must not lose sight that such information must be documented in order to support the premise of an ongoing, accountable IEQ program.

Control of Airborne Contaminants

The third prong of the definition involving the control of airborne contaminants often represents the most complicated aspect of IEQ. This is where the facilities manager may want to consider outsourcing. The basic premise to the complexity of this aspect of IEQ can be identified by simply trying to define what an airborne contaminant is. Webster states that a contaminant is a substance that contaminates another substance; to make impure, unclean, or corrupt, or pollute. Airborne contaminants can be generally sub-divided into three sub-categories that include: particulate, chemical, and biological agents. These categories overlap and are only provided herein as a means to facilitate discussion. The strict application of the definition of an "airborne contaminant" becomes blurred in terms of evaluating IEQ because the very substances that can "contaminate" the air are present in air most all of the time. To some degree, these substances are present in air considered to have appropriate quality. So the actual evaluation of IEQ as a function of these agents not only involves the kinds of agents that are present, but also the concentrations of those agents. This is where the IEQ puzzle can get very complicated. For example, there are 1000's of different chemicals that might be present in a building. The presence of some of these chemicals could be considered common; however, the presence of others may not. Each of these chemicals might require a specific and unique set of sampling methods to evaluate both its presence and concentration. The data obtained from sampling can be reported in a variety of different units. Some results may require conversion into other units of measure for appropriate interpretation. While references are available to compare results to regulated or recommended levels in industrial and non-industrial environments, respectively, these references are often extremely complex and difficult for the untrained person to understand and interpret. It's precisely because of these complexities why the evaluation of airborne contaminants might be one of those areas where a facility manager would be better served by outsourcing the testing, monitoring, and interpretation processes. Some exceptions exist so read on!

Particles

Airborne particles are "solid" materials that are "suspended" in air and include such items as soil, dust, and lint, but can also include particles of biological or chemical origin such as, skin cells, pollen, mold spores, and particulate organic matter, respectively. There has been a great deal of research performed on particle loads in both indoor and outdoor environments and this information has provided substantial knowledge about the dynamics and origins of particles in indoor environments. Some of the more interesting studies have revealed that the majority of particles in the indoor environment are extremely small with very little weight. Studies by the National Air Filtration Association reveal that approximately 99.6 % of the particles in air are 1 micron in size or less, and that these components of the air contribute less than 10% of the weight of the total particles in air. This fact becomes important when one considers that the primary method by which particulate matter in air has been evaluated in the past is by gravimetric (weight) methods. While approved methods to evaluate airborne dust loads by gravimetric methods have been established and are of some importance in industrial settings, application of the gravimetric methods of particle analyses to non-industrial environments, such as offices, schools, etc., is not practical nor necessarily beneficial.

In fairly recent times, the use of the LASER light particle counter has emerged as an extremely useful tool to evaluate particles in indoor environments. Typically such devices sample the air and produce concentrations for pre-defined "ranges" of particle size. The "ranges" of particle sizes offered is a function of the instrument. Typically, the more "particle ranges" available on a piece of equipment, the greater the costs. While these devices do not specifically identify "what" the particle is, they are extremely useful in tracking particle dynamics within a building, developing hypotheses regarding particle origin, and evaluating corrective actions. LASER light particle counters were, at least at the onset, expensive instruments to acquire and maintain. In the past cost alone generally prohibited most facilities managers from obtaining such equipment and thus particle evaluation as a function of IEQ was traditionally something that had to be outsourced. **Photograph 3** illustrates a typical LASER light particle counter. However, over the past few years, competition in the industry has resulted in more manufacturers producing these products and some decrease in the costs of LASER particle counters. As a result, an in-house IEQ program that provides for the evaluation of particle analysis through the use of a LASER light particle counter has become more common. However, before running out and getting one of the units, be certain to evaluate the ongoing costs of maintaining and calibrating these units. One simply cannot rely on the data produced if the instrument is out-of-date with regards to its calibration, so an appropriate oversight schedule must be maintained if the facilities manager plans to purchase this type of equipment. Be prepared to take on this cost or choose to rent or lease equipment, or simply outsource this service.

There is an increasing volume of research on the use of LASER light particle counting devices as a means to evaluate particulate loads in indoor environments. A Google search using "indoor particulate" will take you to a host of them. While informative, no standards have been implemented as a result of these studies; however, such information is useful in comparing particulate loads from the facility you may by evaluating. Additionally, it is a good idea to perform a thorough evaluation of a facility during periods of occupancy and activity, non-occupancy or non-activity, to determine what background levels exist, as well as, identify potential sources of particulate loads. When this is accomplished, specific "remedial" or "control" mechanisms can be developed to address any IEQ concerns that might arise.

Typically, filtration is the principal control mechanism for particles within a building. In my opinion, the evaluation of data obtained from a LASER particle counter, in conjunction with the minimum efficiency rating values (MERV) provided for various filters in ASHRAE Standard-52, provides the most reasonable and practical means to design, implement, and monitor a program that addresses potential particle contamination and control within a building. The data obtained from the LASER particle counter will identify what activities within a building may be generating specific particles. The particle counter will also provide the size of the particles. Control and background sample comparison provide target ranges for these areas. If something is out of line, then evaluate the particle size against the MERV ratings for filters in ASHRAE-52, acquire those specific filters, establish a filtering regime, and re-evaluate the efficacy with the particle counter. If a budget can support the purchase and upkeep of a LASER particle counter, then the control and monitoring of "particle contaminants" are really a rather simple process for the facility manager to bring into an "in-house" IEQ program.

Chemical and Biological Contaminants

Chemical and biological contaminants represent two areas of potential contamination that, in my opinion, is simply outside of the realm of a typical "in-house" IEQ program for a facility. The scope of potential contaminants, the equipment required for specific sampling, the interpretation of the results, and the relationship of the results to industry accepted and/or regulated levels is often too much of a technical leap for most facilities managers to attempt to undertake. For example, if chemical sampling is desired, then a host of questions must be addressed in order to appropriately ascertain the sampling and analytical methodologies. Is the chemical an element, such as lead or mercury, or is it a chemical compound of some sort? If a chemical compound, is it an inorganic compound or an organic compound? In what matrix (solid, liquid, or gas) does the chemical exist and what specific sampling and analytical procedure must be selected to provide the specific type and units of measure for the results? These are complicated questions that must be appropriately addressed prior to the undertaking of any chemical sampling. Similar complexities exist with biological sampling as well. Certainly incorporation of such chemical and biological sampling methods is possible, but the facilities manager should be prepared to receive detailed training prior to implementation. This alone could require a significant budget commitment to travel, and course-related expenses before the actual sampling equipment and collection media is even purchased. Often, it is simply more cost effective for the facility manager to outsource the collection and analysis of chemical and biological contaminants. The data obtained and interpreted by independent and qualified consultants can readily be inserted and integrated into the ongoing IEQ records for the facility. However, again, some exceptions exist. An instrument called the "Aircuity Building Performance Monitor" is a multifunction instrument that provides a variety of IEQ data **(Photograph 4)**. In addition to basic direct and real-time data collection of temperature, relative humidity, and carbon dioxide, the Aircuity also provides collection of carbon monoxide, radon, ozone, particulate, biological components, and a TVOC index, which is a relative expression of total concentrations of volatile organic compounds that may exist in the air. The Aircuity can be used as a stand-alone device or linked through computer and/or telephone lines to provide remote monitoring. The data can be used exclusively in-house or readily compared with other similar facilities via the Internet.

Summary

Many aspects of IEQ testing can be readily assimilated into an ongoing in-house IEQ program. These include the real-time monitoring of temperature and relative humidity for occupant comfort, the real-time monitoring of carbon dioxide with spot sampling for building pressure to evaluate appropriate ventilation, and if the budget allows, the purchase of a LASER light particle counter to evaluate potential particle contamination. The development of an "in-house" IEQ program that addresses these previous aspects of IEQ allows the facility manager to monitor a large portion of the IEQ puzzle at costs that would be significantly less than if outsourced. Typically, the complexities associated with biological and chemical testing require the facility manager to outsource these services to qualified consultants and companies. If the facility manager elects to bring these aspects of IEQ testing into the "in-house" program, then care must be taken to assure proper training in the use and application of sampling equipment, collection media, analytical requests, and analytical interpretations. All data and actions from both in-house and outsources should be appropriately documented and maintained so as to provide a readily available reference if and/or when an IEQ problem occurs at the facility.

IEQ problems can often escalate when occupants do not perceive that the building and/or facilities managers care about the quality of the air in their building. Having an appropriate, pro-active IEQ program in place often serves as the major deterrent to the escalation of an IEQ event. The evidence of a well-documented, ongoing program can often resolve occupant concerns and fears, which is a large component of why IEQ problems escalate. The program also provides for the establishment of a "facility baseline" that enables the facility manager to "predict" what should occur when testing occurs and when to "react" when something is out of line. The development of a pro-active IEQ program is something that every facility manager should consider, as the benefits can be measured in increased productivity, reduced litigation potential, and improved energy management. Don't delay any longer. Make a commitment to starting a pro-active IEQ program in your facility today. You will never be sorry you did.

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